Computer modeling of passive/active solar stills by using inner glass temperature

G.N. Tiwari*, S.K. Shukla, I.P. Singh

Centre for Energy Studies, Indian Institute of Technology (IIT), Hauz Khas, New Delhi 110016, India
Tel. +91 (11) 6591258; Fax +91 (11) 6862037; email: gntiwari@ees.iitd.ernet.in

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Abstract

Expressions for water and glass temperatures, hourly yield and instantaneous efficiency for both passive and active solar distillation systems have been derived. The analysis is based on the basic energy balance for both the systems. A computer model has been developed to predict the performance of the stills based on both the inner and the outer glass temperatures of the solar stills. In the present work two sets of values of $C$ and $n$ ($C$, $n$ and $C$, $n$) obtained from the experimental data of January 19, 2001 and June 16, 2001 under Delhi conditions, have been used. It is concluded that (i) there is a significant effect of operating temperature range on the internal heat transfer coefficients and (ii) by considering the inner glass cover temperature there is reasonable agreement between the experimental and predicted theoretical results.

Keywords: Solar distillation; Solar energy; Purification of brackish/saline water

1. Introduction

A historical review on solar distillation system had been carried out by Malik et al. [1] in 1982. Later on, this work was updated by Tiwari [2]. Most of the work done on solar stills [3-6] has used the expressions for internal heat transfer coefficients as developed by Dunkle [7] under simulated conditions. However, these expressions are valid only for small inclinations of condensing cover and low operating temperatures and are independent of the average distance between the condensing and evaporating surfaces. Kumar and Tiwari [8] have recently developed a model, based on regression analysis, to determine the values of $C$ and $n$ using the experimental data obtained from the stills. This method does not impose any limitations on the determination of expressions for internal heat transfer coefficients.

In this paper, analytical expressions for various parameters have been derived for passive [1] as
well as active solar stills [9-11]. Experimental validation has also been carried out by using following measured climatic parameters: (i) solar intensity on the glass cover; (ii) solar intensity on collector panel, and (iii) ambient air temperature.

Modified values of $C$ and $n$, obtained from the experimental data collected for typical days, namely, January 19, 2001 and June 16, 2001 on the solar stills located at iIT Delhi, have been used in this model. The proposed model predicts the theoretical values of water temperature, glass temperature, and the yield at hourly intervals with respect to inner and outer glass temperatures, respectively. The calculated results are compared with the experimental data. Very close agreements between the theoretical predictions and experimental results have been observed on using the values of $C$ and $n$ based on the inner glass temperature.

2. Experimental setup

2.1. Passive solar still

The schematic diagram and photograph of the single slope solar still are shown in Figs. 1a and 1b, respectively. It is reported [4] that the output of the still is maximum for the least water depth in the basin. However, to avoid the daily feeding of water, the basin was designed for a maximum depth of water of 40 mm. Moreover, to avoid the spilling of basin water into the distillate channel and to prevent the contact of distillate channel with the glass cover, the height of the lower vertical side of solar still was kept at 60 mm (0.06 m). For a 10° inclination of the glass cover, the required height of the other vertical side was 190 mm. This conventional single slope solar still has an effective basin area of $1 \text{ m} \times 1 \text{ m}$ and it is fabricated using fibre reinforced plastic (FRP) material. A glass cover with an inclination of 10° to the horizontal is fixed to the top of the vertical walls of the still using a rubber gasket and an adhesive (M-Seal trademark). To ensure that vapors are not lost to the atmosphere, the glass cover is further sealed with window-putty (chalk mixed with linseed oil). The distillate output is collected by a channel, fixed at the end of the smaller vertical side of the basin. A plastic pipe is connected to this channel to drain the distilled water to an external jar. The thickness of the body of the solar still was 5 mm. The inside of the basin is painted black.

