Monthly performance of passive and active solar stills for different Indian climatic conditions

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Abstract

The monthly performance of passive and active solar stills for different Indian climatic conditions was evaluated. Numerical computations were carried out for hourly variations of average insolation at the Chermai, Jodhpur, Kolkata, Mumbai and New Delhi stations. The analysis was based on the quasi-steady-state condition. Analytical expressions for water temperature, glass cover temperature and yield as a function of climatic parameters—namely solar intensity, ambient air temperature and design parameters (water depth, absorptivity of basin liner, wind velocity, bottom insulation and cover inclinations)—were also derived. On the basis of numerical computations, it was inferred that: (1) the annual yield significantly depends on water depth, inclination of condensing cover and collector as expected for both passive and active solar stills; and (2) the annual yield for a given water depth increases linearly with the collector area for an active solar still.

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

1. Introduction

Solar distillation is a process for distilling saline/brackish water by using solar energy. The distillation system can be classified under two categories: passive and active. Malik et al. [1] reviewed the work on passive solar distillation. In 1992, further review was carried out by Tiwari [2], which also includes work on active solar distillation (Fig. 1).

Recently Tiwari et al. [3] carried out a study on the present status of research work on both passive and active solar distillation systems. They have recommended that only passive solar stills can be economical to provide potable water. An
2.2. Energy balance

Following Kumar et al. [4], the energy balance equations for an active solar still are as follow:

- Glass cover:
  \[ \alpha_g \cdot I(t) \cdot A_g + h_{gw} \cdot (T_w - T_g) \cdot A_w = h_{lg} \cdot (T_g - T_o) \cdot A_g \]  
  \[ \text{(1)} \]

- Water mass:
  \[ \dot{Q}_w = a_w (I - \varepsilon_g) A_w I(t) (T_g - T_o) A_b \]
  \[ = \left( m_w C_w \right) \frac{dT_w}{dt} + h_{gw} (T_w - T_g) A_w \]  
  \[ \text{(2)} \]

- Basin linear:
  \[ \alpha_g \cdot (1 - \alpha_g) (1 - \alpha_w) \cdot A_b \cdot I(t) \]
  \[ = \left[ h_w (T_b - T_w) + h_b (T_b - T_a) A_b \right] \]  
  \[ \text{(3)} \]

where

\[ Q = A_c F_n \cdot [(aZ) \cdot I'(\cdot) \cdot U_y (T - s)] \]

and

\[ m_w = A_b \times d_w \times \rho \]

For \( \dot{Q}_w = 0.0 \), the above equations become energy balance equations for a passive solar still.

Eqs. (0)-(3) can be solved for \( T_w \) and \( T_g \) for given climatic and design parameters as given by Tiwari [5]. An expression for \( F_B \) becomes \( F_{RN} \) for \( N \) collectors connected in series Tiwari [5].

After knowing \( T_w \) and \( T_g \), the hourly yield per unit area can be evaluated from known values of water and glass temperatures, and is given by

\[ \dot{m}_{vw} = \frac{h_{ev} (T_w - T_g) \times 3600}{L} \text{ kg/m}^2 \text{h} \]  
\[ \text{(4)} \]

where \( L \) is the latent heat of vaporization (J/kg) [5] and \( h_{ev} \) can be taken for the initial values of \( T_w \) and \( T_g \) at \( t = 0 \).
The average daily yield can be obtained as

\[ M_{wi} = \sum_{i=1}^{24} m_{ewi} \]  

(5)

The monthly and annual yield can be evaluated as:

- monthly yield

\[ A_{Cj} = MW^{n_y} \]  

(6a)

- annual yield

\[ \sum_{j=1}^{12} M_{wij} \]  

(6b)

where \( n_y \) is the number of days of the \( j \)th month for an average weather condition.

3. Numerical results and discussion

The climatic parameters of Chennai, Jodhpur, Kolkata, Mumbai and New Delhi were considered for numerical computations [6], and the geographical parameters of five stations are given in Table 1.

