Shanmugan, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin …
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

S439

THERMAL ASYMMETRY MODEL OF SINGLE SLOPE SINGLE BASIN SOLAR STILL WITH SPONGE LINER

by

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An attempt has been made to propose a thermal asymmetry model for single slope basin type solar still with sponge liner of different thickness (3 cm, 5 cm, and 10 cm) in the basin. Two different color sponge liners have been used i. e., yellow and black. In the proposed design, a suitable dripping arrangement has been designed and used to pour water drop by drop over the sponge liner instead of sponge liner in stagnant saline water in the basin. The special arrangement overcomes the dryness of the sponge during peak sunny hours. The performance of the system with black color sponge of 3 cm thickness shows better result with an output of 5.3 kg/m² day and the proposed model have used to find the thermal asymmetries during the working hours of the still.

Key words: *basin type solar still, sponge, thermal asymmetry model*

Introduction

Freshwater is a necessity for the maintenance of life and also the key to human's prosperity. Solar desalination is a process of separation of pure water from saline or sea water using solar energy. Comparatively this requires simple technology, eco-friendly, lower maintenance and no energy costs, due to which it can be used anywhere with lesser number of problems. The solar distillation systems are classified as passive and active solar stills and various scientists throughout the world have carried out research works on design, fabrication methods, testing and performance evaluation, *etc*. The performance of a solar still with different size of sponge cubes placed on the basin has been studied experimentally by Bassam and Hamzeh [1]. It has been confirmed that the still with sponge cubes increased the distillate production ranged from 18% to 273% compared to the identical still without sponge cubes under the same climatic condition. Kalidasa Murugavel *et al.* [3] have taken steps to improve the productivity of single basin passive solar still by using different materials in the basin and found that rubber is the best basin material to enhance the absorption, storage and evaporation effects. Vinoth Kumar and Kasturi Bai [4] have studied the performance of solar still with different samples in the basin (tap water, seawater, and dairy industry effluent). For all the samples, the quality of condensate water is comparable with rain water and mineral water and also confirmed that the condensation occurs not only due to the temperature differences on the glass cover but also on the four side walls which can be cooled by water circulation through tubes attached on the wall surface. Sahoo *et al*. [5] have made an attempt to assess the performance of a solar still using blackened

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S440

Shanmugan, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin ...
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

basin liner and thermocool insulation and found that the fluoride content in fluoride contaminated drinking water has the reduction of 92-96%. The productivity of the basin type solar still have been observed by Velmurugan *et al.* [6] with wick, fin with wicks and sponges in the basin and concluded that the productivity increased by 29.6% when wick was used, 15.3% when sponge was used and 45.5% when fins were used. Velmurugan *et al.* [7] have designed a stepped solar still consists of 25 trays with 5 mm height and 25 trays with 10 mm height and the combination of fin, sponge and pebbles have been used in the basin. It has been inferred that the productivity increased by 98% and theoretical results are in good agreement with the experimental results. Khalifa and Hamood [8] have carried out an experiment to find the effect of insulation thickness on the productivity of basin type solar stills. Solar stills with insulation thickness of 30 mm, 60mm and 100 mm have been tested and concluded that the insulation thickness up to 60 mm has significant impact and influenced the productivity of the still. Khalifa and Hamood [9] proposed a correlation to find the effect of climatic, operational and design parameters on the performance of a basin type solar still. Numerical results have shown that the productivity influenced by the brine depth by 33%, tilt angle by 63% and addition of dye increased the productivity by 20%. A new radiation model has been proposed by Feilizadeh *et al.* [10] for a single slope solar still which accounts the effect of all walls of the still on the amount of incident solar radiation on the water surface and each wall. It has been found that the effect of the back and side walls are considerable to improve the accuracy of the thermal radiation analysis of single slope solar still. Farshad *et al.* [11] have designed a weir-type cascade solar still and found the effect of water flow rate of the brine on internal heat and mass transfer and daily productivity. It has been found that the daily productivity and internal heat and mass transfer decreases with the increase in water flow rate.