A plastic hosepipe is fixed through a hole drilled at the bottom of the basin to drain water and clean the basin. An inlet pipe is also fixed at the rear wall of the still for feeding saline/brackish water. Holes are also drilled in the body of the still to fix thermocouples to sense the temperature of water in the basin and the inner glass temperature. The whole unit is mounted on an angle iron stand. The solar still is oriented due south in order to receive maximum solar radiation throughout the year.
2.2. Active solar still

Enhancement in output can be achieved by increasing the difference in saturation vapour pressure at the water and the glass surface. One of the methods of increasing the temperature of the water in the basin is by coupling the solar still to a solar collector. In the active distillation process, hot water from the collector panel is fed into the basin of solar still in order to achieve a faster rate of water evaporation. The schematic view and photograph of an active solar still is shown in Figs. 2a and 2b, respectively. The bottom surface of the still was painted black by mixing a special dye with a resin. A window glass of 3 mm thickness inclined at an angle of 10° to the horizontal was used to cover the still. The vertical heights of the solar still are 190 mm and 380 mm respectively. The inclination of glass cover was selected so as to let the water droplets slide down the inner surface of the glass to a drainage channel made of aluminum sheet, provided at the lower end of glass cover. A rubber gasket and an adhesive (M-Seal trademark) were used to make the still airtight. Window-putty was also applied to ensure perfect sealing. The still was coupled, by using insulated pipes, to two flat plate collectors having a total effective area of 4 m\(^2\) and inclined at 45° as shown in Fig. 2b. For active solar still the pump had been switched on from 10:00 h—16:00 h only to avoid the heat loss due to reverse flow.

Experiments were performed on both active and passive solar stills during the months of January 2001 and June 2001 for several days, but the observations presented in Tables 1, 2, 3 and 4 represent a typical winter day and a typical summer day, namely, 19 January 2001 and 16 June 2001, respectively. The sunshine hour is one hour more in summer climatic conditions than in winter. The experimental data are used to obtain the internal heat and mass transfer coefficients for passive and active solar stills as given in Table 5.

3. Experimental uncertainty

The experimental method used is an indirect approach for estimating the convective heat transfer coefficient based on the mass of distillate collected from still. It will therefore have a considerable degree of experimental uncertainty. An estimation of uncertainty [13] has been carried out separately for passive and active solar stills. Data of a particular measurement for a number of days have been taken and an estimate of individual uncertainties of the sample values has been calculated. An estimate of internal uncertainty (U) has then been found by:

\[ U_i = \sqrt{\frac{\sum \sigma_i^2}{N^2}} \]
Table 1
Experimental observations of 19 January 2001 for single slope solar still

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Time, h</th>
<th>Water temperature, °C</th>
<th>Inner glass temperature, °C</th>
<th>Outer glass temperature, °C</th>
<th>Ambient temperature, °C</th>
<th>Distillate output, ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>31.1</td>
<td>27.8</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>35.1</td>
<td>33.2</td>
<td>18.0</td>
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<tr>
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<td>34.2</td>
<td>32.4</td>
<td>18.0</td>
<td>160</td>
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<tr>
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Table 2
Experimental observations of 16th June 2001 for single slope solar still

<table>
<thead>
<tr>
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<th>Water temperature, °C</th>
<th>Inner glass temperature, °C</th>
<th>Outer glass temperature, °C</th>
<th>Ambient temperature, °C</th>
<th>Distillate output, ml</th>
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</thead>
<tbody>
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<tr>
<td>2</td>
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<td>170</td>
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<tr>
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Table 3
Experimental observations of 19th January 2001 for active solar still

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Time, h</th>
<th>Water temperature, °C</th>
<th>Inner glass temperature, °C</th>
<th>Outer glass temperature, °C</th>
<th>Ambient temperature, °C</th>
<th>Distillate output, ml</th>
</tr>
</thead>
<tbody>
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<tr>
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<td>45.2</td>
<td>39.7</td>
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<td>48.7</td>
<td>41.6</td>
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<td>280</td>
</tr>
<tr>
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<td>39.9</td>
<td>17.0</td>
<td>210</td>
</tr>
<tr>
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<td>39.1</td>
<td>35.2</td>
<td>18.0</td>
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</tr>
<tr>
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<td>1600</td>
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<td>38.2</td>
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<td>170</td>
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<tr>
<td>8</td>
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<td>36.7</td>
<td>35.1</td>
<td>31.6</td>
<td>17.0</td>
<td>150</td>
</tr>
</tbody>
</table>
Table 4
Experimental observations of 16th June 2001 for active solar still

