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# Productivity enhancement of Evacuated Tubes solar still of different water depth: Thermal modelling and an Experimental analysis.

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**Abstract.** In this research article, the author has conducted the comparative thermal experimental analysis and investigation on Conventional still and Modified Evacuated Tubes solar still with different water volume of 30 and 50 Litre in Basin, in respect of Energy Balance Equation. The various variable elements have been taken into account and duly calculated for both the stills i.e. active still and passive still, based on thermal modelling. The variables calculated comprise inner glass surface temperature, distillate yield, basin water temperature etc. The entire study has been carried out at Akison's Solar Equipments Pvt. Ltd., Shirwal, Maharashtra, India (latitude18.14° N: longitude 73.97° E), with adequate instrumental infrastructure setup appropriate for the purpose. The investigation concluded that there is substantial escalation of. 242% and 246% at 0.03 and 0.05m of water depth respectively in the yields obtained from Modified Evacuated Tubes solar still in comparison of Conventional still. It has been observed that theoretical outcomes from thermal modelling and the outcomes attained from experiments done for simple and modified stills are in respectable consensus.

## 1. Introduction.

Water establishes the primary component for the endurance of life on planet earth and the reduction of drinkable water source, attributed to various reasons such as rapid increase in population, industrial revolution, climate changes resulting in frequent droughts, underground pollution, is quite alarming. Earth surface comprises 71% of water and out of that, most of it, say around 98.8% of it, is not fit for human consumption. That leaves only 2.5% of total the water available on earth fit for drinking. [1]

There are different methods are available to get distilled water but these various methods of water distillation require fossil fuels and electricity. Solar distillation is one of the simplest and eco-friendly technique which uses solar energy as renewable form of energy and it is also non-polluting. So, it is effectively used in costal and remote areas where electricity is unavailable to reduce water scarcity problem.

Solar Still is an environment friendly green energy device, categorized into Active and Passive Solar Still, in which solar energy is primarily employed for purification of water via distillation practice. The difference between Active and 'Passive Solar Still being that in former, in comparison to the latter, additional thermal energy is also utilized to gain potable water. The outcome of the Passive Solar Still is quite less and to increase the desirable outcomes, a lot of research work has been poured into the issue to develop various techniques.

Dimri et al [2] carried out experimental work on the Conventional solar still with copper, glass and plastic as 'condensing cover material' and came to conclusion that the highest outcome was obtained with copper due to its higher thermal conductivity. Rai and Tiwari [3] performed experiment on 'Solar Still' accompanied with 'Flat Plate Collector' and observed that the productivity got accelerated by 24%. In the experiment carried out by Velmurugan et al.[4], a mini solar pond combined with a Conventional Still was constructed and the observations came out that the outcome rate of water in a Solar Still with sponge and combined with a Mini Solar Pond and Ordinary Solar Still were 3.14 and 4.65 kg/m$^2$/day respectively, escalating productivity thereby by 48%. Badran et al and Tiris et al [5, 6] utilized a Flat Plate Collector with a Single Basin Solar Still and observed 52% escalation in the production of drinkable water. Dashtban M et al [7] experimented using the Latent Heat Thermal Energy Storage System in a specially designed Weir Type Cascade Solar Still, to increase the outcome. Prabahar et al [8] studied Modified Double Slope Solar Still. An escalation by 14% in outcome was noticed by utilizing Flat Plate Collector', an escalation of 10% with sponge and 17% by sponge and Flat Plate Collector.

H. Kargar Sharif Abad et.al.[9] introduced a Solar Desalination System by using a Pulsating Heat Pipe and noticed 875 ml/(m$^2$.h) increase in outcome. Z. M. Omara et al, [10] experimented on developed Solar Still with Solar Concentrator. The productivity was increased by 244% and 347% respectively without and with preheating of the brackish water. An inclined solar system was modelled and simulated by Hikmet S.Aybar [11] .The result showed that the system generated distilled water of 3.5-5.4 Litre/m$^2$ and also maximum temperature of hot water reached to 60$^0$C. Hitesh N. Panchal [12] worked on double basin solar still combined with Vacuum Tubes and Black Granite Gravel placed in basin water to enhance the productivity. Anil Kr. Tiwari et.al [13] performed experiment on Conventional Solar Still for different water volumes with cover inclination angle of 30$^0$ and also thermal modelling of the system was carried out. The experimental yield was found in good agreement with theoretical values obtained from thermal modelling. Hitesh N. Panchal [14] worked on the Evacuated Tube Solar Still and noticed a considerable increase in the average distillate output. Rahul Dev et.al [15] conducted experiment on an Inverted Absorber Solar Still (IASS) and Conventional Solar Still (SS) at diverse levels of water depth and they found that higher basin water temperature and yield was obtained with IASS as compared with simple still.

Under Natural Circulation Mode. K. Sampathkumar et al [16] experimentally and theoretically studied Evacuated Tube Solar Still. The results concluded that the performance of Evacuated Tube Solar Still is much higher than the Conventional Solar Still throughout the year. It was observed by Selcuk Selimli et al [17] that the productivity was considerably enhanced by about 62.5%, when Solar Vacuum Tube was integrated with Simple Solar Still. An experiment was carried out by Ali.F. Muftaha et al [18] on Stepped Solar Still integrated with internal and external reflectors, external condensers along with absorber materials, which yielded 29% escalation in the daily outcome of modified solar still. K. Sampathkumar [19] worked on Vacuum tube solar still and noticed that daily outcome was increased by 49.7% and it increased further to 59.48% when coupled with black stones and vacuum tubes. Lilian Malaeb et al [20] studied analytically the modified still with rotating drum to optimize the performance and concluded a noticeable escalation in the productivity was observed in comparison of a Conventional Solar Still.

Hence to enhance the yield from Solar Still, various methods are tried by researchers like use of Flat Plate Collector, concentrating collector, heat pipes, reflectors and internal and external condensers, air

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blower with solar still. Also provide vacuum condition in still, incorporate the phase change materials, sensible heat storage and Nano materials, wick materials and dyes in basin water. Evacuated tube solar still is more efficient as there is no loss of energy through vacuum. The solar radiations are positively tracked continuously through- out the day due to its cylindrical shape. The incident angle of sunlight on the cylindrical tubes is at $90^0$ thought the day; hence the peak absorption is always for it so it's thermal performance is higher than other collectors.
The core objectives of the research are:

- Thermal modelling of Conventional Solar Still and Evacuated Tubes Solar Still with natural circulation for different water depth in Basin.
- Validation of the values like hourly inner glass surface temperature, basin water temperature and distillate yield with Experimental values.
- To evaluate the potential of active solar still by comparing its performance parameters with conventional still.