Kalidasa Murugavel *et al.* [12] have used different energy storing materials in the basin of double slope solar still and thermal model has been proposed. It has been inferred that 3/4 inch sized quartz rock is the effective basin material and theoretical results are in good agreement with the experimental observations. Kalidasa Murugavel and Srithar [13] have made an attempt to find the effective material to be used with minimum mass of water in the basin and inferred that the still with aluminum rectangular fin covered with black cotton cloth have significant impact on the productivity. Also, the theoretical result of the thermal model incorporating the transmittance of the glass cover has found to be in good agreement with the experimental results. The influence of sponge liner on the internal heat transfer coefficients in a simple solar still has been found by Arjunan *et al.* [14] and concluded that the value of C and n in convective heat transfer coefficients should be modified with respect to different Grashof number. Arjunan *et al.* [15] have undergone experiment in a simple solar still by utilizing the energy available on the inner wall surfaces using a sponge liner to predict the performance and also the optimum thickness of sponge liner. It has been inferred that the sponge liner of 5mm thick has given more yield and reduces the conduction heat losses from inner wall surface to outer wall surfaces through back and side wall by 50%.

An inverted absorber solar still has been designed and steps have been taken by Rahul *et al.* [16] to find the optimum water depth in the basin and to compare the different total dissolved solid (TDS) values, pH and electrical conductance between feed saline water and distilled water. It has been inferred that 0.03 m water depth is optimum and the value of pH for the distilled water is found less than 7 *i. e.* acidic in nature and low electrical conductance due to low values of TDS. Khalifa [17] have found the effect of condensing cover tilt angle of simple solar still on the productivity in different seasons and latitudes. It has been found that the tilt angle should be large in winter and small in summer. Mahdi *et al.* [18] have confirmed

Shanmugan, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin …
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

S441

that the tilted-wick type solar with charcoal cloth as absorbing and evaporating material is good material to be used in the still and the efficiency of the still is about 53% on clear days in summer.

In the present study, an attempt has been made to find the thermal asymmetries in the basin type solar still with sponge cubes of different color and thickness in the basin. Three different thickness and two colors of sponge materials *i. e.*, 3 cm, 5 cm, and 10 cm and yellow and black have been used. Energy balance equations have been written for the temperature elements of the still and analytical solutions have been found. Numerical results have been validated with the experimental results and a correlation model is proposed to find the thermal asymmetries in the still. Thermal performance of the still has been found to find the effect of sponge materials in the basin.

Design of the system

The photograph of the experimental single slope single basin solar still is shown in the fig. 1. The still consists of outer and inner enclosure made of plywood with dimension of 1.3 × 1.3 m and 1.25 × 1.25 m. The gap between the enclosures is filled with glass wool having the thermal conductivity of 0.038 W/mK. The height of the backwall is 0.03 m and frontwall of 0.10 m. The glass cover of thickness 4 mm is used as the condensing surface and the slope of the glass cover is fixed as 11° which is equal to the latitude of the location (Coimbatore). The still is made vapor tight with the help of metal putty. The j-shaped drainage channel is fixed near the front wall to collect the distillate yield and the output trickled down to the measuring jar. The basin of the still is made of galvanized iron sheet a thin copper sheet is pasted in the basin and painted black to absorb more solar radiation. A special arrangement has been made to pour saline water drop by drop over the sponge kept in the basin.

The lengthwise dripping arrangement is made of heat resistant pipes with drip button fixed at regular intervals of 0.10 m horizontally in the basin. The saline water tank is provided with a gate valve and is connected to the inlet pipe of the dripping arrangement in the basin. The dripping arrangement made is kept in the basin with drip buttons projecting upwards. Saline water in the tank is allowed to flow through the dripping arrangement with constant pressure and water drips into the basin drop by drop through the drip button. Care has been taken such that water is not flown into the basin through drip buttons with high speed. Excess amount of water leads to the increase of thermal capacity of the system resulting in decrease of rate of evaporation. The water temperature in the sponge and condensing cover temperature has been measured by fixing copper-constantan thermocouples which has been calibrated initially. Solar radiation intensity and ambient temperature have been measured with solar radiation monitor and digital thermometer.

Experiment has been carried out from 6 am to 6 am of 24 h duration with sponge materials of different color (yellow and black) and thickness (3 cm, 5 cm, 7 cm and 10 cm) at Department of Physics, Karpagam University, Coimbatore (latitude 11° N, long 77° 52' E), Tamil Nadu, India. Figures 2 and 3 show the photograph of the different sponge liner materials and dripping arrangement used in the experiment.