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Time, h</th>
<th>Water temperature, °C</th>
<th>Inner glass temperature, °C</th>
<th>Outer glass temperature, °C</th>
<th>Ambient temperature, °C</th>
<th>Distillate output, ml</th>
</tr>
</thead>
<tbody>
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<td>42.2</td>
<td>34.2</td>
<td>32.0</td>
<td>130</td>
</tr>
<tr>
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<td>1100</td>
<td>67.3</td>
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<td>56.2</td>
<td>34.0</td>
<td>210</td>
</tr>
<tr>
<td>3</td>
<td>1200</td>
<td>72.3</td>
<td>64.3</td>
<td>58.3</td>
<td>37.6</td>
<td>260</td>
</tr>
<tr>
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<td>1300</td>
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<td>70.2</td>
<td>65.2</td>
<td>38.8</td>
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</tr>
<tr>
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<td>61.2</td>
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<td>40.2</td>
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<td>1700</td>
<td>57.2</td>
<td>55.3</td>
<td>43.2</td>
<td>40.0</td>
<td>260</td>
</tr>
<tr>
<td>9</td>
<td>1800</td>
<td>52.3</td>
<td>51.2</td>
<td>41.1</td>
<td>39.0</td>
<td>160</td>
</tr>
</tbody>
</table>

Table 5
C and n values for passive and active solar still

<table>
<thead>
<tr>
<th>Date</th>
<th>Passive solar still</th>
<th>Active solar still</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With inner glass temperature</td>
<td>With outer glass temperature</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>n</td>
</tr>
<tr>
<td>19/01/2001</td>
<td>0.0112</td>
<td>0.4088</td>
</tr>
<tr>
<td>16/06/2001</td>
<td>0.0621</td>
<td>0.3999</td>
</tr>
</tbody>
</table>

where \(\sigma_i\) are the standard deviations of each sample and \(N\) is the total number of samples.

The total uncertainty for passive and active stills has been calculated as 25% and 21%, respectively. The results will also be influenced by the thermal storage effect. The percentage error caused by thermal storage can be calculated as follows:

\[
\text{% error} = \frac{\text{distillate output during non-sunshine hours}}{\text{distillate output during daylight hours}} \times 100
\]

The errors due to thermal storage effect for passive and active stills have been estimated to be 10% and 5%, respectively.

4. Mathematical models
The following assumptions have been made while writing the energy balance for each component:

- the heat capacity of the glass cover and the insulation (bottom and sides of the still) is negligible;
- the solar still is vapour-leakage proof;
- side area of the still is very small as compared to area of basin liner due to a small depth of water in the basin;
- no stratification of water occurs in the basin of the solar still;
- absorptivity of the glass cover is negligible.

4.1. Passive solar still
The energy balance for different components of the single slope passive solar still is given below. The symbols used have been explained in the Appendix.
Glass cover:

\[ h_w(T_w - T_g) = h_g(T_g - T_a) \]  
(1)

Water mass."

\[ \alpha'_w I(t) + h_w(T_h - T_w) = (MC)_w \frac{dT_w}{dt} + h_w(T_w - T_g) \]  
(2)

Basin liner.

\[ \alpha'_b I(t) = h_w(T_h - T_w) + h_b(T_b - T_a) \]  
(3)

4.2. Active solar still

The energy balance equation for different components of the active solar still is given below:

Water mass."

\[ a'_w j(t) + K(T_b - T_w) + q_u - \]  
\[ = (MC)_w \frac{dT_w}{dt} + h_w(T_w - T_g) \]  
(4)

where \( \dot{c}_w = F_{w} / \gamma \{(ct)_{L} / (T_{w} - T) \} \)

and \( A' = \frac{A}{A_w} > 1 \),

Energy balance equations for glass cover and basin liner for active solar still are the same as that for passive solar still [Eqs. (1) and (3)].

Substituting the expressions for \( T \) and for \( T_b \) from Eqs. (1) and (3) for both the active and the passive solar stills, one obtains the following differential equation:

\[ \frac{dT_w}{dt} + aT_w = f(t) \]  
(5)

where \( a \) and \( f(t) \) have different expressions for active and passive solar stills, i.e.:

\[ a = \frac{U_L}{(MC)_w} \]  
for passive solar still

\[ rU_L + \frac{FA - U_L}{(MC)_w} \]  
for active solar still.

Similarly,

\[ f(t) = \frac{(\alpha'_w I(t) + U'_w T_w)}{(MC)_w} \]  
for passive solar still,

and

\[ f(t) = \frac{(\alpha'_w + h_w \alpha'_w) I(t) + FA - (a'T)(T_{L}(t) + (U'_L - U'_w)T_w)}{(MC)_w} \]  
for active solar still.