## 2. Experiment.

The experiment set was designed and installed at Akison's Solar Systems Pvt. Ltd. at Shirwal (Latitude18.14° N: Longitude 73.97° E), Maharashtra (India) and as shown in Fig.1.For the experiment Solar Still Basin used with inner side painted in black up to 10mm high so that it could absorb maximum solar radiation. It is made up of galvanized iron plates, 1.5mm thick and 1m × 1m area, with bottom and all sides of it are comprised of Rockwool insulation (50mm thick) with thermal conductivity of 0.045W/mK to achieve minimum heat loss from it. A toughened glass (4mm thick) was fixed, at upper side of Solar Still at $19^0$ angles, in accordance with horizontal axis (Latitude of Shirwal), which acts as condensing surface. The glass was tightened with solar still by a silicon rubber sealant to prevent the vapour leakage from the system. The condensate water from inclined glass cover was collected in U shape mild steel channel which is located at lower side of solar still. A rubber pipe was utilized to accumulate distillate in measuring jar from collection tray. A hole had been drilled in Solar Still body to attach 'K Type Constantan Thermocouples' to measure basin, water and inner glass cover temperature respectively. The same material and Dimensions was used for active solar still. Total 13 holes of diameter 0.063 m were made at the bottom end of front wall of the Solar Still to attach the one end of same number of Evacuated tubes with specifications of length 1.8m, outer diameter 0.058 m, inner diameter 0.047m and glass thickness of 0.0016m, with the help of rubber gaskets, at an angle of $30^0$ with horizontal surface, and whose other ends were fixed at a metal frame connected to the Solar Still stand again at $30^0$ angle.

## 3. Instrumentation.

- For the accurate measurement of radiation from sun incident on the 'Solar Still' surface, a calibrated solarimeter was used with a range of 0-1200 W/m$^2$ & accuracy of $\pm 1W/m^2$ .
- For accurate measurement of water temperature in the basin, inner glass cover and ambient temperature, 'K type Thermocouples 'were used with accuracy of $\pm 0.1^0 C$ .
- For measurement of wind velocity, an 'Anemometer' with range of 0-15m/sec & accuracy of $\pm 0.2 m/\sec$ was used.
- A plastic jar of 1 litre capacity with an accuracy of $\pm 10 ml$ was used to collect the distillate yield.

Extensive experiments were carried out on both Simple solar Still and Active Solar Still with water depths precisely 0.03m and 0.05m during May 2019 from 9 am to 6 pm on clear sunny days.
Dimensions of experimental set up are shown in Table No.1

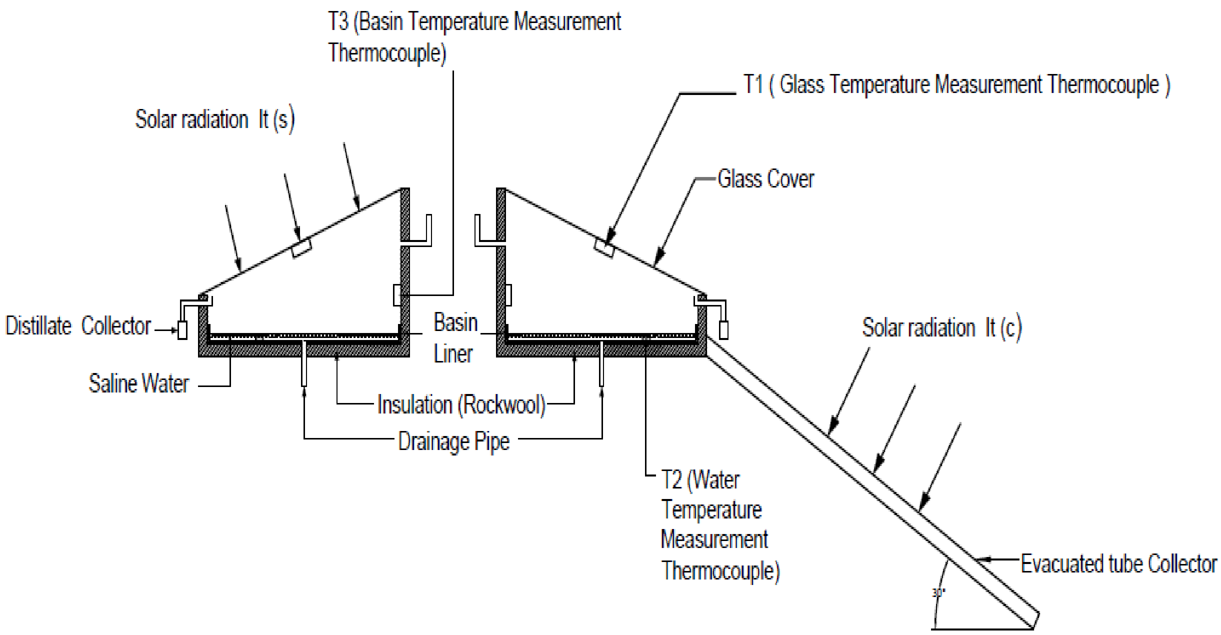


**Figure 1.** Schematic diagram of the experimental setup.

**Table 1.** Dimensions of experimental set up

| **Particulars** | **value** |
|---|---|
| Simple Solar Still and Active Solar Still Area. (As and Aa) | $1 m^2$ |
| Evacuated Tubes Area integrated with Solar Still ($A_I$) | $3.455 m^2$ |
| Absorber area of evacuated tubes. ($A_{ET}$) | $1.099 m^2$ |
| Solar still outer area. | 1 m× 1m |
| Glass cover inclination to horizontal. | $19^0$ |
| Length of each evacuated tubes | 1.8 m. |
| Inner diameter of evacuated tubes | 0.047 m |
| Outer diameter of evacuated tubes | 0.058 m |
| Glass thickness in each evacuated tube. | 0.0016m |

**Table 2.** List of various 'Constants and Designs' parameters employed in theoretical modelling.

| Parameters | Value | Parameters | Value |
|---|---|---|---|
| $\alpha_b$ | 0.36 | $C_w$ | 4190 J /Kg $^0$K |
| $\alpha_g$ | 0.05 | $h_w$ | 250 W/m$^2$K |
| $\alpha_w$ | 0.34 | t | 3600 s |
| $F_R$ | 0.831 | $\sigma$ | $5.67\times 10^{-8}$ W/ m$^2$K |
| $M_w$ | 30 and 50 kg | $(\alpha\tau)_e$ | 0.8 |
| $\varepsilon_{eff}$ | 0.82 | $U_{LC}$ | 2.44 W/ m$^2$K |
| $L_i$ | 0.05m | $h_{tg}$ | 5.7+3.8 $V_a$, $V_a$=4 m/sec |
| $K_i$ | 0.045 W/ mK | L | $2.25\times 10^5$ J/Kg |

## 4. Thermal modelling:

The Thermal Model of Conventional Solar Still and Evacuated Tubes Solar Still is developed by utilizing First Law of Thermodynamics.

