Wasil Jamal, Prof. M. Altamush Siddiqui / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 2,Mar-Apr 2012, pp.1659-1665

Effect of water depth and still orientation on productivity for passive solar distillation

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ABSTRACT

Passive solar distillation is very simple and attractive. It can be employed for potable water in remote areas where supply of fresh water is not available. Productivity of passive distillation is generally low. However, it can be enhanced by considering different parameters. In this communication, attempt has been made to investigate the effect of depth of water in the basin at two orientations East-West and North-South. A double slope solar still was fabricated and investigations were carried out under the open environmental conditions of Aligarh, India. The radiative, convective and evaporative heat transfer coefficients between the water surface and the glass cover surfaces have been evaluated using standard correlations utilizing experimental data. Heat transfer rates have been estimated by making energy balance at various sections in the solar still. Experiments were carried out for 2 cm, 3 cm, 4 cm and 5 cm water depths. Results show that the yield is maximum for shallow water depth in the basin and when the still is placed in the North-South orientation. Further, as the water depth increases in the basin productivity goes on decreasing being least for 5 cm.

Keywords – Solar Distillation, Double Slope, Water Depths, Orientations, Productivity

Nomenclature

T_a	*Atmospheric temperature……...°C*	T_b	*Temperature of the basin……..°C*
T_{bw}	*Basin-water mean temperature…°C*	T_{gi}	*Glass inner surface temperature…°C*
T_{go}	*Glass outer surface temperature..°C*	T_w	*Water Temperature………….…°C*
DPW	*Depth of water in the basin…… m*	$\dot{m}_e$	*Mass transfer rate…………….. kg/s*
A_b	*Area of basin…………………. m²*	A_w	*Surface area of water………..... m²*

1. INTRODUCTION

Water is the fundamental source of life on the earth. Although water is abundant on the earth but fresh water is scarce. Fresh water demand is increasing all over the world due to rapid growth of population and increasing trend of the agricultural explosion projects. In addition to quantity of water, there are many places even in urban areas, where water is polluted and is not always completely safe for drinking. Most diseases in these areas are caused by polluted water. According to the study made by the World Health Organization, polluted water and sanitation deficiency are the cause of 80% of all the diseases which make a person unfit, temporarily or even permanent. It has been estimated that around 500 million people in the developing countries suffer from diseases produced by water [1]. To solve these problems, new drinking water sources should be discovered. Solar distillation is an economical, effective and environmental friendly method over all the conventional distillation methods (which are energy and cost intensive techniques) for getting the pure water through the use of solar energy.

The various factors affecting the performance of the solar still are solar intensity, wind velocity, ambient temperature, water–glass temperature difference, free surface area of water, absorber plate area, temperatures of inlet water, glass angle, still orientation and depth of water. The solar intensity, wind velocity, ambient temperature cannot be controlled as they are meteorological parameters whereas the remaining parameters can be varied to enhance the productivity of the solar stills. By considering the various factors affecting the productivity of the solar still, various modifications are being made to enhance the productivity of the solar still.

