Enhanced Performance of a Floating Cum Tilted Wick Type Solar Still for the Climatic Conditions of Coimbatore during winter

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Abstract-- Day by day the scarcity for pure drinking water is reducing all over the world. We know that the solar distillers are the path for the production of pure drinking water which works with the availability of solar radiation from the sun. Many a solar stills like single slope basin type solar stills, double slope basin type solar stills, wick type solar stills, multiple wick type solar stills, tilted wick type solar stills etc… have been designed by the researchers for improving the performance. But, they still stand behind for their lower productivity except wick type solar stills with effective performance when compared with other solar stills. So in this present situation, there is need for enhancing the performance of a solar still by modifying them with different effects and with the usage of wick materials in the basin. This article deals with the study of a tilted wick type solar still and the enhanced performance under the weather condition of Coimbatore (11° North Latitude) during the winter season.

Keywords-- *Tilted Wick Type Still, Enhanced Performance, Climatic Conditions, Greater Efficiency.*

I. INTRODUCTION

It was Ho-Ming Yeh and Lie-Chiang Chen 1986 [1], who have studied the effects of climatic, design and operational parameters on the performance of wick type solar stills and proposed that for a better amount of distillate yield, the insulation plays an important role and suggested that the still without insulation yields less. Dhiman and Tiwari 1990 [2], have studied the effect of water flowing over the glass cover of a multi-wick solar still and have shown that the distillate is more in the case when water is flowing over the glass cover in a very thin layer and the output is increased by approx. 10%. Al-Karaghouli and Minasian 1995 [3], have constructed a floating wick type solar still and proposed that the maximum daily output of the still is 10.5 1 m 2. Recommendations have been made to utilize this type of still as split units to meet the drinking water requirements for families living in remote or isolated regions.

Later Minasian and Al-Karaghouli 1995 [4], have designed a new model of an improved solar still with wick basin type and inferred that the proposed still was more efficient and produces a higher output than the wick-type throughout the year and economically more sound when compared with other types of conventional stills as they produce the least output. Ohshiro et al.1995 [5], Our net-unit stills, however, have much higher productivities than these multi-wick stills. This is because our net-unit stills have much smaller gaps between evaporating and condensing surfaces in the units than the other stills, and because they have more units than most of the other stills.

Ho-Ming Yeh et al. [1] have carried out the study to improve the productivity of the basin type solar stills with wick materials and also carried out theoretical analysis by solving energy balance equations for the glass cover and for the water sheet for this purpose. Sengar et al. have given their concepts of tilted wick solar stills represented in fig 1. to increase the productivity. The following assumptions were made during the analysis.

The daily amount of distillate of the wick type still is more when compared with other types of basin type stills. The efficiency of the still with wick as absorbing material inside the still is also looked increasing for [2] than other two stills. The still is tested with different slope angles of 10°, 20°, 30° and 40°. The result showed that the still gives more yield in summer when the slope of the still is 10° and yields more in winter when the slope of the still is 40°.

The wick-basin type solar still by Minasian et al.[4] has great potential because of high productivity than the other types of basin and wick type stills. Here both the basin type and the wick type are combined to form a wick-basin type still. The results have shown that on yearly distillate yield, the wick-basin has yielded 85% more than basin type and 43% more than the wick type stills. The results have also shown that they are economically best when compared with wick-type solar stills.

In a floating wick type solar still have been proposed by Al-karaghouli et al.[5] with blackened jute wick and Safwat Nafey et al. [6] with aluminium black plate as floating materials inside the still. Thus the results found shows for floating-wick still with blackened jute wick [5] have shown increase in minimum average value of about 82% and 72% for the tilted wick and floating wick types. But in the case of the still with perforated aluminium black plate a special case of water depth has been considered. The still have shown an increase in productivity by 15% and 40% when the depth of the water is 3cm and 6cm respectively [6].

Shukla et al. [9] have proposed a multi-wick solar still. A double slope solar still has been taken under consideration for the purpose and is shown in figure. Similarly energy balance equations have been written as written by Dhiman et al.[8], with slight changes in the heat transfer equations.