Thermal modeling

Glass cover transmission

The south facing condensing glass cover receives the radiation at different angles and quantities. To calculate the energy received by the water mass in the basin, the radiation

Figure 1. Photograph of the experimental still (for color image see journal web-site)

Figure 2. Photograph of the different sponge liner (for color image see journal web-site)

Figure 3. Photograph of the dripping arrangement with black sponge liner (for color image see journal web-site)

energy actually received by the glass cover and variation of transmittance of the glass cover with time are to be considered. Researchers have carried out the theoretical evaluation only by considering the radiation energy on horizontal surface and fixed transmittance of glass cover. For any given instant, the total energy to the still is the total radiation falling on the south facing glass cover:

$$Q_i = Q_s \tag{1}$$

where $Q_s = A_g H_t$.

The utilization of radiation energy by the still for any given instant is the total solar radiation transmitted through the south facing covers and it is given by:

$$Q_\tau = Q_{\tau s} \tag{2}$$

where $Q_{\tau s} = \tau_s A_a H_t$.

Since the transmittance of the glass cover at any time is a function of solar radiation incidence angle (θ) and thickness of the glass cover (d), Kalidasa Murugavel *et al.*[2] have developed a correlation equation and it has been used in this study.

Energy balance equations

The transmitted radiation through the glass cover is absorbed by the sponge liner in the basin. The sponge liner temperature increases and heat is transferred from water in the sponge to glass cover by three modes. Convective, radiative and evaporative heat transfer occurs due to temperature difference between the water in the sponge and lower surface of the glass cover. The evaporative heat transfer is accompanied by the mass transfer due to partial vapor pressure difference between the water in the sponge and glass cover. The evaporated water vapor condenses at the lower surface of the glass cover and releases its latent heat of vaporization to the glass cover. A small fraction of heat is lost to ambient through the bottom and side walls by conduction and convection. The saline water is allowed through a dripping arrangement such that drop by drop flow of water compensates the water mass evaporated from the water in the sponge liner.

The following assumptions have been made to write the energy balance equations.
–   There is no temperature gradient throughout the glass cover surface.
–   The system is made vapor tight such that there is no vapor leakage from the still.
–   The inclination of the condensing glass cover is 11° and hence the evaporating and condensing glass cover surfaces are considered to be parallel.

Shanmugan, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin …
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

S443

Glass cover:

$$H_t \alpha_g A_g + h_1 (T_{sp} - T_g) A_{sp} = h_2 (T_g - T_a) A_g \tag{3}$$

where

$$h_1 = h_{cspg} + h_{espg} + h_{rspg}; \quad h_2 = h_{cga} + h_{rga}$$

where according to [19]:

$$h_{cspg} = 0.884 \left[T_{sp} - T_g + \frac{(P_{sp} - P_g)(T_{sp} + 273)}{268900 - P_{sp}} \right]^{\frac{1}{3}}, \quad h_{espg} = 0.016273 h_{cspg} \frac{P_{sp} - P_g}{T_{sp} - T_g},$$

$$h_{rspg} = \frac{\varepsilon \sigma \left[(T_{sp} + 273)^4 - (T_g + 273)^4 \right]}{T_{sp} - T_g}, \quad h_{cga} = 5.7 + 3.8\, V$$

and V is the wind velocity.

$$h_{rga} = \varepsilon_g \sigma \left[(T_g + 273)^4 - (T_a + 261)^4 \right]$$

Sponge liner:

$$(m_w C_{sp}) \frac{dT_{sp}}{dt} = Q\, \tau \alpha_{sp} - h_1 (T_{sp} - T_g) A_{sp} + h_3 (T_{sp} - T_a) A_{bs} - h_{fw} (T_a - T_w) \tag{4}$$

where $\alpha_{sp} = x \alpha_b; h_3 = (L_b / K_b)^{-1}$.

Solving eq. (3), the equation for T_g can be written as:

$$T_g = \frac{H_t \alpha_g A_g}{h_2 A_g + h_1 A_{sp}} + \frac{h_1 T_{sp} A_{sp}}{h_2 A_g + h_1 A_{sp}} + \frac{h_2 T_a A_g}{h_2 A_g + h_1 A_{sp}} \tag{5}$$