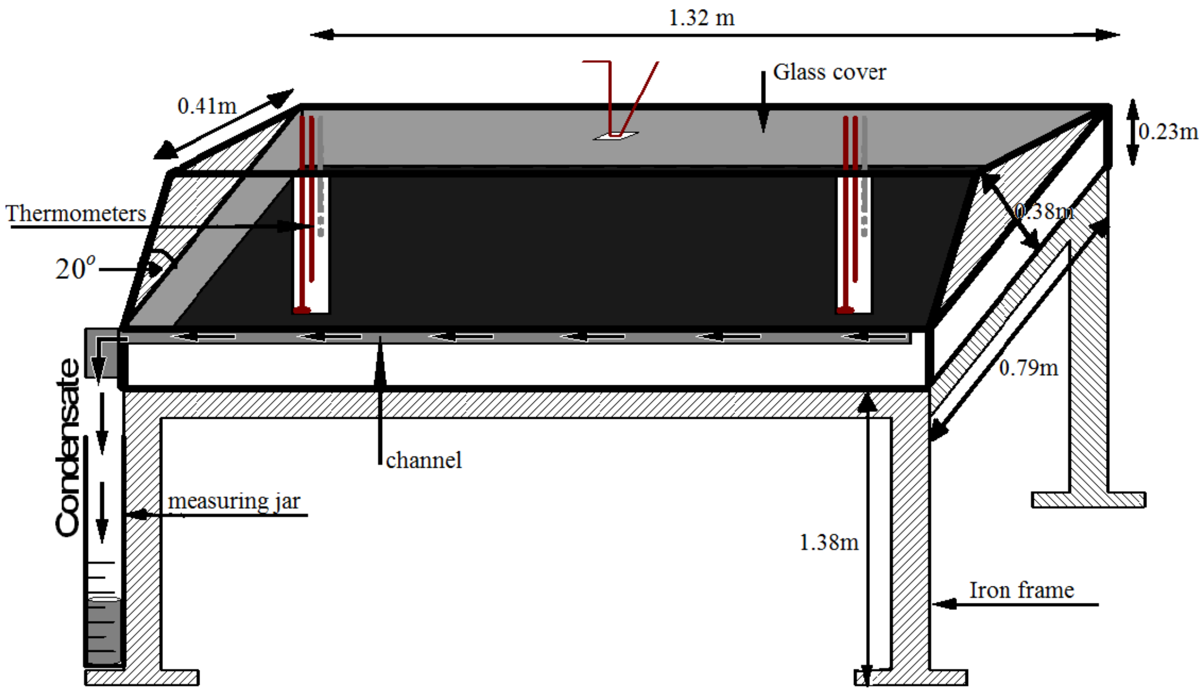
The yield of a solar still mainly depends on the difference between water and glass cover temperatures which acts as a driving force of the distillation process. Regenerative solar still [2], solar still with double glasses [3, 4] and triple-basin solar still [4] were used to increase the temperature difference between glass and the water. Singh and Tiwari [5] found that the annual yield of the solar still was maximum when the condensing glass cover inclination was equal to the latitude of the place.

It has been reported that the yield is maximum for the least water depth. While maintaining minimum depth in the solar still, dry spot may occur. So, it is very difficult to maintain minimum depth in the solar still. Wick type solar stills [6,7], a plastic water Purifier [8] and stepped solar still [9] were therefore developed. The effect of varying depths of water [10] in the solar still is verified by Khalifa and Hamood. Rubio-Cerda et al. [48] studied Performance of the condensing covers under two still-orientations, east-west and north-south. Their results showed larger differences in the condensers' temperatures and higher productivity when the still covers were facing east- west.

2. EXPERIMENTAL SET-UP & PROCEDURE

The distiller is a single basin double slope solar still whose schematic diagram is shown in fig.2.1. Its basin is made of 22 SWG (0.711 mm) thick G.I sheet having a unit base area. The basin is placed in another box of the same sheet. There is a thermocol of 5 cm thickness for thermal insulation in between these two boxes. The basin of the distiller is blackened to increase the solar energy absorption. The glass (5mm thick) surfaces cover the top portion of the still making a symmetrical slope of 20^o with horizontal on either side. The area of the glass surface is 1.32mX0.41m. However, its effective area is 1.28mX0.36m. The tilted glass cover (5mm thick) served as solar energy transmitter as well as a condensing surface for the vapor generated in the basin. The condensate trickles down past the sloppy glass covers and collects in a suitably fabricated trough of aluminum at the bottom end which is then subsequently drained out into a measuring jar.

Measuring parameters of the experiments were temperatures at different locations, solar radiation reaching the horizontal surface near the distiller and distillate output with respect to time. For the measurement of temperatures, 10 Mercury thermometers were used. The global solar radiations falling on a horizontal surface were recorded by means of a Pyranometer. The volumes of distillate output were measured by two measuring jars placed at the end of the drainage channel. The temperatures of the solar still and the corresponding solar radiation were recorded for different days in the months of April and May-2011. The readings were taken at intervals of fifteen minutes, and were continued for almost seven and half hours. The temperature of the water in the basin was found to increase and after a certain time of heating distillation started. The condensate then trickled down past the sloppy glasses cover and collected in the channels of aluminum at the bottom end which drained out into the measuring jars.



3.