A floating cum tilted wick type solar still is simple in construction. The new tilted cum floating wick type have been proposed by Janarthanan et al.[11-12] is shown in the figure.

In this study, the blackened jute wick is spread along with a 15° tilted portion and the remaining part of the wick have been prepared in a corrugated shape and floated in the inside water reservoir of the still with a thermocole sheet with 2-1/2 cm thick. The water level in the reservoir is always maintained to stay below the reservoir by 0.25 cm to make the water not to overflow in the tilted portion.

The instantaneous efficiencies for the closed and the open cycle systems are almost constant during 10 am to 2 pm and the theoretical values agree close to the experimental values. But in the case of water flowing over the glass cover the deviation between them is much reduced to 0.76191%.

The tilted wick type solar still with a flat plate reflector have been proposed by Hiroshi Tanaka et al. [13] is simple in construction. It consists of a glass cover, tilted-glavanized iron tray, wick material and a flat plate reflector to improve the amount of distillate output for different seasons of the year. The still is completely reviewed by Ayush kaushal et al. [24].

Similarly Hiroshi Tanaka et al. [14-17] have studied the increase in distillate productivity of a tiled wick type solar inclined with external flat plate reflector [14], with one step azimuth tracking of a tilted wick solar still [15], tilted wick type still with bottom reflector [16] and tilted wick still optimum inclination study for the still and reflector [17].

The study concluded that the bottom reflector can reflect the sun rays to the evaporating wick and increases the distillate productivity during summer by (25%) and in winter by (10%). Another study with external flat plate reflector to a tilted wick type solar still, the optimum inclination of still and reflector has been proposed [17]. The optimum inclination of the still is 10° in summer and 50° in winter. And the inclination of the still and the reflector has shown 21% difference in daily distillate than conventional stills.

Selva kumar et al. [18] have proposed a ‘V’ type solar still with charcoal as absorbing material. The construction of the still is simple. The still consists of galvanized iron tray, glass cover, charcoal absorber, boosting mirror and water collection segment which is shown in the figure 8. The results have shown that the charcoal absorber has increased the absorption of radiation in water and it results in increasing evaporation rate. Also the boosting mirror had increased in further evaporation.

Similarly the performance of a solar still with a concave wick evaporation surface has been proposed by Kabeel [19]. The construction of the still is different from other types of stills. The schematic representation of the still is shown in the figure. This study have shown that the instantaneous efficiency of 45% and average daily efficiency of 30% than conventional stills.

Velmurugan et al. [20] have studied a single basin solar still with fin for enhancing productivity with three different types of modified still with three different absorbing materials (i.e.,) wick, sponge pieces and fins of equal sizes have been used.

A. Sponge type

Due to capillary force, sponges absorb more water. Thus exposure area increased. This leads to increase in evaporation rate. The productivity of the still has been increased by about 15.3% when sponges were used. The maximum deviation between experimental and theoretical analysis was less than 6.2%.

B. Wick type

The productivity of the still increased around 29.6% when wicks were used in the still. The theoretical and experimental values agreed with a deviation of 10.8%.

C. Fin type

As fins have been used at the bottom of the still, absorber plate can absorb more solar radiation due to increase in exposure area and preheating time for saline water has been decreased. The productivity has been found to be 45.5% increased when fins were used and it has a maximum deviation of 9.2% when experimental values are compared with the theoretical.

Helmy et al. [21], have proposed a new model for distillation in which the still consists of glass cover, clothes belt, wooden box with insulation, Dc motor for rotating the clothes by connecting it to the copper tube with mirror on one side and without mirror on the other side is shown in the figure. The input water enters the still through an inlet. The clothes wick is immersed in water when the motor is ON, and the wet clothes are subjected to solar radiation when the motor is in OFF period. The black cloth is fixed on a two copper rollers and a belt. The lower roller is free, while the upper roller is fixed with a high torque motor. Another main component of the system is microcontroller PICI8F2455 from a microchip company. This microcontroller has been chosen, since it provides the capability of connecting it to a computer via USB (Version 2.0) interface. Its speed is 12 Mb/s and it has been used for the high speed data transfer between the computer and the microcontroller.