The other expressions, which are the same for both the solar stills, are given by

\[ U'_L = U_L + U, \]

\[ U_b = \frac{h_w h_b}{h_w + h_b}, \]

\[ U_f = \frac{h_w h_g}{h_w + h_g} \]

In order to solve Eq. (7), the following assumptions have been made:

- \( \dot{f}(t) \) has been considered as constant, \( f(t) \) over the time interval \( 0 - t \), and
- \( a \) has also been considered constant over the same time interval \( 0 - t \).

The solution of Eq. (7) for the initial condition that at time \( t = 0, T = T_{g,0} \) is given by:

\[ T_w = \frac{f(t)}{a} \left[ 1 - \exp(-at) \right] + \left[ T_{w,0} \exp(-at) \right] \]  
(6)

The glass temperature in terms of the water temperature can be obtained from Eq. (1).

\[ T_g = \frac{h_w T_w + h_g T_a}{(h_w + h_g)} \]  
(7)
for both passive and active solar stills.

Values of $T$ and $T$ calculated from Eqs. (7) and (8) at the end of a time interval become the initial condition for the next set of numerical computations, and so on.

The rate of evaporative heat loss and the hourly yield for both the cases is given by:

\[ \dot{q}_{ev} = h_{ev}(T_w - T_g)A, \]  

(8a) and

\[ \dot{m}_e = \frac{h_{ev}(T_w - T_g)}{I}.x3600\text{kg/m}^2\text{h} \]  

(8b)

The instantaneous efficiency can be determined for passive solar still:

\[ \eta_p = \frac{q_{ex}}{I(t)} = \frac{h_{ev}(T_w - T_g)}{I(t)} \]  

(9a) for passive solar still;

\[ \eta_a = \left\{ h_{ev}(T_w - T_g)\right\} [\lambda s(t)+A'M] \]  

(9b) for active solar still.

For a passive solar still, the instantaneous efficiency can be written as:

\[ \eta_p = F'_x \left[ (ax) + U_{LS} \left( \frac{T_w - T_g}{I(t)} \right) \right] \]  

(10)

where

\[ F'_x = \frac{h_{ev} \cdot h_g \cdot 1}{h_{ev} + h_g \cdot U'_{Ls}} \]

\[ (ax) = (ax)_{off} \left( 1 - e^{-ao} \right) \]

\[ U_{LS} = U_L e^{-ao} \]

Eq. (10) can be defined as the characteristic equation of a still, which is similar to the characteristic equation of a Flat Plate Collector (FPC) [12]. However there are differences and the interpretation of Eq. (10) can be given as follows:

- the still efficiency factor ($F'$) is temperature dependent due to variation of $h$ with temperature, which is unlike the efficiency factor of Flat Plate Collector [12] and;
- the slope of Eq. (10) is positive unlike the slope of characteristic equation of FPC. This is the reason for having maximum efficiency for solar still for the maximum upward heat loss.

5. Internal heat transfer coefficients

Computer programmes have been developed in 'C' language to predict the hourly variations of water temperature, glass temperature, distillate output and the various heat transfer coefficients of solar still. This model takes the modified values of convective heat transfer coefficients for both inner and the outer glass temperatures and carries out the computation of all performance parameters. It then compares them with the experimental data and finally brings out the percentage deviation between the experimental and theoretical results.

5.1. Methodology for evaluating $C$ and $n$

The rate of heat transfer from the water surface to glass cover by convection, $q_{mo}$, in the upward direction through a humid fluid is given by the following equation:

\[ \dot{q}_m = h(T_w - T_g) \]  

(i i)

The coefficient $h_{cs}$ can be determined from the relation:

\[ N_u = \frac{h_v d_j}{K_j} = C(GrPr)^{n} \]  

(12)

Malik et al. [1] have assumed that water vapour obeys the perfect gas equation and have given the expression for evaporative heat transfer rate, \( \dot{q}_m \), as:

\[ \dot{q}_m = 0.0163h_{cs}(P_w - e_g) \]  

(13)
Eq. (13) combined with Eq. (11) can be written as:

$$\dot{q}_{sw} = 0.0163 \left( P_w - P_g \right) \left( \frac{K_f}{d_j} \right) \left( \frac{3600}{l} \right) C \left( Ra \right)^n \tag{14}$$

where \( Ra = \frac{Gr}{Pr} \).