Eq. (6a) was computed for the monthly yield from a passive solar still for New Delhi climatic conditions for various inclinations of the condensing cover and water depth. The design parameters for solar stills and flat-plate collectors used for numerical computation are given in Table 2. The monthly variation of yield from a

![Graph](image1)

Fig. 2a. Monthly yield of a passive solar still with different inclinations of the condensing cover (\( A_s = 1 \text{ m}^2, d_w = 0.03 \text{ m} \)).

![Graph](image2)

Fig. 2b. Annual yield of a passive solar still with different inclinations of the condensing cover (as above).

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude, °</th>
<th>Longitude, °</th>
<th>Elevation, m (above mean sea level)</th>
<th>Data period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chennai</td>
<td>13.00 N</td>
<td>80.18 E</td>
<td>16</td>
<td>1957-1978</td>
</tr>
<tr>
<td>Jodhpur</td>
<td>26.30 N</td>
<td>73.02 E</td>
<td>224</td>
<td>1960-1978</td>
</tr>
<tr>
<td>Kolkata</td>
<td>22.65 N</td>
<td>88.45 E</td>
<td>6</td>
<td>1957-1978</td>
</tr>
<tr>
<td>New Delhi</td>
<td>28.58 N</td>
<td>77.20 E</td>
<td>216</td>
<td>1957-1978</td>
</tr>
</tbody>
</table>
Table 2
Design parameters for a flat-plate collector and solar still [4]

<table>
<thead>
<tr>
<th>Solar still parameters</th>
<th>Single collector parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_c = A_b = 1 \text{ m}^2 ), ( d_c = 0.01-0.27 \text{ m} )</td>
<td>( 4 = 2 \text{ m}^2 ), ( C_f = 4190 \text{ J/kg}^\circ \text{C} )</td>
</tr>
<tr>
<td>( C_a = 4190 \text{ J/kg}^\circ \text{C} ), ( a_w = 0 )</td>
<td>( p_v = 5-45^\circ ), ( m = 50 \text{ kg} )</td>
</tr>
<tr>
<td>( I_\theta = 5-45^\circ ), ( h_c = 100 \text{ W/m}^2\text{C} )</td>
<td>( F^\prime = 0.8 ), ( U_L = 8 \text{ W/m}^2\text{C} )</td>
</tr>
</tbody>
</table>

Fig. 3a. Monthly yield of a passive solar still with various depths at an optimized tilt of 13.58°.

Fig. 3b. Annual yield of a passive solar still with different water depths at an optimized tilt of 13.58°.

The performance of passive solar still in terms of annual yield for all the weather stations for different water depths is given in Table 3 where it can be seen that at 0.01 m water depth in basin, the annual yield is at its maximum for the Jodhpur climatic conditions. This may be due to a fall in ambient air temperature because of the cold temperature during the night. However, at a higher water depth (0.15 m), the annual yield reached a maximum for the Chennai climatic conditions.

Further, effects of water depth on the monthly yield for the active solar still for New Delhi climatic conditions are shown in Fig. 4a. Eq. (6b) was used to evaluate the annual yield for the active solar still, and its variations are shown in Figs. 4b and 5 for various water depths and inclinations of the flat-plate collector. The variation of annual yield with water depth for
Table 3
Annual yield (L/m$^2$) of the passive solar still at optimum tilt of the condensing cover at various water depths for different Indian climatic conditions

<table>
<thead>
<tr>
<th>Station</th>
<th>Water depths, m</th>
<th>0.01</th>
<th>0.05</th>
<th>0.10</th>
<th>0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chennai</td>
<td></td>
<td>1041</td>
<td>753</td>
<td>504</td>
<td>371</td>
</tr>
<tr>
<td>Jodhpur</td>
<td></td>
<td>1161</td>
<td>750</td>
<td>432</td>
<td>280</td>
</tr>
<tr>
<td>Kolkata</td>
<td></td>
<td>896</td>
<td>625</td>
<td>409</td>
<td>298</td>
</tr>
<tr>
<td>Mumbai</td>
<td></td>
<td>1017</td>
<td>712</td>
<td>463</td>
<td>337</td>
</tr>
<tr>
<td>New Delhi</td>
<td></td>
<td>1034</td>
<td>673</td>
<td>402</td>
<td>270</td>
</tr>
</tbody>
</table>

