EXPERIMENTAL ANALYSIS ACRYLIC PYRAMID SOLAR STILL COUPLED WITH FLAT PLATE COLLECTOR

B. Selvakumar¹, R. Jayaprakash², T. Arun Kumar and Sanjay Kumar³*

1. Department of Science and Humanities, RVS College of Engineering and Technology, Coimbatore, Tamilnadu, (INDIA)
2. Department of Physics, Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore, Tamilnadu, (INDIA)
3. Department of Physics, BR Ambedkar Bihar University, Muzaffarpur, Bihar, (INDIA)

*E-mail : solarselva@rediffmail.com

Received March 25, 2009 Accepted June 05, 2009

ABSTRACT

An attempt has been made to study the effect of coupling of flat plate collector with the pyramid acrylic solar still. The top cover of the still is made up of transparent acrylic sheet of 3mm thickness. The objective of the present paper is to study the behavior of the still performance coupled with flat plate collector by analysing the internal heat transfer coefficients and thermophysical properties of the pyramid solar still.

The study incorporates the influence of different environmental and operational parameters on the still productivity. Environmental parameters include solar intensity, ambient temperature and wind speed. Operational parameters include inner and outer cover temperature, basin water temperature, basin air temperature and basin water depth. The maximum distillate output of 2 L/m²/day was obtained for pyramid solar still and 2.66 L/m²/day for solar flat plate collector coupled with the pyramid solar still. The efficiency of the experimental still varies from 7% to 29% and the variation for flat plate collector coupled with pyramid solar still in the range of 2% to 8%. These results indicated that there is decrease in efficiency, even though the increase in still productivity is observed as the added advantage for this study.

Key Words : Solar Still, Water Collection, Efficiency, Flat Plate Collector.

INTRODUCTION

Today, a quarter of the world population has no drinking water, which achieves the quality standards of the World Health Organization (WHO), who restricted to 500mg/l the salinity for drinking water. In arid regions, the production of fresh water is often a serious problem. Many lands are devoid of natural fresh water because wells produce only salty or brackish water. In these regions, solar energy received on a horizontal surface is nearly constant in intensity throughout the year, and the water yield will be proportional to the horizontal area covered by solar distillation equipment. It is obviously important that the efficiency of the
solar distillation process be high and the initial cost of construction be as low as possible. When these aims are attained, fresh water can be produced by solar distillation for consumption and for irrigation, augmenting the amount of water supplied as rain.

Solar distillation is a thermal desalination method where solar energy is used to distill fresh water from saline and brackish water. A distillation is one of many processes available for water purification, and sunlight is one of several forms of energy that can be used to power that process. Sunlight has the advantage of zero fuel cost but it requires more space for its collection. It is a great practical alternative, which offers life to those regions where the lack of fresh water hinders development.

The availability of potable water is a main problem for the communities who will be lived in arid new regions or especially for people in remote region. These regions are recognized by a high intensity of solar radiation, which makes the direct use of solar energy represents a promising option for these communities to reduce the major operating cost for pumping drinking water, such as wind pumping systems. The solar energy can be utilized to obtain drinkable water from salty or brackish water through the use of solar still to capture the evaporated (or distilled) water by condensing it onto a cool surface (slope), and the output will be clean water.

Solar distillation is one of the available methods for water distillation, and sunlight is also one of several forms of heat energy that can be used to power that process. For households without access to portable water, a simple solar still can easily produce the water needed for drinking and cooking. Also the distilled water can be used for industrial purposes (water jackets, batteries, chemical solutions).

There are several types of solar stills the simplest of which is the single basin still. But the yield of this is in the range of 2 to 4 liters per day per sq. m. Different still designs for solar distillation that have been used in different regions globally where high-quality drinking water supplies are scarce and the solar option is viable. A review of passive solar distillation units has been presented which includes various new designs and economical viability of a system for the supply of drinking water. Lawrence S.A and Tiwari G.N. have analysed a solar distillation system integrated with a collector panel for a high operating-temperature range under the thermosyphon mode of operation. In their analysis, the effect of the temperature dependence of internal heat transfer modes on the performance of the system has also been taken into account. Raj S.N and Tiwari G.N. analysed a system and they found to be very difficult to control the reverse heat flow from the distillation unit to the collector panel during off-sunshine hours or low insolation periods, which affects the system performance significantly.