Substituting the equation for T_g in eq. (4) and re-arranging, the equation can be written in the form:

$$\frac{dT_{sp}}{dt} + S T_{sp} = J \tag{6}$$

The solution of the equation is given by:

$$T_{sp} = \frac{J}{S} + c e^{-St} \tag{7}$$

where

$$S = \frac{h_1 A_{sp}}{m_w C_{sp}} - \frac{h_1^2 A_{sp}^2}{(m_w C_{sp})(h_2 A_g + h_1 A_{sp})} - \frac{h_3 A_{bs} + h_{fw}}{m_w C_{sp}}$$

and

$$J = \frac{Q_\tau \alpha_{sp}}{m_w C_{sp}} + \frac{h_1 H_t \alpha_g A_g A_{sp} + h_1 h_2 T_a A_g A_{sp}}{(m_w C_{sp})(h_2 A_g + h_1 A_{sp})} - \frac{h_3 A_{bs} + h_{fw}}{m_w C_{sp}} T_a$$

Using initial conditions $t = 0$, $T_{sp} = T_{spi}$ from eq. (7), constant of integration c can be obtained:

$$c = T_{spi} - \frac{J}{S} \tag{8}$$

Substituting c in eq. (7), we get:

$$T_{sp} = \frac{J}{S}(1 - e^{-St}) + T_{spi}e^{-St} \tag{9}$$

Equations (5) and (9) are explicit expressions for the temperatures of the sponge liner *i. e.*, water and glass cover of the still.

The instantaneous hourly distillate output per unit basin area of the still is calculated by:

$$m_e = \left[\frac{h_{espg}(T_{sp} - T_g)}{L}\right] 3600 \text{ kg/m}^2\text{h} \tag{10}$$

The instantaneous efficiency of the still is expressed as:

$$\eta\% = \frac{m_e L}{A_{sp} H_t} 100 \tag{11}$$

Results and discussion

Experiments have been conducted with sponge liner of different color (yellow and black) and thickness (3 cm, 5 cm, 7 cm, and 10 cm) in the basin of the still during the month of May and June. Energy balance equations have been written for the temperature elements of the still and solved to get analytical solutions for water and glass cover temperature. To validate the analytical solutions, numerical calculations have been done for one of the typical days for different sponge liner in the basin and the relevant design parameters of the still are $\alpha_g = 0.05$, $A_g = 1 \text{ m}^2$, $A_{sp} = 1 \text{ m}^2$, $\alpha_{spw} = 0.70$ (yellow), $\alpha_{sp} = 0.85$ (black), $A_{bs} = 0.25 \text{ m}^2$, $K_b = 0.038 \text{ W/mK}$, and $L_b = 0.05$ m. The hourly variation of tilted solar radiation and ambient temperature for various thicknesses and color of sponge liner have been drawn and shown in the fig. 4. From the figure, it is clear that the intensity of solar radiation gradually increases up to 1.30 pm and decreases in the afternoon hours. These climatological parameters have been used for the numerical calculations.

Figure 4. Hourly variation of tilted solar radiation and ambient temperature
(for color image see journal web-site)

The experimental observations and theoretical results of glass cover temperature and

Shanmugan, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin …
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