The experiments were performed at different motor OFF periods, 5, 10, 20, 30, 40, 50 and 60 minutes and found that the thermal efficiency increases to a maximum at 25 mins period OFF. This research has also proved that, the operation of this type of solar still with the computer have reduced the cost of production of distilled water.

Kalidasa murugavel et al.[22] have proposed the single basin double slope solar still. The double slope has been tested for a single basin solar still because of lower productivity of single slope, single basin solar stills. The stills productivity depends on the parameter like solar radiation, wind velocity, atmospheric temperature, basin water depth, glass cover material, thickness, its inclination and the heat capacity of the still. The still is very easy in construction and consists of a basin made of mild steel, inner basin, outer basin, two glass covers enclosing the still and tight insulation (rice husk). The still has been shown in the figure.

The performance of the still have been justified with absorbing materials like light cotton cloth, light jute cloth, sponge, quartzite rock and washed natural rock and found that light cotton cloth has its maximum production rated value than any other materials. Because the temperature raise rate is higher for the still with light cotton sloth as basin material during heating and reaches a maximum value at around 1:00 pm.

In this paper, an attempt has been made to investigate the enhanced performance of the single slope floating cum tilted wick type solar still for the weather conditions Coimbatore (11° N Latitude) during winter. Energy balance equations have been written for the various temperature components of the still and have been solved for the analytical solutions with the following assumptions.

The proposed system is vapour tight

1. There is no temperature gradient over the thickness of the condensing glass cover
2. The capillarity effect of the wick is sufficient to maintain the wetness during peak sunny hours
3. The waste hot water during late and early working hours is fed into the system
4. The water level in the tank is maintained in such a way that it should not overflow in the tilted-wick surface.

II. DESIGN OF THE PROPOSED STILL

Fig 1 and Fig 2 shows the schematic diagram and cross sectional view with energy transfer of a proposed tilted wick type solar still of area $1m^2$. The bottom surface of the still was painted black for greater absorptivity. The glass cover of 4mm thickness covers the still. The inner dimension of the still is 1m*1m*0.38m and the outer dimension is being 1.17m X 1.17m X 0.53m. The gap between the inner and outer dimensions is filled with thermal insulator to minimize the heat loss. A jute wick material painted black is spread over the 13° tilted portion and the remaining part of the wick has been prepared in corrugated shape and made to float over the water reservoir of the still with a thermocole of 0.002m thick. The water level in the reservoir was maintained so as not to overflow in the tilted portion and always to be 0.025m below the tilted portion through an inlet controlled by a valve. The corrugated floating wick always coincides with the upper level of the water in the reservoir which makes tilted wick always wet due to capillary action. This arrangement causes evaporation from the tilted wick and floating wick surfaces.

A. Thermal modelling

The thermal modeling of the single slope floating cum tilted-wick type solar still have been proposed based on the energy balance equations for the temperature elements of the system and written as

Inner surface of the glass cover (T_{gi}):

$$\alpha_g I(t)_g \tau_g l_g b_g + h1(T_w - T_{gi}) l_w b_w + h2(T_m - T_{gi}) l_m b_m = h3(T_{gi} - T_{go}) l_{gi} b_{gi} \quad (1)$$