Many experimental and theoretical studies have been done on single basin solar stills. They have noticed that the influence of side insulation is significant on the rate of water production, especially for the double-basin type have developed a computer model to predict the performance of the single slope solar still based on both the inner and outer glass temperatures. They concluded that there is a significant effect of operating temperature range on the internal heat transfer coefficients. Similarly, some evaluated experimentally and theoretically a simple and efficient method for the behavior of solar stills. Their method relates the main climatic data and operating conditions of the still with distilled water output in daily and night base with linear equations using characteristic coefficients.
The aim of the present paper is to conduct an experimental work for the solar still in passive mode under the Indian climate. The passive still is combined with flat plate collector have been proposed to improve its productivity. All the results were compared together to reach to the best operating technique that can be used in future for solar still augmentation for production of drinking water to population of arid regions in the Indian desert.

MATERIAL AND METHODS

Passive solar still (Pyramid slope solar still)

Photographic and schematic diagram of the pyramid slope solar still are shown in Fig. 1a and Fig. 1b, respectively. This conventional pyramid slope solar still has an effective basin area of 0.50 m × 0.50 m and it is fabricated using stainless steel material. An acrylic cover with an inclination of 11° 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). 3mm thickness acrylic sheet is used to design the top pyramid cover. To ensure that vapors are not lost to the atmosphere, the acrylic cover is further sealed. The stainless steel is bent in the form of ‘U’ strip of dimension 0.55m × 0.025m × 0.015m and is provided at the top edge of four sides of basin to collect the condensed water from the slope of acrylic cover that is evaporated as a result of heating. Two outlets are located at diagonally opposite to each other to collect distilled water. A plastic pipe is connected to this channel to drain the distilled water to an external jar. Base of the basin is painted with black paint for good absorption of radiation. The thickness of the water layer in the solar still is 5 cm. ½ inch steel pipe is fixed through a hole drilled at the bottom of the basin to drain water and feed the basin. The inlet and outlet pipes are placed diagonally opposite to each other. Pipes are placed at the sides of the basin for maintaining water level at various heights and also one hole is provided to insert thermocouples to sense the temperature of water and air inside the still along the inner glass temperature. 4mm thickness wood is used to construct the outer cover box. Side loss and bottom loss in still are minimized by filling glass wool and sawdust in between basin and cover box.

Fig. 1a: Photographic view of pyramid solar still.
Fig. 1b: Schematic view of pyramid solar still.
Active solar still (Pyramid Slope Solar Still + FPC)

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 photographic view of an active solar still and schematic view of flat plate collector is shown in Fig. 2a and Fig. 2b, respectively. The Flat Plate Collector (FPC) setup is placed at 45° to absorb the incident solar radiation. The absorber is coated with black paint in order to increase efficiency of absorption. The area of 0.82m² plate is fused by the heat exchanger at the base of copper plate. The liquid heat exchanger is made up of copper tube. The outer diameter of the tube is about 0.10m and inner diameter of tube is 0.08m. There are eight vertical copper tubes are joined to the two horizontal inlet and outlet flow tubes at top and bottom of the vertical pipes. The copper tube is completely covered to increase the contact area of the absorber plate with copper tube.

The inlet and outlet are also made up of copper pipes. The outer diameter of the tube is 12mm. The inner diameter of the tube is 0.10m. The inlet tube is connected to bottom end of heat exchanger setup. The absorber plate along with copper tube arrangement is properly fitted with wooden frame. The outer cover is made up of wood with thickness 0.16m. The total dimension of the wooden box is 1m x 1m x 0.2m. The losses at the edge are protected by providing the rubber gaskets.

The still was coupled by using insulated pipes to the flat plate collector having a total effective area of 1.3 m² and inclined at 45° as shown in Fig. 2b.