S445

water temperature with different thickness and color sponge liners have been represented in figs. 5, 6, 7, and 8. The standard deviation between theoretical and experimental observations has been found to signify the closeness of numerical and experimental observations. It has been found that the average standard deviations between theoretical and experimental results of glass and water temperature are 0.664 (T_g – YS 0.10 m), 0.604 (T_g – YS 0.05 m), 0.557 (T_g – YS 0.03 m), 0.568 (T_w – YS 0.10 m), 0.754 (T_w – YS 0.05 m), and 0.534 (T_w – YS 0.03 m) and for black sponge the values of average standard deviations between theoretical and experimental observations for glass and water temperature are 0.520 (T_g – BS 0.10 m), 0.517 (T_g – BS 0.05 m), 0.557 (T_g – BS 0.03 m), 0.511 (T_w – BS 0.10 m), 0.477 (T_w – BS 0.05 m), and 0.542 (T_w – BS 0.03 m). The average standard deviation values have shown that the theoretical results are in close agreement with the experimental observations with less error. The graphs drawn are used to identify the experimental and theoretical asymmetries of the temperature components of the still.
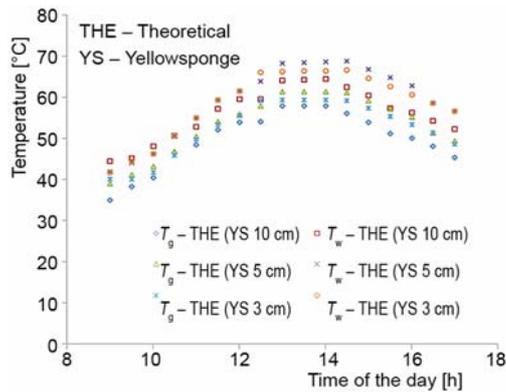
Figure 5. Variation of glass and water temperature (theoretical)
(for color image see journal web-site)
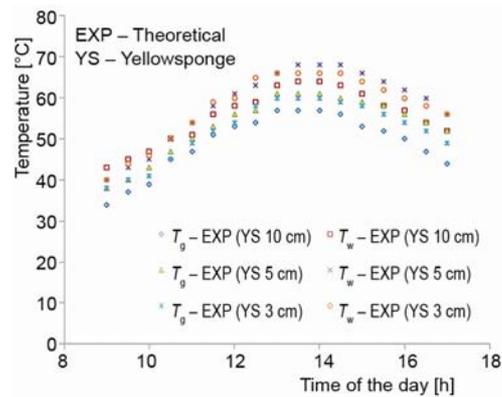
Figure 6. Variation of glass and water temperature (experimental)
(for color image see journal web-site)
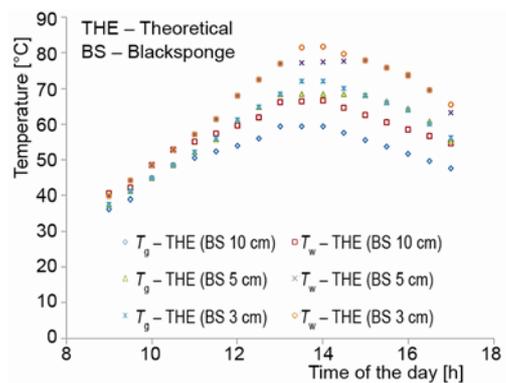
Figure 7. Variation of glass and water temperature (theoretical)
(for color image see journal web-site)
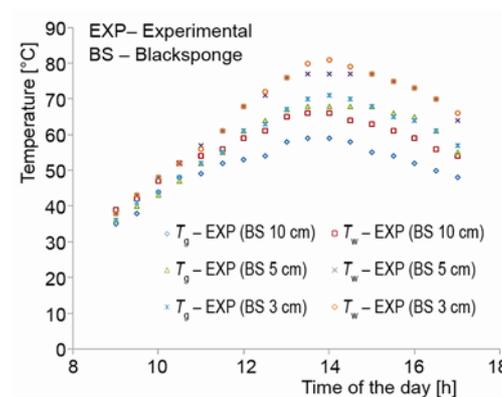
Figure 8. Variation of glass and water temperature (experimental)
(for color image see journal web-site)

It is also observed that for yellow sponge of 3 cm, 5 cm, and 10 cm thickness, water in the sponge liner reached a maximum temperature of 66 °C, 68 °C, and 64 °C and for black sponge of 3 cm, 5 cm, and 10 cm thickness; water temperature reached a maximum of 81 °C,

77 °C, and 66 °C, respectively. Among these sponge liners, black sponge liner of 3 cm thickness shows significant effect on the performance of the still.

It is also confirmed that black sponge liner 3 cm thick is optimum and best absorbing material in the basin for more distillate yield. This is due to the fact that the porosity of 3 cm black colored sponge is more than enough for better evaporation of saline water in the upward direction towards the condensing surface with optimum thermal capacity. Beyond the thickness, thermal capacity increases thereby decreasing the evaporation rate of saline water. Moreover the absorptivity of the black colored sponge is higher than that of the yellow colored sponge.