Eq. 1 is solved to get

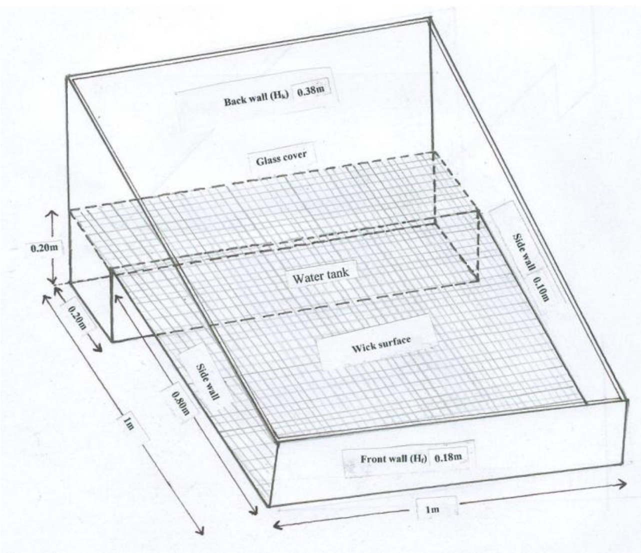

Figure 1: Schematic representation of the proposed tilted wick type solar still.

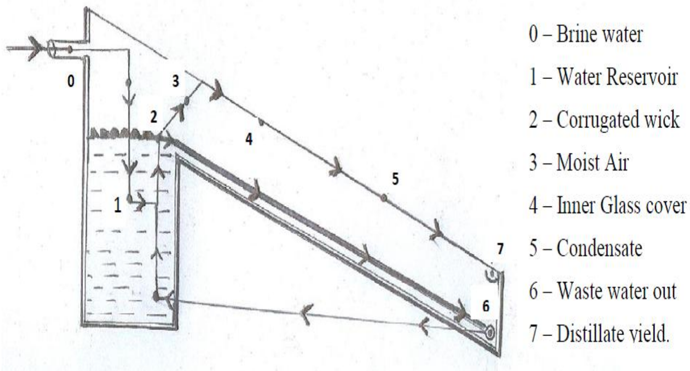

Figure 2: Cross sectional view and energy transfer diagram of the proposed still.

$$T_{gi} = \frac{\alpha_g I(t)_g \tau_g l_g b_g + h1(T_w - T_{gi}) l_w b_w + h2(T_m - T_{gi}) l_m b_m + h3(T_{gi} - T_{go}) l_{gi} b_{gi}}{h1 l_w b_w + h2 l_m b_m + h3 l_{gi} b_{gi}} \quad (2)$$

Outer surface of the glass cover (T_{go}):

$$\alpha_g I(t)_g l_g b_g + h3(T_{gi} - T_{go}) l_{gi} b_{gi} = h4(T_{go} - T_a) l_{go} b_{go} \quad (3)$$

Eq. 3 is solved to get

$$T_{go} = \frac{\alpha_g I(t)_g l_g b_g + h3 T_{gi} l_{gi} b_{gi} + h4 T_a l_{go} b_{go}}{h3 l_{gi} b_{gi} + h4 l_{go} b_{go}} \quad (4)$$

For moist air (T_m)

$$I(t)_g \tau_g + h(T_w - T_m) l_w b_w = h2(T_m - T_{gi}) l_m b_m + h5(T_m - T_a) l_m b_m \quad (5)$$

Eq.5 is solved to get

$$T_m = \frac{I(t)_g \tau_g + h(T_w) l_w b_w + h2(T_{gi}) l_m b_m + h5(T_a) l_m b_m}{h l_w b_w + h2 l_m b_m + h5 l_m b_m} \quad (6)$$

For the evaporating wick surface

$$\alpha_g I(t)_g \tau_g l_g b_g = M_w \frac{dT_w}{dt} l_w b_w + h1(T_w - T_{gi}) l_w b_w + h(T_w - T_m) l_w b_w + h6(T_w - T_a) l_w b_w \quad (7)$$

Substituting the value for T_{gi} in Eq.7, the equation becomes

$\alpha_g I(t)_g \tau_g l_g b_g =$
$M_w \frac{dT_w}{dt} l_w b_w +$
$h1 \Big(T_w -$
αgItgτglgbg+h1Tw−Tgilwbw+h2Tm−Tgilmbm+h3Tgi−Tg
olgibgih1lwbw+h2lmbm+h3lgibgilwbw+hTw−Tmlwbw+
$h6(T_w - T_a) l_w b_w$ (8)