Initially the still performance is analysed individually and then the combined effect of flat plate collector on the productivity of distillate yield is studied. Instantaneous efficiency, overall efficiency, average incident solar radiation, daily distillate yield, internal heat transfer values, external heat transfer values, dimensionless numbers, thermophysical properties, performance ratio and saturated vapour pressure are predicted.
Heat transfer modes in a solar still

It is very important to know accurately the heat and mass transfer processes in basin type solar stills for improving their performance. Many researchers have conducted a great many experimental and theoretical studies about them. For the most normal range of operation for a conventional solar still, the most commonly used relationship to evaluate heat and mass transfer coefficients and it is proposed by Dunkle R.V [15]. The study carried out by Adhikari S. et al., [16] for verifying the applicability of Dunkle’s relationships over a wide range of operating temperatures within a solar still reported that Dunkle’s relationships behave well in the lower temperature ranges. So Dunkle’s [15] relationship needs the modification in the higher ranges of temperatures. Thus they proposed a relationship for evaluating heat and mass transfer coefficients including higher temperature ranges as follows.

Internal heat transfer modes

a) Convection : Heat is transported inside the still by free convection of air. It releases its enthalpy upon air, which is coming in contact with the top cover. The heat transfer per unit area per unit time due to convection is

\[ Q_{ci} = 0.884 \left( T_w - T_c \right) + \left( \frac{(P_w - P_v)(T_w + 273)}{268.9 \times 10^3 - P_v} \right)^{1/3} \left( T_w - T_c \right) \]  

(1)

b) Evaporation : Dunkle connects convective and evaporation heat transfer coefficients as.

\[ Q_{ei} = 16.273 \times 10^{-3} h_{cv} \left( T_w - T_c \right) \]  

(2)

c) Radiation : Using Stefan Boltzmann’s constant, the heat transfer coefficient is given by,

\[ Q_{ri} = \sigma \varepsilon \left[ (T_w + 273)^4 - (T_c + 273)^4 \right] \]  

(3)

External heat transfer mode

The external heat transfer modes are convention and radiation. Due to the small thickness of the top cover, it is assumed that the temperature of the cover is uniform. The external convention loss from top cover to the outside atmosphere is,

\[ Q_{ce} = h_{ca} \left( T_c - T_a \right) \]  

(4)
here, $h_{ca}$ is a function of wind velocity and is given by Duffie, 1974, as,

$$h_{ca} = 5.7 + 3.8 V$$

The external radiation loss from the acrylic cover to the atmosphere is given by,

$$Q_{re} = \varepsilon \sigma \left[ (T_c + 273)^4 - (T_{sky} + 273)^4 \right]$$  \hspace{1cm} (5)

$T_{sky} = (T_a - 12)$ is the apparent sky temperature for long wave radiation.

The value of conduction heat loss through the base $Q_{bc}$ is given by

$$Q_{bc} = h_b (T_w - T_a)$$  \hspace{1cm} (6)

**Efficiency**

The efficiency of the still is calculated using the formula

$$\eta = \frac{(M \times L)}{(H \times A \times t)}$$  \hspace{1cm} (7)

**Thermophysical Properties**

Thermophysical properties are estimated using experimentally measured temperatures of evaporation and condensation surfaces. These values are given by Toyoma S, *et al.*, [17].

$$k = 0.0244 + (0.7673 \times 10^{-5}) T_{av}$$  \hspace{1cm} (8)

$$\mu = (1.718 \times 10^{-5}) + (4.620 \times 10^{-8}) T_{av}$$  \hspace{1cm} (9)

$$\rho = 353.44 / (273.35 + T_{av})$$  \hspace{1cm} (10)

$$h_v = 2324.6 \{(1.0727 \times 10^{3}) - (1.0167T_{av}) + (1.4087 \times 10^{-4}) T_{av}^2 - (5.1462 \times 10^{-6}) T_{av}^3\}$$  \hspace{1cm} (11)

The arithmetic mean of the temperatures of evaporation and condensation surface can be expressed as follows:

$$T_{av} = (T_w + T_c) / 2$$

Similarly the values of saturation vapour pressure are predicted under the expression, which is suggested by Brooker D.B, *et al.*, [18].