The instantaneous theoretical and experimental distillate yield for yellow and black sponge liners have been shown in figs. 9 and 10. The average standard deviation between theoretical and experimental results for both yellow and black sponge are found to be 0.00124 (YS) and 0.0009 (BS). It is clear that, the numerical results are in close agreement with the experimental observations for most of the hours and uncertainty occurs in some hours due to the unavoidable factors such as the clouds and wind *etc*. The uncertainty is very small and found to be negligible. In that scenario, the predicted results slightly underestimate for the distillate yield. Among the different sponge liners, the maximum distillate yield of 0.262 kg/m^2 30 minutes is obtained between 1.30 pm and 2 pm for 3 cm black sponge which is expected. The yellow sponge of 10 cm thickness have shown minimum distillate yield and found to be least. The black sponge (3 cm) provides a total distillate yield of 725 kg/m^2 from 9 a. m. to 5 p. m. Over a 24 h cycle, still with black sponge (3 cm) produced 5.625 kg/m^2 day. Hence a black sponge 3 cm thick is an effective absorbing material in the proposed still to give a better performance.
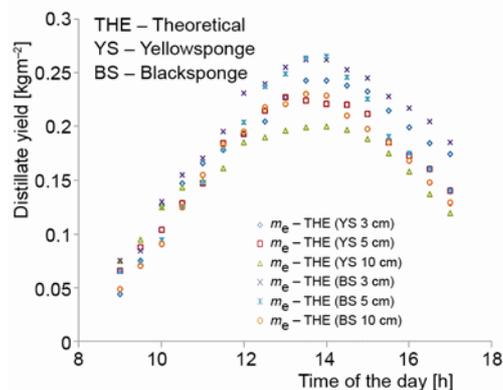
Figure 9. Theoretical values of distillate yield with yellow and black sponge materials (for color image see journal web-site)
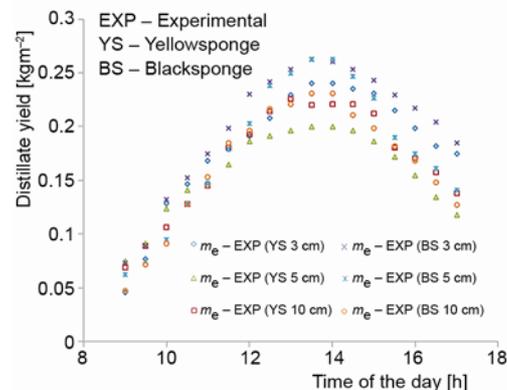
Figure 10. Experimental values of distillate yield with yellow and black sponge materials (for color image see journal web-site)

Similarly the instantaneous theoretical and experimental efficiency with yellow and black sponge liners have shown in the fig. 11 and 12. The graph has clearly reflected that the instantaneous distillate yield with black sponge (3 cm) is found to be higher than the other sponge liners. Both the experimental and theoretical results are in good agreement as the average standard deviation values are 0.0146 (YS) and 0.000684 (BS).

The productivity of the still over 24 h cycle for different thickness and color of sponge materials in the basin has been shown in fig. 13. From the above inferences, to propose thermal asymmetry model, the results of the black sponge (3 cm) have been used. The experimental and theoretical results of water, glass, distillate yield and efficiency have been

Shanmugan, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin …
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

S447

considered. A correlation model has been proposed for water temperature and it is shown in the fig. 14. The linear trend line has been drawn and the corresponding regression coefficient is found to be 0.998. It is observed in most of the hours, the modeled temperature is found to be agreed with the experimental observations and in few hours, there exists some asymmetries. The asymmetry is due to the change in thermal inertial of the water in the sponge liner. In the similar way, correlation models have been developed by plotting theoretical results of glass cover temperature, distillate yield and efficiency against the experimental observation and shown in figs. 15-17. From all the graphs, it is clear that the model reproduced in good agreement and the regression coefficients are 0.993, 0.998, and 0.998 for glass cover temperature, distillate yield and efficiency.
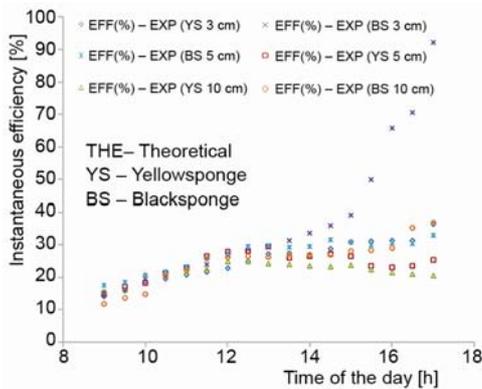
Figure 11. Theoretical values of instantaneous efficiency for yellow and black sponge (for color image see journal web-site)
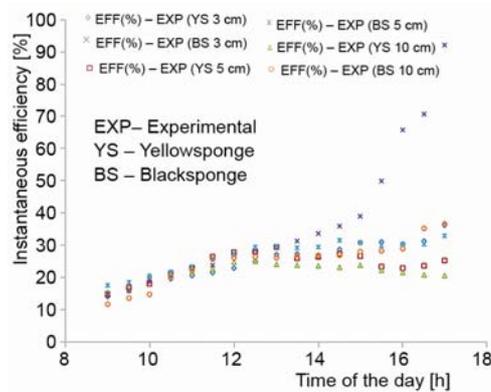
Figure 12. Experimental values of instantaneous efficiency for yellow and black sponge (for color image see journal web-site)