For analysis the following assumptions are made:

- No vapour leakage in Solar Still.
- Glass cover, basin liner and insulation are having negligible heat capacity.
- Steady state condition is reached at every hour.
- Across the glass cover of the Solar Still and Basin water of the ‘Solar Still, no temperature gradient exists.
- No change in the water level inside the Solar Still Basin throughout the experiment. It is maintained constant.
- Inside the glass cover, it has been assumed that only film type condensation of water occurs.

### 4.1 Energy Balance of Glass Cover

$$\alpha'_g I_{effs} + [q_{cw} + q_{ew} + q_{rw}] = q_{cg} + q_{rg}$$

$$\alpha'_g I_{effs} + h_{tw}(T_w - T_g) = h_{tg}(T_g - T_a) \quad (1)$$

The rate at which glass absorbs solar energy and sum of energies transferred from water surface via radiation, convection & evaporation to glass are equivalent to energy lost by glass to atmosphere via convection & radiation.

$$h_{tw} = h_{cw} + h_{ew} + h_{rw}$$

The ‘Convective Heat Transfer Coefficient’ between water and glass [21] has been given by

$$h_{cw} = 0.884 \times [(T_w - T_g) + \frac{(P_w - P_g) \times (T_w + 273)}{268.9 \times 10^3 - P_w}]^{1/3} \quad (2)$$

The ‘Evaporative Heat Transfer Coefficient’ between water and glass [21] has been given by

$$h_{ew} = \frac{16.273 \times 10^{-3} \times h_{cw}(P_w - P_g)}{T_w - T_g} \quad (3)$$

The ‘Radiative Heat Transfer Coefficient’ between water and glass [21] has been given by

$$h_{rw} = \varepsilon_{eff} \times \sigma \times (T_w + 273)^2 + (Tg + 273)^2 + (T_w + T_g + 546) \quad (4)$$

Where $\varepsilon_{eff}$ = The ‘Effective Emissivity’ between the water surface and the glass cover has been taken [22] as 0.82.

The total ‘Heat Transfer Coefficient’ between glass and atmosphere [23] is given by

$$h_{tg} = 5.7 + 3.8(v) \quad (5)$$

V has been taken as 4 m/sec for numerical calculations.

The ‘glass cover temperature’ $T_g$ is derived from energy balance equation as

$$T_g = \frac{\alpha'_g I_{effs} + h_{tw}T_w + h_{tg}T_g}{h_{tw} + h_{tg}} \quad (6)$$

### 4.2 Energy Balance for Basin Liner

The energy transferred to water by convection and conduction energy lost from bottom and sides of the basin are equivalent to the rate of solar energy absorbed by basin

$$\alpha'_b(1-\alpha'_g)(1-\alpha'_w)I_{effs} = q_w + q_b$$

$$\alpha'_b(1-\alpha'_g)(1-\alpha'_w)I_{effs} = h_w(T_b - T_w) + h_b(T_b - T_a) \quad (7)$$

The 'Convective Heat Transfer' between basin and water is given by [4]

$$q_w = h_w(T_b - T_w) \quad (8)$$

The 'Convective Heat Transfer Coefficient' between basin and water is taken as 135 W/m$^2$ K. [4].
The 'Conductive Heat Transfer' between basin and atmosphere is given by (22)

$$q_b = h_b(T_b - T_a) \quad (9)$$

The 'Basin Liner Temperature' $T_b$ is derived from 'Energy Balance Equation' of the basin liner

$$T_b = \frac{\alpha'-bI_{effs} + h_w T_w + h_b T_b}{h_w + h_b} \quad (10)$$

Where $\alpha'-b =$ $\alpha'_b(1-\alpha'_g)(1-\alpha'_w)$

### 4.3 Energy balance of water mass for 'Simple Solar Still'

The heat deposited due to solar energy in water and the heat transferred to glass cover is equivalent to the radiation energy absorbed by water mass in basin and convective heat gained from basin liner.

$$\alpha'_w(1-\alpha'_g)I_{effs} + q_w = (MC)_W \frac{dT_W}{dt} + [q_{cw} + q_{ew} + q_{rw}] \quad (11)$$

Substituting Equations 6 and 10 in Equation 11, the following Differential Equation is obtained.

$$\frac{dTw}{dt} + aTw = f(t) \quad (12)$$

Where $a = \frac{UA_{effs}}{(MC)_w}$ & $f(t) = \frac{IA_{effs} + UA_{effs}Ta}{(MC)_w}$

Expressions for $UA_{effs}$ & $IA_{effs}$ are given in the Appendix

To obtain the approximate analytical solution, the following assumptions have been made. The time interval $\Delta t(0 < t < \Delta t)$ is small

a is constant during the time interval $\Delta t$

1) The function $f(t)$ is constant i.e. $\overline{f(t)} = f(t)$ for the time interval between 0 and $t$

In equation 12, by using initial condition at $t = 0$ , $Tw(t = 0) = Two$ , the expression for water temperature is derived as

$$Tw = \frac{\overline{f(t)}}{a}[1 - e^{-at}] + Twoe^{-at} \quad (13)$$

The following expression is used for deriving the hourly yield:

$$m_{ew} = \frac{h_{e,w-g}(T_w - T_g)}{L} \times 3600 \times A_s \tag{14}$$

**4.4 Energy Balance of water mass for Solar Still with evacuated tubes**

The Radiation Energy absorbed by water mass in basin and Convective Heat gained from basin liner and heat energy supplied to basin water from Evacuated tubes is equivalent to the heat stored in water and heat transfer to glass cover.

$$\alpha'_w(1-\alpha'_g)I_{effs} + q_w + Q_u = (MC)_W \frac{dT_W}{dt} + [q_{cw} + q_{ew} + q_{rw}] \tag{15}$$

The Thermal Energy supplied to the Solar Still via Evacuated Tubes has been given by [22]

$$Q_u = F_R[\,(\alpha T)_e\ I_{effe} - U_{LE}\ (\frac{A_L}{A_{ET}})\,(T_w - T_a)\,] \tag{16}$$

Substituting equations 6 and 10 in Equation 15, the following differential equation has been obtained.

$$\frac{dTw}{dt} + aTw = f(t)$$

Where $a = \frac{UA_{effe}}{(MC)_w}$ and $f(t) = \frac{IA_{effe} + UA_{effe}Ta}{(MC)_w}$

Expression for $UA_{effe}$ and $IA_{effe}$ are given in the Appendix.