$$P = 6893.03 \exp (54.63 - 12301.69/T' - 5.17 \ln T')$$  \hspace{1cm} (12)

where $T' = (1.8T + 491.69)$

The Performance Ratio is calculated using the formula

$$PR = (m_{ev,i} h_v) / (H_s)$$  \hspace{1cm} (13)

The convective heat transfer is considered in terms of dimensionless parameters, viz. the Nusselt number (Nu), the Grashof number (Gr), the Reynolds number (Re) and the Prandtl number (Pr); the expressions for these numbers are

$$Nu = (h_{ci} L / k)$$  \hspace{1cm} (14)

$$Gr = (x_i^3 \rho_i^2 \beta g \Delta T') / \mu_i^2$$  \hspace{1cm} (15)

$$Pr = (C_p \mu / k)$$  \hspace{1cm} (16)

The values of constants C and n are determined by the following conditions:

$$C = 0.21, \quad n = \frac{1}{4} \quad \text{for} \quad 10^4 < \text{Gr} < 2.51 \times 10^5$$

$$C = 0.1255, \quad n = \frac{1}{5} \quad \text{for} \quad 2.51 \times 10^5 < \text{Gr} < 10^{15}$$

$$Gr = (x_i^3 \rho_i^2 \beta g \Delta T') / \mu_i^2$$  \hspace{1cm} (15)

$$Pr = (C_p \mu / k)$$  \hspace{1cm} (16)

1228
RESULTS AND DISCUSSION

The performance of the pyramid solar still is analysed individually and also combined with flat plate collector. The following predictions are made for all the studies and their performance is discussed in this chapter.

The radiative heat transfer ($Q_{ri}$), convective heat transfer ($Q_{ci}$) and evaporative heat transfer ($Q_{ei}$) under internal heat transfer modes are predicted. Similarly external heat transfer modes by conduction heat transfer ($Q_{be}$), external heat transfer through radiation from the glass cover ($Q_{re}$) and heat transfer from acrylic cover to atmosphere by convection ($Q_{ce}$) are also estimated and it is shown in Table 1. The instantaneous efficiency, performance ratio, saturation vapour pressure, latent heat and dimensionless parameters are also calculated for the pyramid solar still and still combined with flat plate collector. The readings are recorded for number of clear sky days and almost equal average radiation received during the three studies are considered for the analysis and reported.

Table 1: Heat transfer values

<table>
<thead>
<tr>
<th></th>
<th>$Q_{ci}$ (W/m$^2$)</th>
<th>$Q_{ri}$ (W/m$^2$)</th>
<th>$Q_{di}$ (W/m$^2$)</th>
<th>$Q_{ce}$ (W/m$^2$)</th>
<th>$Q_{re}$ (W/m$^2$)</th>
<th>$Q_{be}$ (W/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyramid Solar Still</td>
<td>17.22</td>
<td>51.52</td>
<td>127.47</td>
<td>37.11</td>
<td>78.93</td>
<td>4.65</td>
</tr>
<tr>
<td>Pyramid Solar Still combined with Flat Plate Collector</td>
<td>23.41</td>
<td>64.96</td>
<td>247.16</td>
<td>41.43</td>
<td>84.09</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Fig. 1 shows the variation of temperature for water, air, inner surface of the cover, outer surface of the cover and ambient with respect to time in pyramid solar still performance study. The maximum rise in water temperature is observed as 55.5°C. Similarly the maximum air temperature of 58.5°C is obtained. The variation of ambient temperature is in the range of 32°C to 37°C during the study. The impact of the ambient temperature over the still is more because the condensation at the top cover is mainly based on it. Similarly the variation of top cover temperature is in the range of 32°C to 44°C. Normally, the rise in top cover temperature affects the condensation of water vapour over the top cover, because the top cover temperature rises to a maximum of 44°C. This rise in top cover temperature is higher than the ambient temperature. The difference between top cover temperature and ambient temperature is only 7°C. Hence distillate yield obtained from the still is not slowed down. The difference in the rate of yield for the regular intervals measured between 2.00 p.m. and 5.00 p.m. is more than the rate of yield measured between from 9.30 a.m. and 2.00 p.m. Finally the yield reduces at 8.00 p.m due to the decrease of water temperature and evaporation rate.