Further, the rate of distillate output is evaluated by:

$$\dot{m}_{sw} = \frac{\dot{q}_{sw}}{l} \times 3600 \tag{15}$$

Eq. (15) after substituting \( \dot{q}_{sw} \) from Eq. (14) becomes:

$$\dot{m}_{sw} = 0.0163 \left( P_w - P_g \right) \left( \frac{K_f}{d_j} \right) \left( \frac{3600}{l} \right) C \left( Ra \right)^n \tag{16}$$

The above equation can be rewritten as:

$$\dot{m}_{sw} = R C \left( Ra \right)^n \tag{17}$$

or:

$$\frac{\dot{m}_{sw}}{R} = C \left( Ra \right)^n \tag{18}$$

where:

$$R = 0.0163 \left( P_w - P_g \right) \left( \frac{K_f}{d_j} \right) \left( \frac{3600}{l} \right) \tag{19}$$

Eq. (18) can be rewritten in the following form:

$$Y = a X^n \tag{20}$$

where \( Y = \frac{\dot{m}_{sw}}{R}; \quad X = Ra; \quad a = C; \quad b = n. \)

Eq. (20) can be reduced to a linear equation by taking log on both the side:

$$\ln (Y) = \ln (a) + b \ln (X) \tag{21}$$

or;

$$r = a' + b' x \tag{22}$$

where:

$$F = \ln (F); \quad d = \ln (a); \quad b' = b; \quad X' = \ln (X) \tag{23}$$

From Eq. (23) the values of coefficients \( d \) and \( V \) are calculated using regression analysis. The expressions for \( d \) and \( b' \) are given by:

$$b' = \frac{N \left( \sum X' Y' \right) - \left( \sum X' \right) \left( \sum Y' \right)}{N \left( \sum X'^2 \right) - \left( \sum X' \right)^2} \tag{23a}$$

and:

$$d' = \frac{\sum Y' - b' \sum X'}{N} \tag{23b}$$

where \( N \) is number of experimental observations.

Knowing \( d \) and \( b' \) from Eq. (23), the value of \( C \) and \( n \) can be obtained by the following expressions:

$$C = \exp \left( a' \right) \quad \text{and} \quad n = V.$$

The experimental values of \( C \) and \( n \) for passive and active solar stills for 19 January 2001 and 16 June 2001 are shown in Table 5.

Once the value of \( C \) and \( n \) are known, Eq. (12) can be used to obtain the convective heat transfer coefficient \( h_{cw} \). Dunkle [7], by using the values of \( C = 0.075 \) and \( n = 1/3 \), gave the following expression for \( h_{cw} \), valid for a mean operating temperature range of approximately 50°C:

$$h_{cw} = 0.884 \left( \frac{T_w - T_g}{268.9 \times 10^3} \right) \tag{24}$$

where:

$$T_w = T_{water} \quad \text{and} \quad T_g = T_{glass} \tag{25}$$

Figs. 3 and 4 depict the hourly variation of \( h_{cw} \) for passive and active solar stills using inner and outer glass temperatures for a typical day in January 19,2001 (winter conditions) and June 16, 2001 (summer conditions). It is clear from the graph that the value of heat transfer coefficients obtained by using inner glass temperatures are greater than those obtained by using outer glass temperatures and Dunkle's model for the same climatic conditions. These variations are seen more under summer climatic conditions than under winter climatic conditions due to higher...
operating temperature range. This is due to the fact that the variations in solar intensity are more during summer than winter.

Figs. 5 and 6 depict the comparison between the hourly variation of \( h_w, h_{nr} \) and \( h \) for passive and active solar stills in January 19, 2001 and June 16, 2001 respectively. It is further noted from these figures that radiative and convective heat transfer coefficients do not vary much, unlike evaporative heat transfer coefficient. This is true for passive as well as active solar stills for both inner and outer glass temperatures. This indicates the sensitivity of evaporative heat transfer coefficient on the operating temperature range (see Appendix). The heat transfer coefficients in the case of active solar still are significantly higher due to higher operating temperature range.

6. Numerical results and discussions

6.1. Performance studies

The following design parameters have been used to compute the hourly water temperature, glass temperature and distillate output for passive and active solar stills using the earlier obtained internal heat transfer coefficients for both the stills.