Table 4
Annual yield (L/m$^2$) of the active solar still at optimum tilt of the condensing cover and collector at various water depths for different Indian climatic conditions

<table>
<thead>
<tr>
<th>Station</th>
<th>Water depths, m</th>
<th>0.05</th>
<th>0.10</th>
<th>0.15</th>
<th>0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chennai</td>
<td></td>
<td>2564</td>
<td>1890</td>
<td>1334</td>
<td>1001</td>
</tr>
<tr>
<td>Jodhpur</td>
<td></td>
<td>2783</td>
<td>1958</td>
<td>1300</td>
<td>916</td>
</tr>
<tr>
<td>Kolkata</td>
<td></td>
<td>2285</td>
<td>1571</td>
<td>1091</td>
<td>810</td>
</tr>
<tr>
<td>Mumbai</td>
<td></td>
<td>2525</td>
<td>1805</td>
<td>1260</td>
<td>926</td>
</tr>
<tr>
<td>New Delhi</td>
<td></td>
<td>2539</td>
<td>1742</td>
<td>1163</td>
<td>831</td>
</tr>
</tbody>
</table>

Fig. 4a. Monthly yield of an active solar still at various water depths ($A_s = 1 \text{m}^2, A_c = 2 \text{m}^2$), inclination of (a) solar still = 13.58° and (b) FPC = 18.58°.

Fig. 4b. Annual yield of an active solar still with different water depths ($A_s = 1 \text{m}^2, A_c = 2 \text{m}^2$), inclination of (a) solar still = 13.58° and (b) FPC = 18.58°.

Fig. 5. Annual yield of an active solar still with different collector tilts ($d_w = 0.03 \text{m}, A_s = 1 \text{m}^2, A_c = 2 \text{m}^2$, inclination of condensing cover = 13.58°).

The annual yields of the active solar still for the weather stations for different water depths are given in Table 4 [Eq. (6b)]. As discussed above, for the passive solar still, similar conclusions were also observed for the active solar still.
4. Conclusions

On the basis of the results and discussion, the following conclusions can be drawn for maximum annual yield:

1. The annual yield is at its maximum when the condensing glass cover inclination is equal to the latitude of the place.

2. The optimum collector inclination for a flat-plate collector is $28.58^\circ$ for a condensing glass cover inclination of $18.58^\circ$ for New Delhi's climatic conditions.

5. Symbols

- $A$ — Area, $m^2$
- $C_w$ — Specific heat of water in the solar still, $J/kg°C$
- $d_w$ — Depth of water mass, $m$
- $F_g$ — Collector heat removal factor
- $F$ — Collector efficiency factor
- $K$ — Overall heat transfer coefficient from the basin liner to ambient air through bottom and side insulation, $W/m^2°C$
- $h_{1g}$ — Convective heat transfer coefficient from the glass cover to ambient, $W/m^2°C$
- $h_{1w}$ — Total heat transfer coefficient from the water surface to the glass cover, $W/m^2°C$
- $h_w$ — Convective heat transfer coefficient from the basin liner to the water, $W/m^2°C$
- $h_{em}$ — Evaporative heat transfer coefficient from the water surface to the glass cover, $W/m^2°C$
- $I(0)$ — Solar radiation available on the glass cover of the solar still, $W/m^2$
- $I'(t)$ — Solar radiation available on the absorber of the collector, $W/m^2$
- $L$ — Latent heat of water, $J/kg$
- $m_w$ — Mass of water in basin, $kg$
- $m_{evi}$ — Hourly yield per unit area, $kg/m^2h$
- $I_{u}$ — Rate of useful energy from collector, $W$
- $T$ — Temperature, $°C$
- $T_a$ — Ambient air temperature, $°C$
- $t$ — Time, $s$
- $At$ — Time interval, $s$
- $U_L$ — Heat loss coefficient for collector, $W/m^2°C$

Greek

- $a$ — Absorptivity
- $\tilde{z}$ — Solar altitude angle, $°$
- $(\sim Z)_c$ — Product of absorptivity and transmittivity of collector
- $\varepsilon_{eff}$ — Effective emissivity

Subscripts

- $b$ — Basin linear
- $c$ — Collector
- $g$ — Glass cover
- $s$ — Still
- $w$ — Water

References