To derive the approximate analytical solution, the same assumptions were made as in the case of Simple Solar Still. By using initial condition at $t = 0$ , $Tw(t = 0) = Two$

The expression for Water Temperature has been obtained as

$$Tw = \frac{\overline{f(t)}}{a}[1 - e^{-at}] + Twoe^{-at}$$

MATLAB 14' which is primarily used for computing various Heat Transfer Coefficient has been utilized to develop the Thermal Model. In order to compute various Heat Transfer Coefficients, the values of various designs and climatic parameters are prerequisites and which are duly provided in Table 2. The values of Heat Transfer Coefficients are further utilized for computing the theoretical values of inner glass surface temperature, water temperature and hourly yield, by giving initial values of glass and water temperature. The values of solar radiation and ambient temperature have taken with respect to daily observation. Figure 2 represents a flow chart for computation of theoretical values.

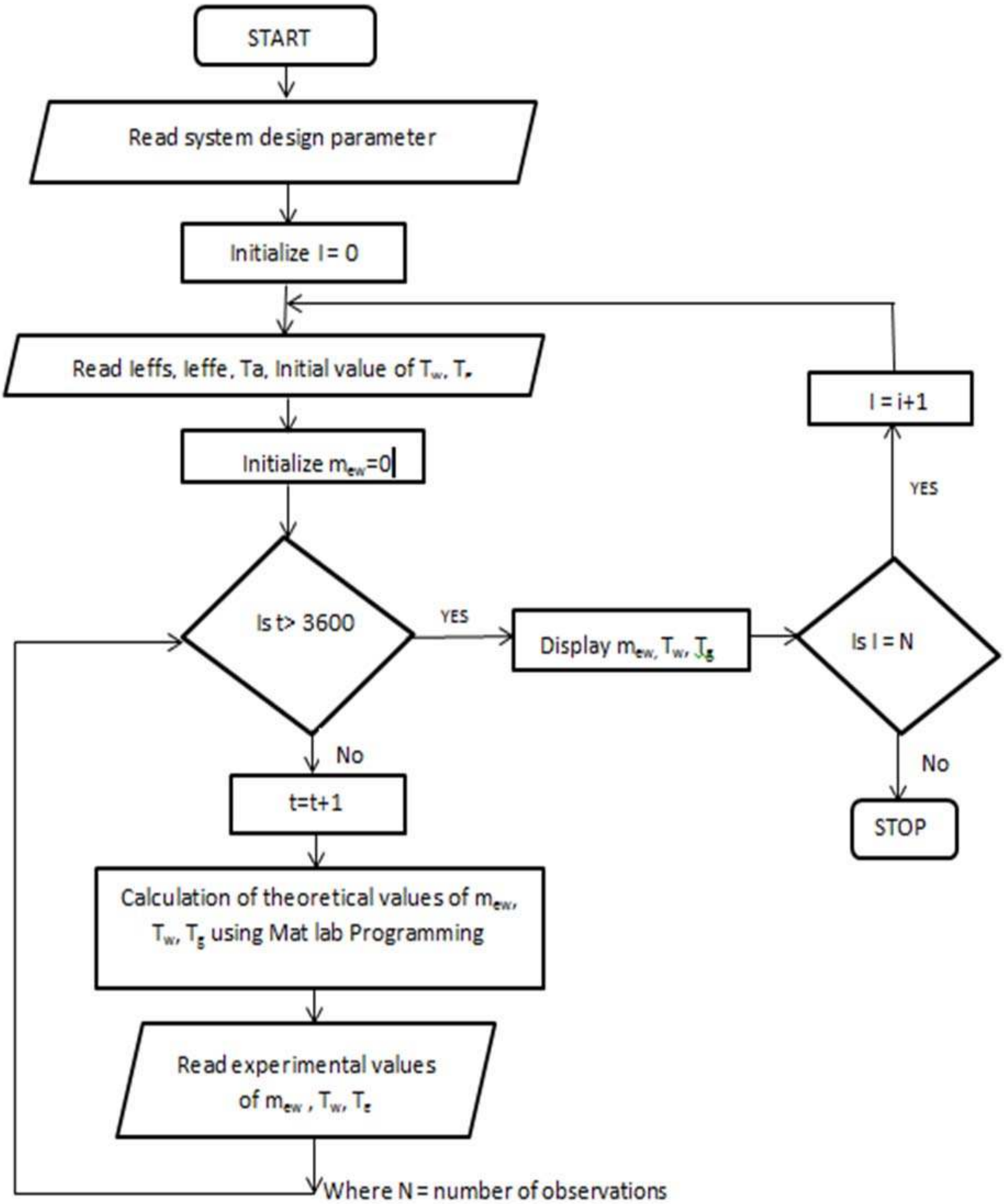


**Figure 2.** Flow Chart representing 'Computer Model of Solar Still'

**Table 3.** Ambient ($T_a$), Water ($T_w$) and Inner Glass cover Temperature ($T_g$) for 0.03-meter water depth solar still.

| Time of the Day | Ambient Temperature $T_a$(° C) | | Water Temperature $T_w$ (° C) | | Inner Glass cover Temperature $T_g$ (° C) | |
|---|---|---|---|---|---|---|
| | Passive Still (31-05-19) | Active Still (29-05-19) | Passive Still (31-05-19) | Active Still (29-05-19) | Passive Still (31-05-19) | Active Still (29-05-19) |
| 9 | 33 | 36 | 40 | 44 | 42 | 45 |
| 10 | 37 | 39 | 47 | 55 | 49 | 54 |
| 11 | 40 | 40 | 58 | 69 | 58 | 62 |
| 12 | 41 | 41 | 65 | 76 | 63 | 70 |
| 13 | 43 | 42 | 72 | 84 | 67 | 75 |
| 14 | 42 | 42 | 74 | 88 | 68 | 79 |
| 15 | 41 | 43 | 72 | 89 | 64 | 81 |
| 16 | 40 | 42 | 69 | 86 | 59 | 77 |
| 17 | 35 | 39 | 58 | 82 | 48 | 72 |
| 18 | 33 | 35 | 53 | 75 | 42 | 63 |