6.1.1. Design parameters

- For passive solar still:
  \( T_{w0} = 35^\circ C; \ T_{o} = 32^\circ C; \ V= 1.0 \, m/s; \ A_s = 1.1 \, m^2 \)
  \( d = 0.015 \, \mu; \ C = 4190 \, J/kg; \)
  \( a^* = 0.8; \ o_0 = 0.0; \ p = 1000 \, kg/m^3 \)
  \( A_f = 15 \, kg \) (initial mass of the water in basin)
  \( e = 0.9. \)

---

Fig. 3a. Hourly variation of \( h_w \) with inner and outer glass temperatures for passive solar still in January 2001.

Fig. 4a. Hourly variation of \( h_w \) with inner and outer glass cover temperatures for active solar still in January 2001.

Fig. 3b. Hourly variation of \( h_{nr} \) with inner and outer glass temperatures for passive solar still in January 2001.

Fig. 4b. Hourly variation of \( h \) with inner and outer glass temperatures for active solar still in June 2001.
6.1.2. Climatic parameters

The hourly variation of solar intensity falling on the solar stills and collector glass surfaces and the ambient temperature in passive and active stills has been shown in Figs. 7 and 8 respectively.

Eqs. (6)-(8) have been used to evaluate the performance parameters, namely $T$, $T_a$ and distilled output for passive and active stills. It is computed by using inner and outer glass temperatures. In
both cases it is observed that the theoretical values obtained by using inner glass temperature are closer to the experimental values than those obtained by using outer glass temperature. Comparative graphs of theoretical and experimental results have been shown in Figs. 9-10 and Figs. 11-12 for passive and active stills, respectively. It is observed from the graphs that a fairly good agreement has been achieved between the theoretical predictions and experimental results by using the inner glass temperature.

The variation of $r_l$ vs. $(T, - T)/h(t)$ [Eq. (11)] (generally known as the characteristic curve) for passive and active solar still have been shown in Figs. 13 and 14 respectively. It is observed that:

- the slope of this curve is unlike the slope of characteristic curve of a flat plate collector. It is due to the fact that a solar still gives better performance for maximum upward heat losses unlike a flat plate collector (FPC) and;
- the variation is non-linear due to non-linear behavior of internal heat transfer coefficients unlike FPC.

7. Conclusion

On the basis of the present study, it is inferred that the internal heat transfer coefficients should be determined by using inner glass cover temperature for thermal modeling of passive and active solar stills. It is due to the fact that the heat transfer coefficients depend on the temperature difference between water and the inner glass cover, and the shape and material of the condensing cover of a solar still.

**Symbols**

- $A_Y$ — Area of solar still, m²
- $A_c$ — Collector area, m²
- $C$ — Constant
- $C_s$ — Specific heat of working fluid, J/kg °C
- $d_f$ — Average spacing between water and glass cover, m
Fig. 9a. Hourly variations of theoretical and experimental water and inner glass temperatures for passive solar still in January 2001.

Fig. 9b. Hourly variation of theoretical and experimental water and inner glass temperatures for passive solar still in June 2001.

Fig. 10a. Hourly variation of theoretical and experimental water and outer glass temperatures for passive solar still in January 2001.
Fig. 10b. Hourly variation of theoretical and experimental water and outer glass temperatures for passive solar still in June 2001.

Fig. 11a. Hourly variation of theoretical and experimental water and inner glass temperatures for active solar still in January 2001.

Fig. 11b. Hourly variation of theoretical and experimental water and outer glass temperatures for active solar still in January 2001.

Fig. 12a. Hourly variation of theoretical and experimental water and inner glass temperatures for active solar still in June 2001.

Fig. 12b. Hourly variation of theoretical and experimental water and outer glass temperatures for active solar still in June 2001.
Fig. 13. Characteristic curve of passive solar still.

Fig. 14. Characteristic curve of active solar still.

\( F \) — Collector efficiency factor

\( g \) — Acceleration due to gravity, m/s\(^2\)

\( \text{Gr} \) — Grashof number

\( h_{cw} \) — Convective heat transfer coefficient from water surface to the glass cover, W/m\(^2\)°C

\( h_{evr} \) — Evaporative heat transfer coefficient from water surface to the glass cover, W/m\(^2\)°C

\( h_{nr} \) — Radiative heat transfer coefficient from water surface to the glass cover, W/m\(^2\)°C

\( K_{tr} \) — Total heat loss coefficient from the glass cover to the ambient, W/m\(^2\)°C

\( h_{lw} \) — Convective heat transfer coefficient from basin liner to water, W/m\(^2\)°C