The productivity of the still over 24 h cycle for different thickness and color of sponge materials in the basin has been shown in fig. 13. From the above inferences, to propose thermal asymmetry model, the results of the black sponge (3 cm) have been used. The experimental and theoretical results of water, glass, distillate yield and efficiency have been considered. A correlation model has been proposed for water temperature and it is shown in the fig. 14. The linear trend line has been drawn and the corresponding regression coefficient is found to be 0.998. It is observed in most of the hours, the modeled temperature is found to be agreed with the experimental observations and in few hours, there exists some asym-

Figure 13. Distillate yield for sponge liner in the basin

metries. The asymmetry is due to the change in thermal inertial of the water in the sponge liner. In the similar way, correlation models have been developed by plotting theoretical results of glass cover temperature, distillate yield and efficiency against the experimental observation

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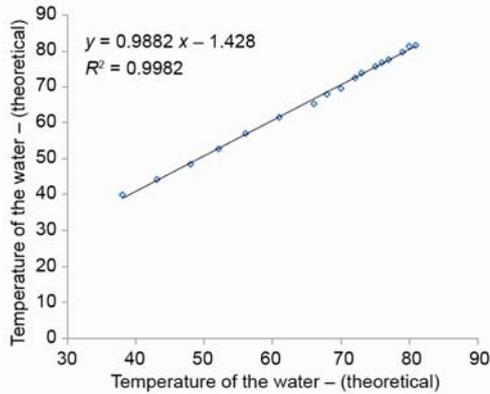
Figure 14. Correlation model for water temperature
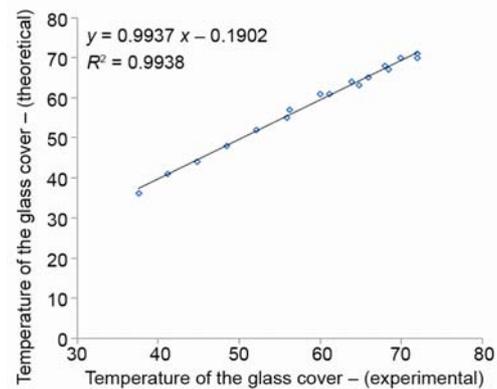
Figure 15. Correlation model for glass cover temperature
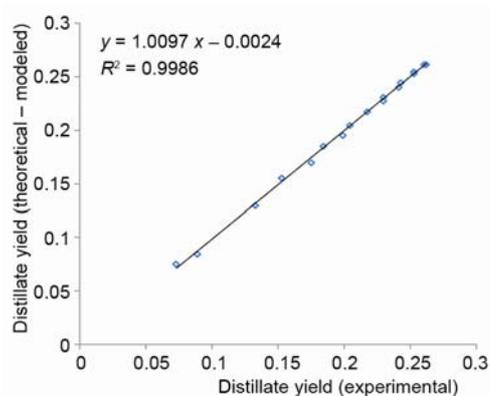
Figure 16. Correlation model for distillate yield
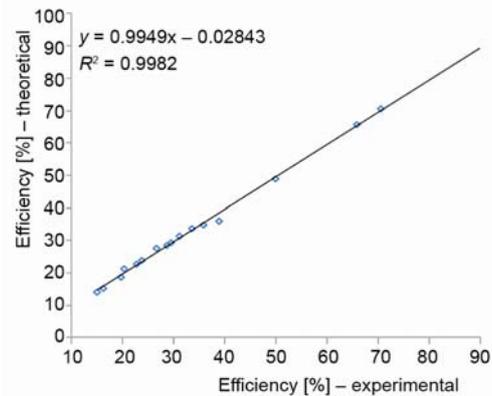
Figure 17. Correlation model for efficiency

The correlation equation for the temperature elements of the still and distillate yield and efficiency have been derived:

– for water temperature $y = 0.988\,x + 1.428$
– for glass cover temperature $y = 0.993\,x - 0.190$
– for distillate yield $y = 1.009\,x - 0.002$
– for efficiency $y = 0.994\,x - 0.284$