**Table 4.** Ambient ($T_a$), Water ($T_w$) and Inner Glass cover Temperature ($T_g$) for 0.05-meter water depth solar still

| Time of the Day | Ambient Temperature $T_a$ (° C) | | Water Temperature $T_w$ (° C) | | Inner Glass cover Temperature $T_g$ (° C) | |
|---|---|---|---|---|---|---|
| | Passive Still (01-06-19) | Active Still (30-05-19) | Passive Still (01-06-19) | Active Still (30-05-19) | Passive Still (01-06-19) | Active Still (30-05-19) |
| 9 | 32 | 35 | 31 | 41 | 35 | 40 |
| 10 | 33 | 36 | 37 | 49 | 42 | 47 |
| 11 | 35 | 38 | 45 | 60 | 46 | 55 |
| 12 | 36 | 39 | 53 | 70 | 55 | 63 |
| 13 | 37 | 40 | 59 | 78 | 58 | 71 |
| 14 | 40 | 41 | 64 | 83 | 60 | 75 |
| 15 | 41 | 43 | **65** | 85 | 59 | 78 |
| 16 | 39 | 41 | 64 | **86** | 56 | 77 |
| 17 | 38 | 40 | 61 | 82 | 53 | 73 |
| 18 | 36 | 35 | 57 | 75 | 49 | 65 |

**5. Result and Discussion.**

In this experiment, various values derived from Theoretical Modelling were tested, verified and validated with experimental results for various water depths for both Active and Passive Solar Still. The hourly variations of water and glass temperatures for Evacuated Tubes Solar Still and Conventional Solar Still with 0.03 m water depth have been demonstrated in Figure 3 and 4, wherein it has been revealed that the maximum temperature of water (89 ºC) and glass (81 ºC) are obtained in Evacuated Tubes Solar Still at 15 hours, which are considerably higher than the Simple Solar Still's water (74 ºC ) and glass (68 ºC) temperatures at 14 hours for the same water depth.

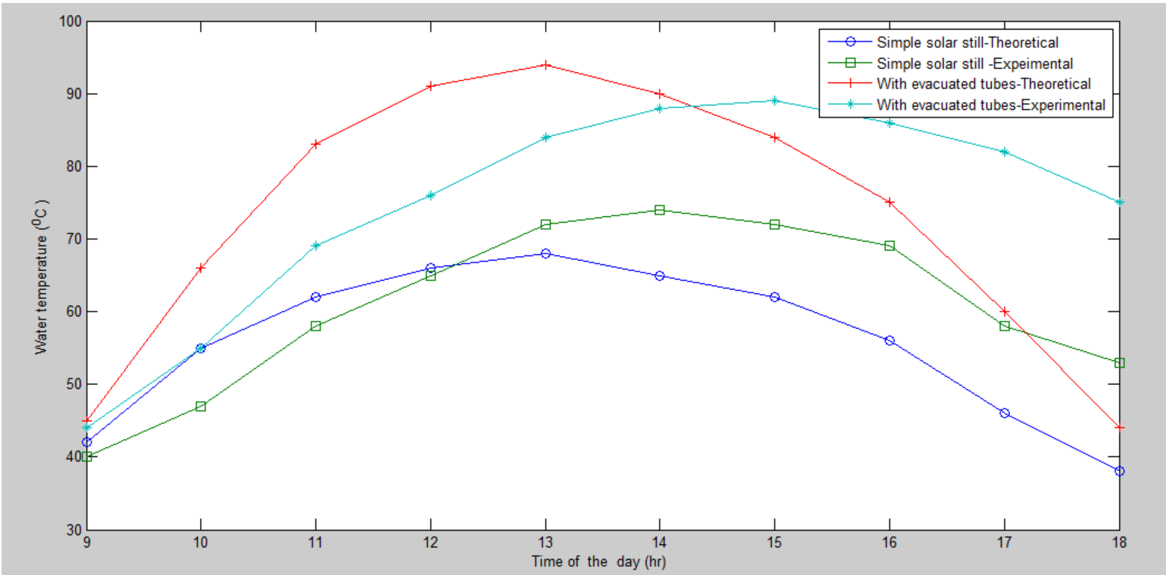


**Figure 3.** Hourly variation of theoretical and experimental water temperature for 0.03 m water depth solar still.

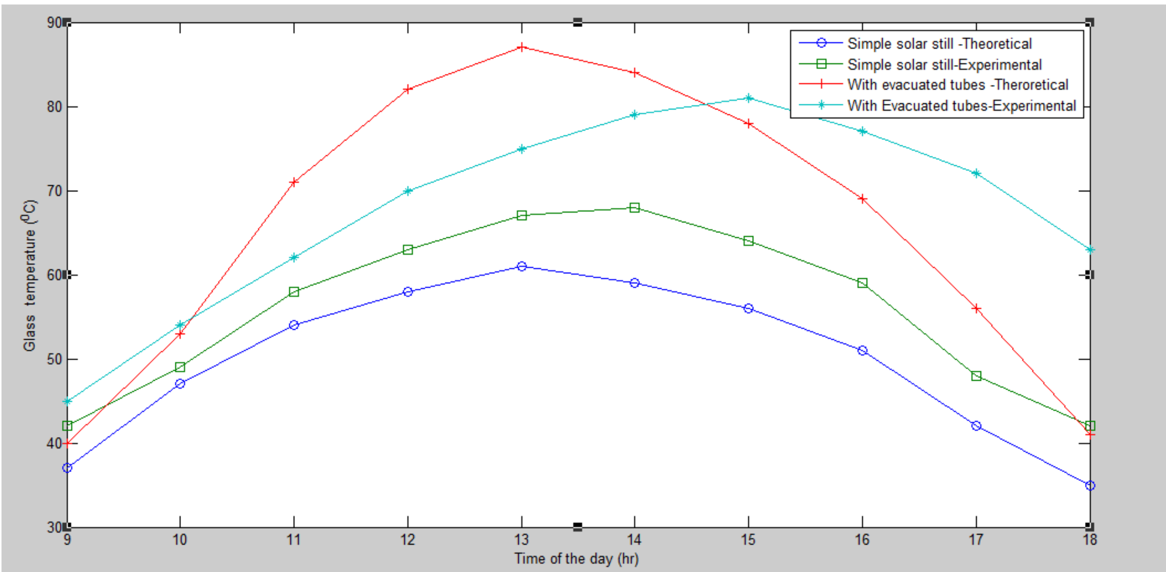


**Figure 4.** Hourly variation of theoretical and experimental glass temperature for 0.03 m water depth solar still.

From figure 5 and 6 ,we can perceive that the maximum temperatures of water (86º C) and glass (77º C) have been obtained in Evacuated Tubes Solar Still at 16 hours, which are considerably greater than the Simple Solar Still water(65°C ) and glass (59 °C) temperatures at 15 hours for 0.05 m water depth. Water and glass temperature values are higher in Evacuated Tubes Solar Still for both the water depths. It is because the Evacuated Tubes provide extra thermal energy to basin water. Also it could be observed from figure 1 to 4 that the theoretical values of water and glass temperatures support the corresponding values with experimental results and are in good agreement.