After suitable rearrangement the equation takes the form as

$$\alpha_g I(t)_g \tau_g l_g b_g + \frac{h1 \alpha_g I(t)_g \tau_g l_g b_g}{M_w (h1 l_w b_w + h2 l_m b_m + h3 l_{gi} b_{gi})} + T_m \left[\frac{h1 h2 l_m b_m}{M_w (h1 l_w b_w + h2 l_m b_m + h3 l_{gi} b_{gi})} - \frac{h}{M_w} \right] + T_{go} \left[\frac{h3 l_{gi} b_{gi}}{M_w (h1 l_w b_w + h2 l_m b_m + h3 l_{gi} b_{gi})} \right] + \frac{h6 T_w}{M_w} - \frac{h6 T_a}{M_w} = \frac{dT_w}{dt} + T_w \left[\frac{h1 + h}{M_w} - \frac{h1 l_w b_w}{M_w (h1 l_w b_w + h2 l_m b_m + h3 l_{gi} b_{gi})} \right] \quad (9)$$

Eq.9 resembles the form

$$\frac{dy}{dx} + Py = Q \quad (10)$$

$$P = \left[\frac{h1 + h}{M_w} - \frac{h1l_w b_w}{M_w(h1l_w b_w + h2l_m b_m + h3l_{gi} b_{gi})}\right]$$

$$Q = \alpha_g I(t)_g \tau_g l_g b_g + \frac{h1\alpha_g I(t)_g \tau_g l_g b_g}{M_w(h1l_w b_w + h2l_m b_m + h3l_{gi} b_{gi})} + T_m\left[\frac{h1h2l_m b_m}{M_w(h1l_w b_w + h2l_m b_m + h3l_{gi} b_{gi})} - \frac{h}{M_w}\right] + T_{go}\left[\frac{h3l_{gi} b_{gi}}{M_w(h1l_w b_w + h2l_m b_m + h3l_{gi} b_{gi})}\right] + \frac{h6T_w}{M_w} - \frac{h6T_a}{M_w}$$

The solutions of the Eq.10 is given by

$$T_w\, e^{\int P.dt} = \int Q(t).e^{\int P.dt} dt + c \qquad (11)$$

Applying initial condition in i.e., when t = 0, $T_w = T_{wi}$, we get

$$c = T_{wi} - \frac{Q}{P}$$

Substituting for the value for c in Eq.11, the solution for T_w can be written as

$$T_w = \frac{Q}{P}\left(T_{wo} - \frac{Q}{P}\right) e^{-Pt} \qquad (12)$$

The mass of the distillate yield obtained is given by

$$M_{ewgi} = \frac{h_{ewgi}\,(T_w - T_{gi})}{L} \times 30 \times 60 \ \left(\frac{kg}{m^2 30 \text{ minutes}}\right) \qquad (13)$$

The instantaneous efficiency of the wick type passive solar still is given by

$$\eta_i = \frac{M_{ewgi} \times L}{\int I(t)dt} \times 100 \qquad (14)$$

III. RESULTS AND DISCUSSION

The climate of Coimbatore city is moderate and pleasant throughout the year with little temperature variation between the seasons. Summers are hot with the mercury reaching to 39 degree Celsius, the dip in the summer to as low as 23 degree Celsius. In winter the climate is mild with the maximum temperature hovering around 33 degree Celsius and the minimum temperature rarely going below 21 degree Celsius. Coimbatore being in Tamilnadu, does not receive rain during south-west monsoon season, that's why it is known as "Rain shadow area".

Coimbatore experiences rains in October - November, which is brought about by the retreating north-east monsoon. Although these rainfalls are not enough for the entire year, small rivers like Siruvani and Atthikadavu fulfill water need of the city.

Fig 3 shows the average high and low temperatures of Coimbatore for the different months of the year [25]. Based on the graph, it is clear that during the months of June to November the average low temperatures have been received by the city.

The fabricated floating cum tilted wick type solar still has been exposed to the sun round the year and the performance study has been done during the months of June to November. The readings have been taken for the inner glass cover, outer glass cover, evaporating wick material and moist air present inside the still. Fig 4 shows the theoretical and experimental values of the above parameters of the still for one of the typical days of September 2013.