Fig. 2.1 Schematic diagram showing dimensions of the still

Figure 3.1 shows distribution of the incident solar radiation (I). The solar radiation, after reflection and absorption by the glass cover is transmitted (τ_gI) inside the enclosed still which on striking the water surface gets partially reflected (R'_wI) and absorbed by the water mass (α_w'I). The remaining solar radiation finally reaches the absorber plate where it is mostly absorbed.

The solar flux absorbed by the glass cover: $$\alpha'_g I = (1-R_g)\alpha_g I \quad (3.1)$$

The solar flux transmitted through the glass cover: $$\tau_g I = (1-R_g)(1-\alpha_g)I \quad (3.2)$$

While, the solar flux reflected from the water surface: $$R'_w I = (1-R_g)(1-\alpha_g)R_w I \quad (3.3)$$

And that absorbed by the water: $$\alpha'_w I = (1-R_g)(1-\alpha_g)(1-R_w)I\left[1-\sum \mu_j \exp(-n_j.d_p)\right] \quad (3.4)$$

Equation (3.4) accounts for attenuation of the solar flux in the water mass that depends on absorptivity and depth of water. The values of μ_j and n_j are taken from Tiwari [11].

Solar flux absorbed by the blackened plate: $$\alpha'_b = \alpha_b(1-R_g)(1-\alpha_g)(1-R_w)I\sum \mu_j \exp(-n_j d_p) \quad (3.5)$$

Thus absorption of the solar flux increases thermal energy of the absorber plate, most of which is convected to the water mass and a part of it is lost to the environment through the insulated box shown in the Fig. 3.1.

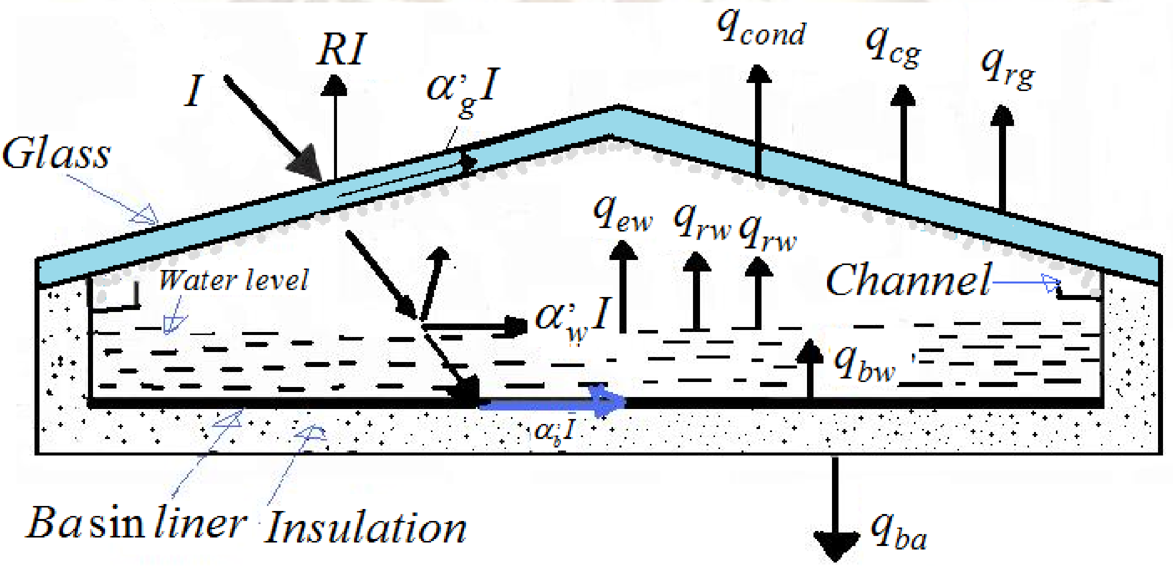


Fig.3.1 Cross sectional view of a double slope solar still

3.1 Heat transfer from water mass

Convective: $$Q_{cw} = h_{cw}(T_w - T_{gi})A_w \quad (3.6)$$

Evaporative: $$Q_{ew} = h_{ew}(T_w - T_{gi})A_w \quad (3.7)$$

Radiative: $$Q_{rw} = \sigma\varepsilon_{eff}(T_w^4 - T_{gi}^4)A_w = h_{rw}(T_w - T_{gi})A_w \quad (3.8)$$