Fig. 2 shows the variation of temperature for water, air, inner surface of the cover, outer surface of the cover for the still, water inlet and water outlet temperature of the flat plate collector and ambient temperature with respect to time in pyramid solar still performance for combined with flat plate collector. As a result water temperature rises during the initial sunshine hours and it falls down when the radiation intensity falls down. The maximum rise in water temperature is observed as 61°C. Similarly the maximum air temperature of 63°C is obtained. The variation of ambient...
temperature is in the range of 33°C to 37.5°C during the study. The impact of the ambient temperature over the still is more because the condensation at the top cover is mainly based on it. Similarly the variation of top cover temperature is in the range of 33°C to 45.5°C. Normally the rise in top cover temperature affects the condensation of water vapour over the top cover, because the top cover temperature rises to a maximum of 41°C. This rise in top cover temperature is higher than the ambient temperature. The difference between top cover temperature and ambient temperature is only 8°C. So distillate yield obtained from the still is not slowed down. Water temperature of the still and flat plate collector starts to increase individually during the initial period (9.00 a.m. to 10.00 a.m.). After this period the thermosyphon effect is taking part to transfer energy from the flat plate collector to the pyramid solar still. This process is confirmed by analyzing the temperature of the inlet, outlet and water temperature of the still. Therefore, water temperature of the still increases simultaneously along with the inlet and outlet water temperature of the still with respect to time and maintains almost a nearer value during 12.30 a.m. to 3.30 p.m. A small decrease in inlet and outlet temperature is observed in the evening. The difference in the rate of yield for the regular intervals measured between 10.30 a.m. and 2.00 p.m. is more than the rate of yield measuring from 9.00 a.m. to 10.30 a.m. and 3.00 p.m. and 5.00 p.m. since the collection rate is more only during thermosyphon effect. Before and after thermosyphon period, the system acts as a normal still. Finally, the yield reduces in the evening due to the decrease of water temperature and evaporation rate. Flat plate collector inlet water temperature is in the range of 33.5°C to 60.5°C and 33.5°C to 61°C for outlet water temperature. At off sunshine hours, water circulation to and from the flat plate collector is closed by using separate valves.

![Fig. 1: Variation of temperature with respect to time for pyramid solar still study.](image)
Fig. 3. shows the variation of instantaneous efficiency and performance ratio with respect to time for performance study of pyramid solar still and still combined with flat plate collector. The instantaneous efficiency is increased according to the time. The variation of the efficiency observed during the study is in the range of 7.52% to 32.73% and 2.41% to 9.01% for the pyramid still performance study and still performance combined with flat plate collector. The efficiency of the combined performance is found to be less because the total area of the combined system is larger than the still area. Even though the instantaneous efficiency in this mode is reduced than the normal pyramid still performance, the distillate water collection rate is increased.

The performance ratio calculated is found increase with respect to time and reaches a steady state after. The performance ratio observed during the study is in the range of 2.11% to 7.25 % and 2.64% to 8.66% for the pyramid still performance study and still combined with flat plate collector. The warming up period causes a change in the performance ratio during rise in temperature. When it rises to maximum, the performance ratio maintains a steady state. This effect is due to the rise in temperature completely utilized for evaporation.

Fig. 4. shows the variation of solar radiation and water collection with respect to time for pyramid solar still and still combined performance study. Radiation increases linearly with time and reaches the maximum value from 12 p.m. to 2 p.m. and then decreases. Radiation received during this study is in the range of 96.62 W/m$^2$ as minimum to 1050.7 W/m$^2$ as maximum for pyramid still performance study and 96.62 W/m$^2$ as minimum to 1074.85 W/m$^2$ as maximum for pyramid still combined with flat plate collector.
Fig. 3: Variation of instantaneous efficiency and performance ratio with respect to time for pyramid solar still under two modes of study.