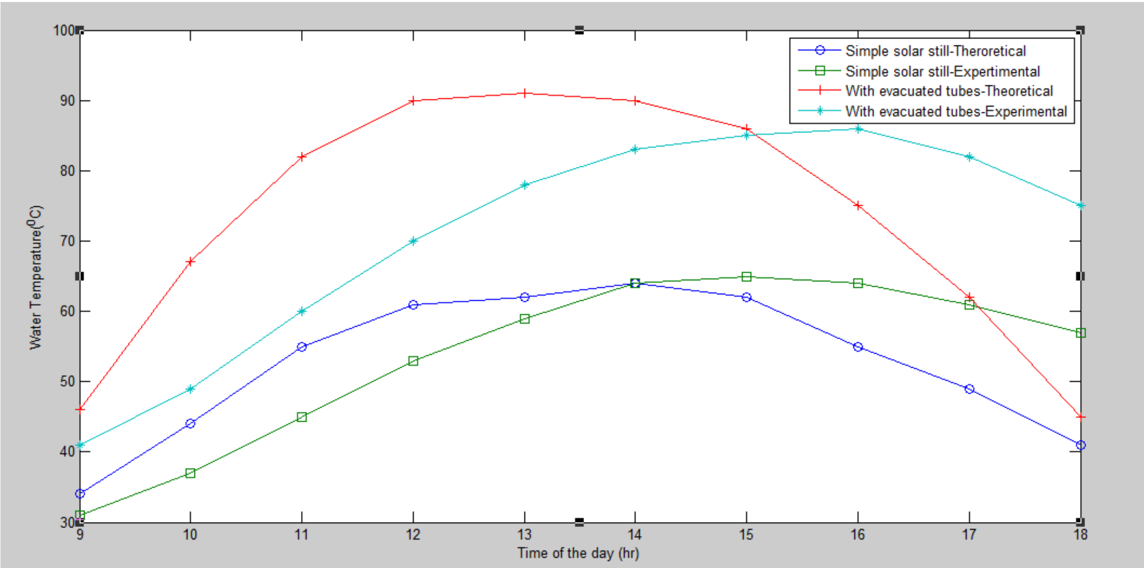


**Figure 5.** Hourly variation of theoretical and experimental water temperature for 0.05 m water depth solar still.

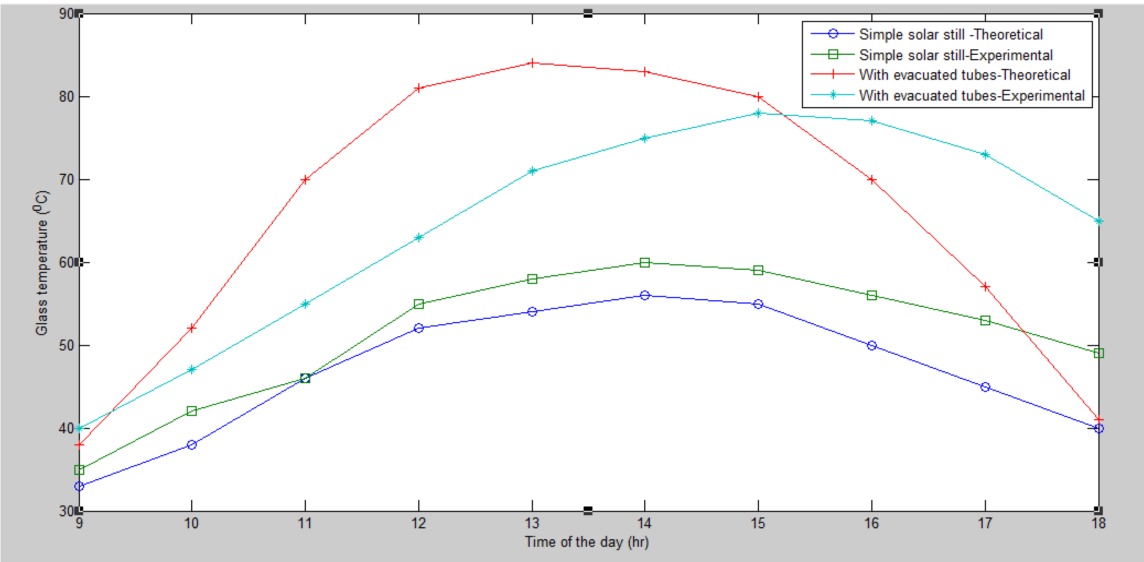


**Figure 6**. Hourly variation of theoretical and experimental glass temperature for 0.05 m water depth solar still.

It also has been discovered that in early hours, the hourly theoretical values of glass and water temperatures are higher, as in theoretical calculations heat losses are not considered. But in the evening hours, the experimental values of water and glass cover temperature are higher as they hold the heat as stored energy. It also has been observed that as the water depth increased from 0.03 to 0.05 m for both Active and Passive Solar Still, the maximum water and glass temperature attainment time was shifted to 1 hour later as more time is required to achieve maximum temperature for more water mass.

Figure 7 and 8 reveals the hourly variation of convective, evaporative, radiative heat transfer coefficients, respectively, for both Simple Solar Still and Evacuated Tubes Solar Still of 30 Litre water in Basin. The results show that the Evaporative Heat Transfer Coefficient escalates with time and in the afternoon hours a decreasing trend is observed in its value attributed to lower temperatures in the evening.

It can be duly observed from figures 7 and 8 that, the values of Evaporative (137W/m$^2$K), Convective (3.07 W/m$^2$K) and Radiative (8.93W/m$^2$K) heat transfer coefficient are high in Solar Stills integrated with Evacuated Tubes than the Simple Solar Still having values of Evaporative (41W/m$^2$K), Convective (2.30 W/m$^2$K) and Radiative (7.16W/m$^2$K) heat transfer coefficient respectively. Due to higher temperature difference between water and glass in the Evacuated Tubes Solar Still attributed to additional thermal energy provided by evacuated tubes, the values of different heat transfer coefficients are higher in Evacuated Tubes Solar Still.