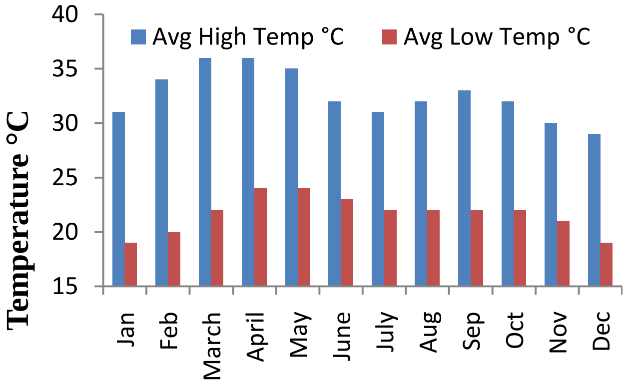

Figure 3: Average Temperature (°C) Graph for Coimbatore (2013).

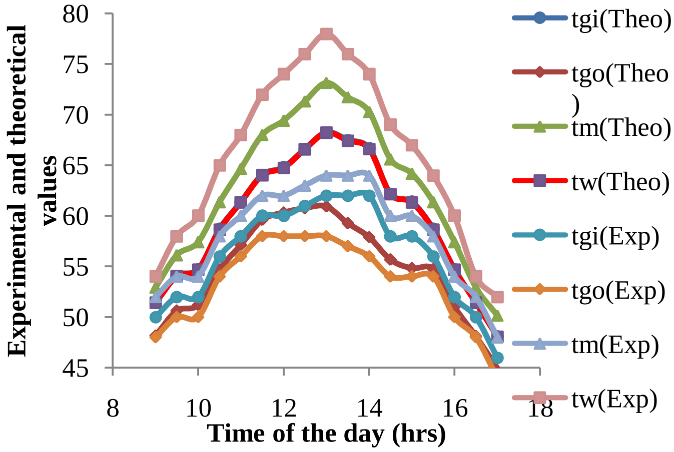

Figure 4: Average theoretical and experimental temperatures of the parameters of the still on a typical day of September.

Table 1: The seasons of Coimbatore and their average maximum and minimum temperatures:

Season	Months (From – to)	Maximum Temperature	Minimum Temperature	Monsoon Responsible
Mild Winter season	Dec - Feb	34	19	Non- monsoon months
Pre-Monsoon season	Mar - May	36	22	Non- monsoon months
South west monsoon season	June - Sep	33	22	South west monsoon
Post monsoon season	Oct - Nov	32	21	Northeast monsoon

It has been noticed that, both the theoretical and experimental values have mere agreement with all the parameters of the still. The temperature of the inner glass cover between the theoretical and experimental goes maximum during 13 hours of the day and gradually decreases during the rest of the hours of the day. Similarly the temperatures for the remaining parameters like the outer glass cover, Evaporating wick surface and the moist air increases during the early hours of the day and reaches maximum at 13 hours and gradually decreases during the later hours of the day. From this it can be concluded that, the temperature difference between the theoretical and experimental values are very minimum.

Fig 5 shows the mass of the distillate output with the proposed still. It has been noticed that, the output is maximum during 13 hours of the day. As the radiation is high during 13 hours, the output is also maximum during that hour. Experimental results show that, an output of 348 ml has been obtained during the hour. The still has obtained an overall output of 3.33 liters of water during the working hours of the day in spite of winter for the climatic conditions of Coimbatore.