Fig. 4: Variation of solar radiation and water collection with respect to time for the pyramid solar still under two modes of study.
The variation of distilled water collection is in the range of 0.01 kg to 0.045 kg and 0.013 kg to 0.062 kg for the pyramid still performance study and still combined with flat plate collector. This instantaneous water collection is observed as maximum of 0.045 kg and 0.062 kg at 2.00 p.m. for both the studies and the minimum water collection of 0.01 kg and 0.013 kg at 9.30 a.m for both the studies. Water collection is increased linearly during the initial hours even though the instantaneous yield rate at regular interval is less because the initial radiation is completely utilized for the warm up temperature than the distillate yield. In later case the temperature is fully utilized for evaporation simultaneously the rise in temperature causes an increase in saturated vapour pressure. So the collection yield during the period of interval is almost nearer to one another. So the yield rate difference in regular interval is less compared to the warm up period. The production rate of distilled water after 2 p.m. is higher than that of warming up period. So the still systems produce more condensation only at optimum temperature.

Water collection of the pyramid still in combined performance is boosted due to the coupling of the flat plate collector with it. Instantaneous distilled water collection is more during the sunshine hours due to the effect of flat plate collector. After sunshine hours, the effect of flat plate collector reduces and the system acts as a simple still performance.

**Fig. 5.** shows the variation of saturation vapour pressure and latent heat inside the pyramid still for two modes of studies. Saturation vapour pressure starts to increase with respect to time and it reaches the peak value around 1:30 p.m. to 2:00 p.m. Saturation vapour pressure reaches maximum value when water collection is more and tends to decrease when water collection decreases. Saturation vapour pressure is predicted in the range of 4842.65 to 11889.52 Pa for pyramid solar still and 5050.66 to 14114.04 Pa for pyramid solar still combined with flat plate collector. The difference in saturated vapour pressure is very less at higher temperature compared to the warm up period. So it suggests that the latent heat value has started or starts to increase and at the same time saturation vapour pressure starts to decrease.

Latent heat value is found to decreases initially with respect to time. It reaches a low value around 1.00 p.m. because the water temperature at this region is more. So it shows that the latent heat is decreased at higher order of temperature. Most of the incoming radiation is utilized for evaporation at this stage. Latent heat value is observed in the range of 2416722.46 to 2375960.52 kg$^{-1}$ for pyramid solar still performance study and 2414936.96 to 2367475.98 kg$^{-1}$ for pyramid solar still combined with flat plate collector. Latent heat is fully utilized for boosting the condensation commencing at lower temperature from 9.00 a.m. to 1.30 p.m. Thus the effect of latent heat is not completely utilized for condensation at higher temperatures. Latent heat values for the combined performance are reduced due to the reason of high values of water temperature. Hence latent heat value is predominant in pyramid still performance alone than that of the combined performance study.

**Fig. 6.** shows the variation of Grashof number and Nusselt number with respect to time for pyramid solar still in two modes of study. It concludes that Grashof number increases with respect to time. Grashof number is found as 10246 to 128075.03 for the pyramid still performance study and 5123 to 163936.03 for the pyramid still combined with flat plate collector. Grashof value is found to increase steadily during warm up period and then it starts to decrease with respect to decrease in water temperature.
Fig. 5 : Variation of saturation vapour pressure and latent heat with respect to time for pyramid solar still under two modes of study.

Fig. 6 : Variation of Grasshof and Nusselt number with respect to time for pyramid solar still under two modes of study.
Nusselt number is found to be increased with respect to time. Nusselt number values are observed in the range of 1.96 to 3.70 for the pyramid still study and 1.65 to 3.93 for the pyramid still combined with flat plate collector. Nusselt number is found to have close linearity similar to that of internal convective heat transfer rates. After attaining the maximum value at higher temperature, the Nusselt value maintains a steady state.

Fig. 7. shows the ratio between the evaporative heat transfers and the total heat transferred from the water to the cover (S) with respect to time. It shows the linear increase for all the mode of study and ‘S’ value is found in the range of 0.37 to 0.71 for the pyramid still performance study and 0.33 to 0.74 for the pyramid still combined with flat plate collector. Comparison of these figures shows that the range of temperature of still operation are sensitive to water temperature and less sensitive to change in top cover temperature.