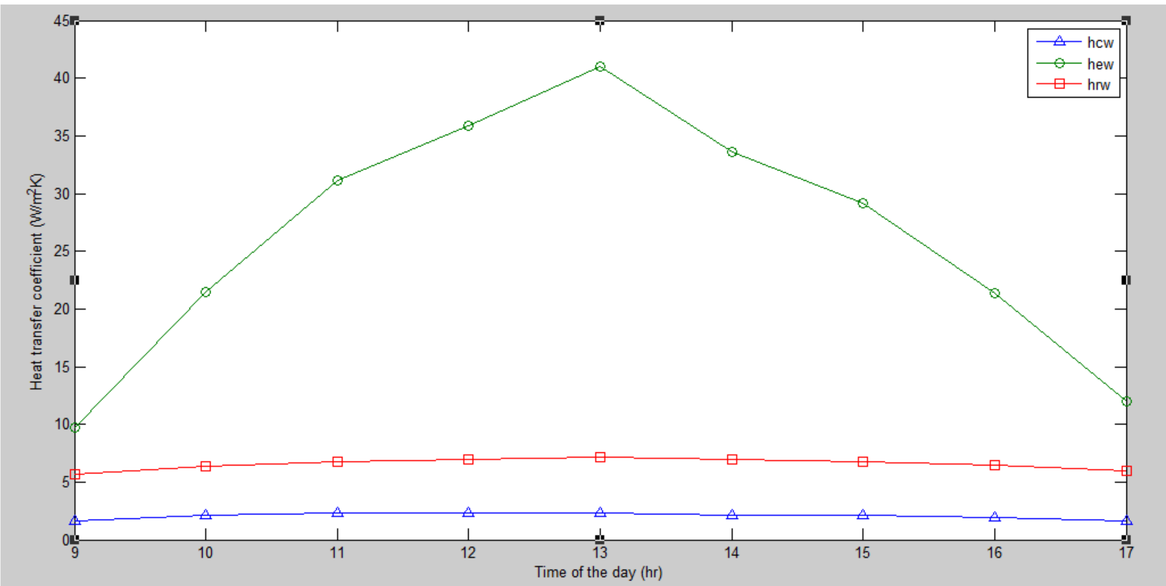


**Figure 7.** Hourly variation of heat transfer coefficient for 0.03 m water depth simple solar still.

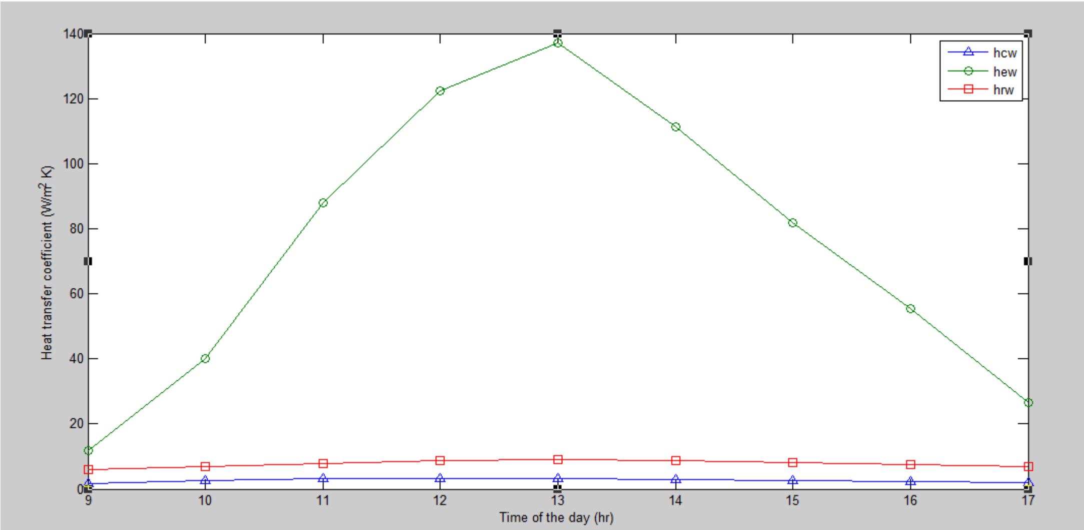


**Figure 8.** Hourly variation of heat transfer coefficient for 0.03 m water depth solar still with evacuated tubes.

Figure 9 and 10 represents the hourly variation in respect of yield obtained from Simple Solar Still and Active Solar Still for 0.03 m and 0.05 m water depths respectively. It has been observed that as water depth was increased, the total yield from the Solar Still was decreased for both stills. The higher water depth increases water mass in basin, which results in more time consumption for evaporation. For this reason, the basin water temperature and evaporation rate are found less in higher water depth Solar Still, which leads to decrease in its output. The maximum values of hourly output for Evacuated Tubes Solar Still were 0.88 Litre/$m^2$ / hr. and 0.770 Litre/$m^2$/ hr for 0.03 and 0.05 water depths respectively.