The modeled glass cover temperature has some asymmetry due to the unavoidable factors such as cloud, wind and ambient temperature. Regarding the distillate yield and efficiency, there exists symmetry between modeled and experimental observations which correlated better. This model provides the information about the dynamical effects taken place inside the enclosure during the working hours of the still. The regression coefficients for the same have shown the better correlation with a strong thermal inertia. The model has been correlated by treating the condensing surface as a single element. Researchers [1, 6, 7, 12] in-

Shanmugam, S., *et al.*: Thermal Asymmetry Model of Single Slope Single Basin …
THERMAL SCIENCE, Year 2014, Vol. 18, Suppl. 2, pp. S439-S450

S449

ferred that the energy storage materials *i. e.*, sponge cubes, wick materials, fin with wick materials, pebbles and small sized rocks in the basin improves the productivity of the still significantly. The results obtained in this study reflect the same inferences (energy storage material *i. e.*, sponge materials) reported by the researchers.

Conclusions

The correlation equation can be used to simulate the proposed system for any climatic conditions for large scale installations. The dynamical effects taking place due to the change of thermal inertia is significant for the slightly underestimated values of glass cover temperature. The approach for the proposed correlation model is based on the energy balance equations of the temperature elements of the still. Dunkle's heat transfer relations is found to be reasonable to predict the thermal performance of the proposed system as it reproduced the evaporative heat transfer from evaporating surface to the condensing surface for the working hours of the system in a coherent manner.

Nomenclature

A_g – area of the glass, [m^2]
A_{sp} – area of the sponge liner, [m^2]
A_{bs} – area of the bottom surface still, [m^2]
C_{sp} – specific heat capacity of the sponge liner materials, [Jkg^{-1}K^{-1}]
d – thickness of the glass cover, [m]
H_t – tilted solar radiation on the glass cover, [Wm^{-2}]
h_1 – total heat transfer coefficient from water to glass, [Wm^{-2}K^{-1}]
h_2 – total heat transfer coefficient from glass to ambient, [Wm^{-2}K^{-1}]
h_3 – heat transfer coefficient from bottom of the still to the ambient, [Wm^{-2}K^{-1}]
h_{fw} – heat transfer coefficient from ambient to feed water, [Wm^{-2}K^{-1}]
h_{espg} – evaporative heat loss coefficient from water to glass of the solar still, [Wm^{-2}K^{-1}]
h_{cspg} – convective heat loss coefficient water to glass of the solar still, [Wm^{-2}K^{-1}]
h_{rspg} – radiative heat loss coefficient water to glass of the still, [Wm^{-2}K^{-1}]
h_{rga} – radiative heat loss transfer coefficient from glass to ambient, [Wm^{-2}K^{-1}]
h_{cga} – convective heat loss transfer coefficient from glass to ambient, [Wm^{-2}K^{-1}]
K_b – thermal conductivity of glass wool, [Wm^{-1}K^{-1}]
L – latent heat of vaporization of water, [Jkg^{-1}]
L_b – thickness of glass wool, [m]
m_e – mass of the distillate output, [kg]

m_{sp} – mass of sponge liner, [kg]
m_w – mass of the saline water, [kg]
P_{sp} – partial vapour pressure at sponge liner water temperature, [Nm^{-2}]
P_g – partial vapour pressure at glass temperature, [Nm^{-2}]
Q_i – instantaneous total heat energy, [Wm^{-2}]
Q_s – total radiation falling on the south facing glass cover, [Wm^{-2}]
Q_τ – total heat energy transmitted through the south facing glass cover, [Wm^{-2}]
$Q_{\tau s}$ – total solar radiation transmitted through the south facing glass cover, [Wm^{-2}]
T_a – ambient temperature, [°C]
T_g – temperature of the glass cover, [°C]
T_{sp} – temperature of water in sponge liner, [°C]
T_{spi} – temperature of initial condition in sponge liner, [°C]
V – wind velocity, [ms^{-1}]
x – Thickness of the sponge liner, [m]

Greek symbols

α_b – absorptivity of the basin liner
α_g – absorptivity of the glass cover
α_{sp} – absorptivity of sponge liner water
η – instantaneous efficiency
θ – incidence angle of the solar radiation, [degree]
τ_s – transmittance south facing glass cover
ε_g – emissivity of the glass cover
σ – Stefan-Boltzmann constant

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