\( h_b \) — Bottom loss coefficient from basin to ambient, W/m\(^2\)°C

\( I(t) \) — Solar radiation on the glass cover of the solar still, W/m\(^2\)

\( I/\) — Solar radiation on the glass cover of the solar collector panel, W/m\(^2\)

\( K_r \) — Thermal conductivity of the humid air, W/m °C

\( K_i \) — Thermal conductivity of the insulation, W/m °C

\( l \) — Latent heat of vaporization, J/kg

\( L_n \) — Thickness of the insulation, m

\( m_{cw} \) — Hourly distillate output, kg/m\(^2\)/h

\( (MC)_w \) — Heat capacity of water mass/m\(^2\) in basin, J/kg °C

\( n \) — Constant

\( Pr \) — Prandtl number

\( P_r \) — Partial vapour pressure of water temperature, Pa

\( P_g \) — Partial vapour pressure at glass temperature, Pa

\( q_{evr} \) — Evaporative heat transfer rate from water to the glass surface, W/m\(^2\)

\( q_{cw} \) — Convective heat transfer rate from water to glass cover

\( T \) — Ambient temperature, °C

\( t \) — Glass temperature, °C

\( \bar{t} \) — Time, s

\( U_b \) — Overall bottom heat loss coefficient, W/m\(^2\)°C

\( U_r \) — Overall heat transfer coefficient, W/m\(^2\)°C

\( U_{tr} \) — Overall top loss coefficient from water surface to ambient, W/m\(^2\)°C

\( U_i \) — Top loss coefficient for passive solar still, W/m\(^2\)°C

\( \nu \) — Viscosity of fluid, N.s/m\(^2\)

Greek

\( \nu \) — Viscosity of fluid, N.s/m\(^2\)
[3°] — Coefficient of volumetric thermal expansion, K°

\( \alpha \) — Product of absorptivity and transmittivity of collector

\( \varepsilon_h \) — Fraction of solar energy absorbed by blackened surface

\( \varepsilon_w \) — Fraction of solar energy absorbed by water mass

\( p_a \) — Density of humid air, Kg/m³

\( T_I \) — Instantaneous efficiency, %

\( AT' \) — Effective temperature difference, °C

\( \varepsilon_g \) — Emissivity of glass

\( \varepsilon_w \) — Emissivity of water

\( a \) — Stefan Boltzman’s constant, 5.6697x10⁻⁸W/m²K⁴

References


Appendix

The various heat transfer coefficients, \( h \)'s are defined as follows:

\[
\begin{align*}
\dot{h}_{r_w} &= h_{r_w} + h_{r_v} + h_{r_e}
\end{align*}
\]

\[
\begin{align*}
\dot{h}_{r_v} &= \varepsilon_{\text{eff}} \sigma \left( \frac{T_w + 273}{T_w + T_g} \right)^\xi \left( T_w + 273 \right) \\
&= \dot{h}_{r_v} \left( \frac{T_w + 273}{T_w + T_g} \right) \left( T_w + 273 \right)
\end{align*}
\]

\[
\begin{align*}
\varepsilon_{\text{eff}} &= \left[ \frac{1 - \varepsilon_g - \varepsilon_w}{\varepsilon_g + \varepsilon_w} \right]^{-1}
\end{align*}
\]

\[
\begin{align*}
K_{\tau} &= \frac{K^\tau \kappa}{\tau} \frac{(GrPr)^\zeta}{\theta}
\end{align*}
\]

\[
\begin{align*}
Gr &= \frac{d_j^3 \beta_j^2 \varrho_j^2 \beta_e^4 \Delta T'}{\mu_j}
\end{align*}
\]

\[
\begin{align*}
AT &= \left( \frac{T_w - T_g}{\phi} \right) \left( p_w - p_g \right) \left( T_w + 273 \right) \\
&= \left( \frac{268 \times 10^3}{\phi} \right)
\end{align*}
\]

\[
\begin{align*}
Pr &= \frac{\mu_j \tau f}{K_{\tau}}
\end{align*}
\]

\[
\begin{align*}
h_w &= 16.273 \times 10^3 \left( \frac{T_W}{T_w} \right) \frac{p_w - p_g}{T_w - T_g}
\end{align*}
\]

\[
\begin{align*}
h_b &= \left[ \frac{1}{K_{\tau} L_2} \right] \frac{1}{h_{r_b} + h_{b_b}}
\end{align*}
\]