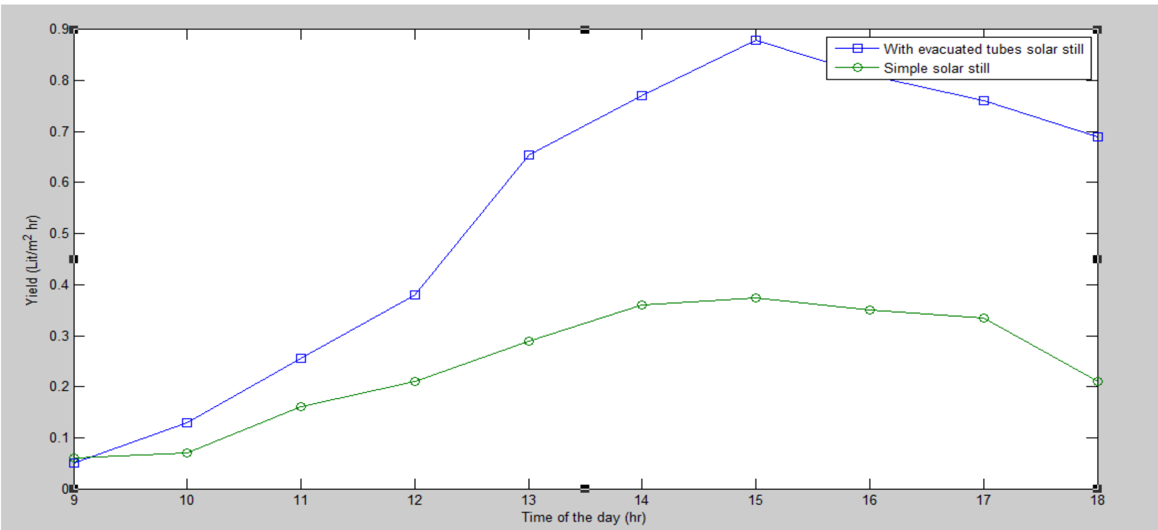


**Figure 9.** Hourly variation of experimental yield for 0.03 m water depth solar still.

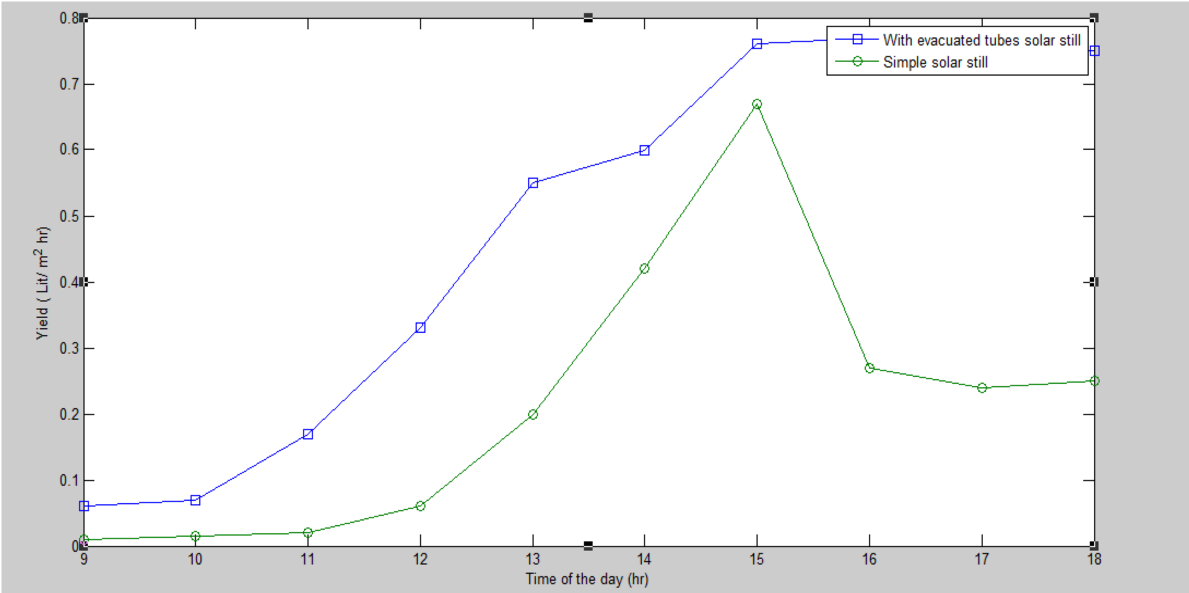


**Figure 10.** Hourly variation of experimental yield for 0.05 m water depth solar still.

## 6. Conclusion.

The Thermal Modelling of Conventional Still and Evacuated Tubes Solar Still has been experimentally confirmed and duly validated for 30 and 50 Litre of water in the research. The following points are highlighted on the basis of experimental and theoretical results:

1. The average water temperature of an Evacuated Tubes Solar Still was found to be increased by 15° C and 21° C for 0.03m and 0.05 m water depths respectively.
2. Due to additional heat energy supplied by evacuated tubes, the basin water temperature was found to be increased in Active Solar Still which further leads to increase in its productivity.
3. The yield of Evacuated Tubes Solar Still has been found as 7.61 & 7.535 Litre/$m^2$/day for 0.03m and 0.05 m water depths respectively, while for Simple Solar Still, it was 3.15 and 3.055 Litre/$m^2$/day for 0.03m and 0.05 m water depth respectively.
4. The total and evaporative heat transfer coefficient for an Evacuated Tubes Solar Still has been found very high, attributed to the higher water temperature difference as compared to conventional Still for both the respective water depths.
5. A fairly good agreement has been found between theoretical results obtained from Thermal Modelling and the Experimental results for both the Solar Stills.

## 7. References

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## 8. Appendices.

For the purpose of numerical analysis of Simple Solar Still and Evacuated Tubes Solar Still, the below mentioned Heat Transfer Equations have been employed.

The design parameters of Evacuated Tubes Solar Still has been calculated in the following expressions.

$$I_{Aeffe} = A_{ET} F_R (\alpha\tau)_e + (\alpha\tau)_{effe} I(t)_{effe}$$

$$Where (\alpha\tau)_{effe} = [\alpha'_b \frac{h_w}{(h_w + h_b)} + \alpha'_w + \alpha'_g \frac{h_{tw}}{h_{tw} + h_{tg}}]$$

The expression of $U_{Aeffs}$ for Simple Solar Still

$$U_{Aeffs} = U_b + U_t$$

$$U_b = \frac{h_w h_b}{h_w + h_b}$$

Where

$$U_t = \frac{h_{tw} h_{tg}}{h_{tw} + h_{tg}}$$

The expression of $U_{Aeffe}$ for Solar Still integrated with Evacuated Tubes

$$U_{Aeffe} = U_b + U_t + A_L F_R U_{LC}$$

## 9. Nomenclature.

English Letters

| | |
|---|---|
| $A_L$ | Area of solar still, $m^2$ |
| $A_{ET}$ | Diameter of outer glass ×total length of the tubes, $m^2$ |
| $C_w$ | Specific heat capacity of Basin water, J/kg K |
| $F_R$ | Heat removal factor |
| $h_b$ | Basin liner overall heat transfer coefficient, $W/m^2K$ |
| $h_w$ | Convective heat transfer coefficient from basin liner to water, $W/m^2K$ |
| $h_{cw}$ | Convective heat transfer coefficient from water to glass cover, $W/m^2K$ |
| $h_{ew}$ | Evaporative heat transfer coefficient from water to glass cover, $W/m^2K$ |
| $h_{rw}$ | Radiative heat transfer coefficient from water to glass cover, $W/m^2K$ |

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$h_{tg}$ Total heat transfer coefficient from glass cover to ambient, $W/m^2K$
$h_{tw}$ Total heat transfer coefficient from water to glass cover, $W/m^2K$
I Intensity of solar radiation, $W/m^2$
Ki Thermal conductivity of insulation material, W/m K
L Latent heat of vaporization, J/kg
$L_i$ Thickness of insulation material, m
$L_g$ Thickness of glass covers, m
$M_w$ Mass of water in the basin, kg
Mew Total distillate output from passive solar still at end of each day (kg)
$P_g$ Partial vapor pressure at inner surface glass temperature, $N/m^2$
$P_w$ Partial vapor pressure at water temperature, $N/m^2$
$Q_u$ Useful thermal energy gain by vacuum tubes, $W/m^2$
t Time, s
$T_a$ Ambient air temperature, K
$T_b$ Basin temperature, K
$T_g$ Glass inner surface cover temperature, K
$T_w$ Water temperature, K
$U_b$ Overall bottom heat loss coefficient, $W/m^2K$
$U_t$ Overall top heat loss coefficient, $W/m^2K$
v Wind velocity, (m/s)
Greek Letters
$\alpha$ Fraction of energy absorbed
$\tau$ Absorptance-transmittance product
$\sigma$ Stefan Boltzman constant,
$\varepsilon$ Emissivity

Subscripts
b Basin liner
e Evacuated tubes
eff Effective
g Glass cover
s Solar still
w Water
0 Initial