Where, $$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1} \quad (3.9)$$

The convective heat transfer coefficient h_{cw} has been obtained from the following relation proposed by Dunkle [12]:

$$h_{cw} = 0.884\left[(T_w - T_{gi}) + \frac{(p_w - p_{gi})(T_w + 273)}{268.9\,x10^3 - p_w}\right] \quad (3.10)$$

The radiative and evaporative heat transfer coefficients were respectively evaluated as:

$$h_{rw} = \frac{Q_{rw}}{(T_w - T_{gi})} \quad (3.11) \qquad \text{and} \qquad h_{ew} = \frac{Q_{ew}}{(T_w - T_{gi})} \quad (3.12)$$

Equation (3.7) gives expression for the evaporative heat transfer rates. It is worth mentioning here that only evaporative heat transfer causes and contributes to water distillation. Here heat transfer for other sections is not presented.
Thus by knowing the evaporative heat transfer rates, mass of the water distilled can be calculated from the equation (3.13) given by:

$$m_{ew} = \frac{Q_{ew}}{h_{fg}} \quad (3.13)$$

Where h_{fg} is the Latent heat of vaporization in (kJ/kg)

4. RESULTS AND DISCUSSION

Heat transfer between the water and the glass cover mainly depends upon their temperature difference. Figure 4.1 shows variation in the inner glass surface temperature for different depths of the water mass and for two orientations of the still (East-West and North-South). From the graphs, it is clear that the glass cover that faces direct sunrays attains higher temperature as compared to the other glass cover. In the East-West orientation because the sun in the northern hemisphere like Aligarh travels from East to West such that its radiation falls directly on the surface facing south. On the other hand, in the North-south orientation of the solar still, the east facing glass has high temperature in the morning, while the west facing glass has it in the evening.