The thermal conductivity of water is analyzed and it is observed in the range of 26.89x10^{-3} Wm^{-2}°C^{-1} to 28.19x10^{-3} Wm^{-2}°C^{-1} for pyramid still performance study and 26.95x10^{-3} Wm^{-2}°C^{-1} to 28.46x10^{-3} Wm^{-2}°C^{-1} for pyramid still combined with flat plate collector. The dynamic viscosity of water is predicted in the range of 18.68x10^{-6} Nsm^{-2} to 19.46x10^{-6} Nsm^{-2} respectively for pyramid still performance study and 18.71x10^{-6} Nsm^{-2} to 19.62x10^{-6} Nsm^{-2} respectively for pyramid still combined with flat plate collector. The thermal conductivity and dynamic viscosity increase with respect to time and posses almost the same trend. The density of water is predicted for the still and it is observed as 11.55x10^{1} kgm^{-3} to 10.94x10^{1} kgm^{-3} for pyramid still performance study and 11.52x10^{1} kgm^{-3} to 10.83x10^{1} kgm^{-3} for pyramid still combined with flat plate collector.
CONCLUSION

It concludes that the density decreases with respect to increase in water temperature and it starts to increase with the decrease in water temperature. The results also indicate that there is decrease in efficiency, even though the increase in still productivity is observed.

REFERENCES

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Area of the still , m²</td>
<td></td>
</tr>
<tr>
<td>A_m</td>
<td>Area of the mirror , m²</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>Acceleration due to gravity, m/sec</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Wind speed, m/sec</td>
<td></td>
</tr>
<tr>
<td>T_w</td>
<td>Water temperature, °C</td>
<td></td>
</tr>
<tr>
<td>T_sky</td>
<td>Sky temperature, °C</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Thickness of insulation, m</td>
<td></td>
</tr>
<tr>
<td>C_pa</td>
<td>Specific heat of air, J/Kg°C</td>
<td></td>
</tr>
<tr>
<td>k</td>
<td>Thermal conductivity, W/m°C</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Saturated Vapor Pressure, Pa</td>
<td></td>
</tr>
<tr>
<td>Q_a</td>
<td>Total heat transferred per unit area per unit time, W/m²</td>
<td></td>
</tr>
</tbody>
</table>

Greek and Suffix

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Air</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Cover</td>
<td></td>
</tr>
<tr>
<td>η</td>
<td>Efficiency of still (%)</td>
<td></td>
</tr>
<tr>
<td>σ</td>
<td>Stefan-Boltzmann constant, 5.6697 x 10⁻⁸ W/m²°K⁴</td>
<td></td>
</tr>
<tr>
<td>ci</td>
<td>Internal convection</td>
<td></td>
</tr>
<tr>
<td>ei</td>
<td>Internal evaporation</td>
<td></td>
</tr>
<tr>
<td>re</td>
<td>External radiation</td>
<td></td>
</tr>
<tr>
<td>w</td>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>ε_o</td>
<td>Emissivity of water</td>
<td></td>
</tr>
<tr>
<td>µ</td>
<td>Coefficient of viscosity, Kg/m sec</td>
<td></td>
</tr>
<tr>
<td>ρ</td>
<td>Density of water vapor, Kg/m³</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>Internal radiation</td>
<td></td>
</tr>
<tr>
<td>ce</td>
<td>External convection</td>
<td></td>
</tr>
<tr>
<td>be</td>
<td>External base</td>
<td></td>
</tr>
</tbody>
</table>

●●●●●

INSTRUCTIONS FROM PUBLISHERS

It is a condition for publication that the author(s) must give an undertaking in the writing at the time of submission of paper(s) that the manuscript(s) (research papers) submitted to JERAD have not been published and have not been submitted for publishing elsewhere, manuscripts are their original work. Furthermore, it should also be noted that the manuscript will not be returned in any case, whether accepted or rejected. Acceptance of research article will be communicated to author(s) in due course of time.