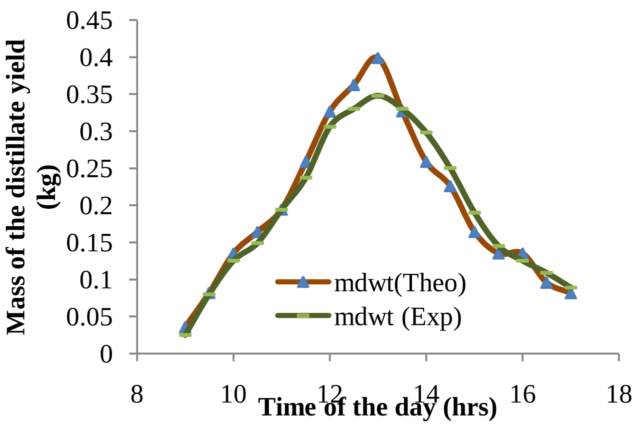

Figure 5: Mass of the distillate output for the typical day.

Fig 6 shows the efficiency of the still. The theoretical value of the still during 13 hours is 45% and that of the experimental value is 39.98%. The overall efficiency of the still is 26.19% and 25.76% for theoretical and experimental values of the still respectively.

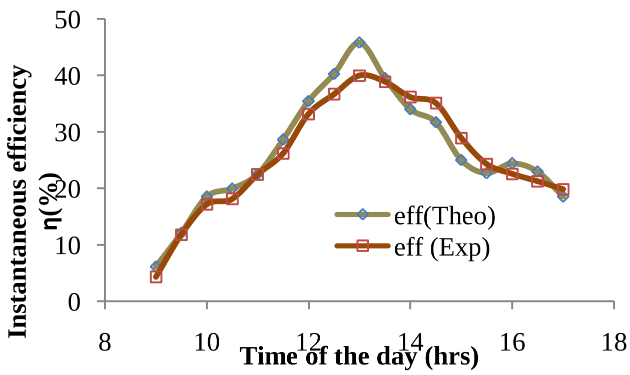

Figure 6: Efficiency of the still for the typical day

IV. DISCUSSIONS

The Experimental analysis of Enhanced performance of a floating cum tilted wick type solar still is done for the climatic conditions of Coimbatore round the year and performance of the still has been analysed only during the winter i.e., during September 2013. A comparison between the theoretical and experimental values has been done along with the calculations for mass of the distillate output and efficiency of the still.

The various temperatures like inner glass cover, outer glass cover, evaporating wick surface and the moist air are recorded using thermocouples and the data is plotted. The solar intensity has shown similar variation between the theoretical and experimental values of the still during the days of the analysis. The mass of the distillate output is 3.33 liters and the maximum efficiency obtained for this system is 25.76%. With the various still performed by the researchers during the winter seasons, the floating cum tilted wick type solar still is more efficient. These analyses are also suggested as a method to produce a low cost distillation unit for acquiring high pure distilled water.

Nomenclature:

α_g - Absorptivity of the glass cover
l_g - Length of the glass (m^2)
b_g - Breadth of the glass (m^2)
l_w - Length of the wick surface (m^2)
b_w - Breadth of the wick surface (m^2)
l_{gi} - Length of the inner glass cover (m^2)
b_{gi} - Breadth of the inner glass cover (m^2)
T_w - Temperature of the wick surface (°C)
T_{gi} - Temperature of the inner glass cover (°C)
T_{go} - Temperature of the outer glass cover (°C)
T_a - Ambient temperature (°C)
T_m - Moist air temperature (°C)
h - Total heat transfer coefficient from wick surface to inner glass cover ($W/m^2 K$)
h1 - Total heat transfer coefficient from Wick surface to the inner glass cover ($W/m^2 K$)
h2 - Total heat transfer coefficient from moist air to the inner glass cover ($W/m^2 K$)
h3 - Total heat transfer coefficient from inner glass cover to the outer glass cover ($W/m^2 K$)
h4 - Total heat transfer coefficient from outer glass cover to the ambient ($W/m^2 K$)
h5 - Total heat transfer coefficient from moist air to the ambient ($W/m^2 K$)
h6 - Total heat transfer coefficient from wick surface to the ambient ($W/m^2 K$)
ηi - Instantaneous energy efficiency of the first and second systems.
M_{ewgi} - Mass of the distillate water collected from innerside of the glass cover. (Kg/m^2)
M_w - Mass of the distillate output (Kg/m^2)

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