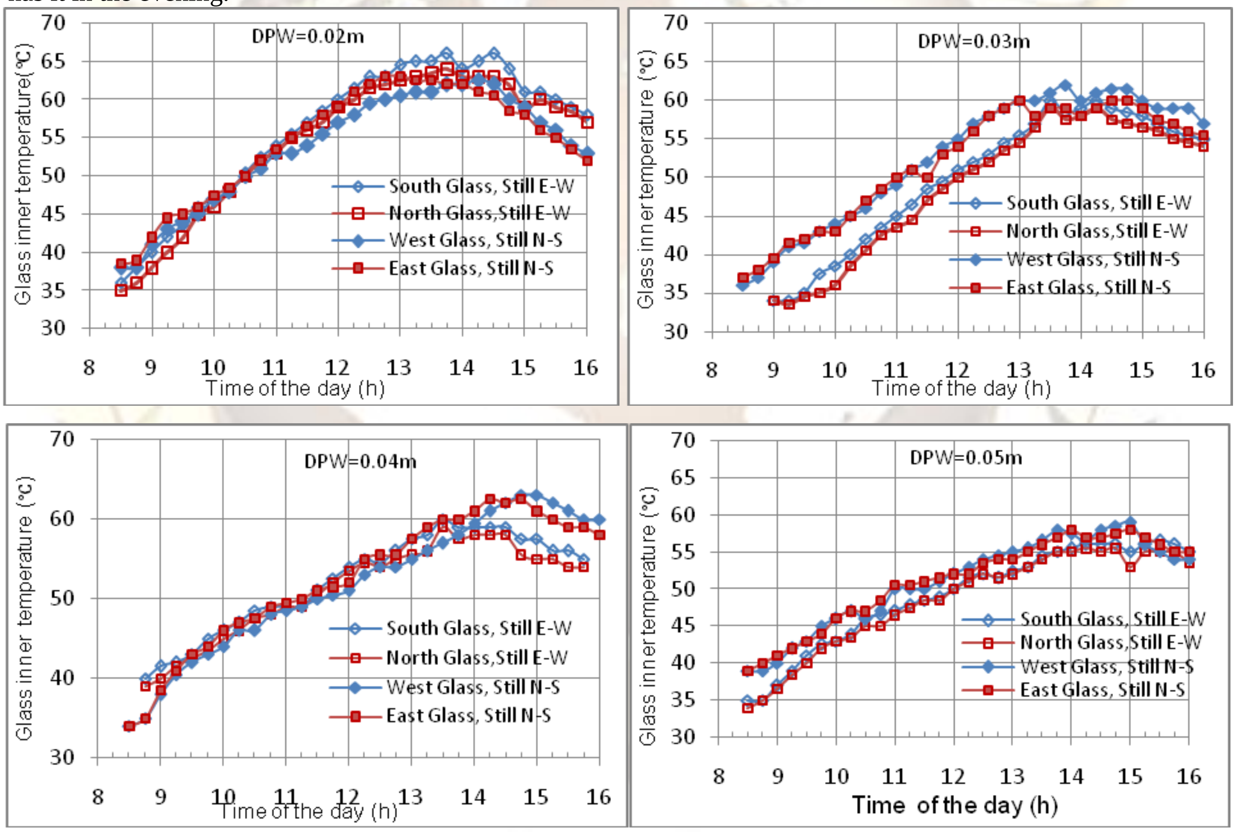


Fig.4.1 Variation in glass inner surface temperature for different depths and orientation

Figure 4.2 shows variation in the temperature difference between the average water mass and glass inner surfaces. From figure, it can be seen that initial temperatures of the glass surfaces are higher than those of the water mass. It takes some time for the water temperature to go above the glass surface temperature. The positive value of (T_w-T_{gi}) in the still, being the driving force, is the instant at which heat transfer from the water starts. Thus, the evaporation of water in the basin initiates only after a period the solar heating results in the positive values of (T_w-T_{gi}). This temperature difference is however, large for low water depths. In case of the East-West orientation, the north facing glass surface side always has larger temperature difference as compared to the south facing glass. However, during the North-South orientation, the west facing glass side attains larger temperature difference in the morning while the east facing glass side attains it in the evening, which is obvious due to change in the direction of radiation from the sun.

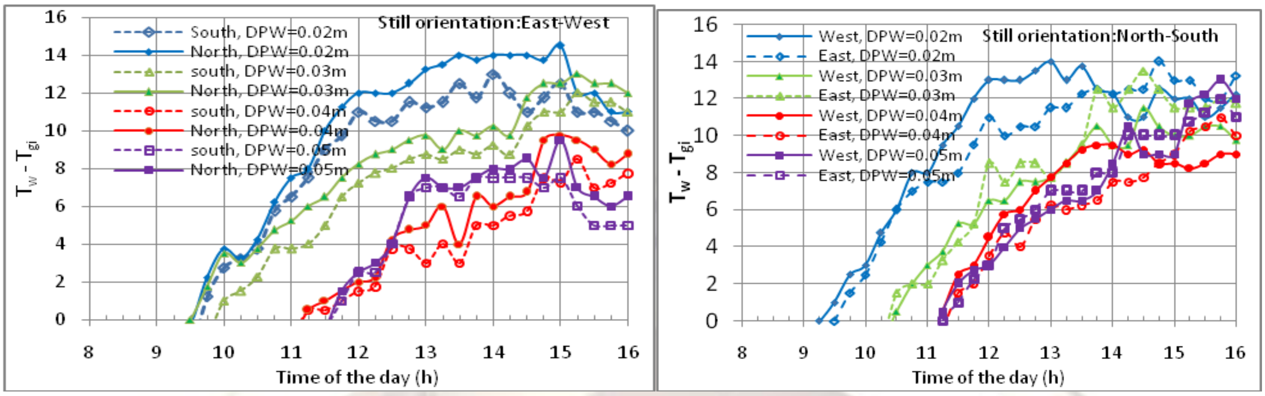


Fig.4.2 Variation in temperature difference

Figure 4.3 shows variations in the evaporative heat transfer coefficient between the water mass and the glass cover with time for different water depths and for the two still orientations. It initially increases with time of heating and then starts decreasing as the solar flux declines after a certain period of time. It is generally high for the low water depths and when the still is placed in the north-south orientation. From the results it is found that at low water depths of 0.02m, the evaporative heat transfer coefficient for the east-west orientation comes out to be around 5 to 50 w/m^{2}k and for the north-south orientation, it is 5 to 60 w/m^{2}k. while at the water depths of 0.05m, the evaporative heat transfer coefficient goes as high as around 30 w/m^{2}k. From the above observation, it can be deduced that the evaporation rate would be maximum for low water depth and when the still is placed in North-South orientation.

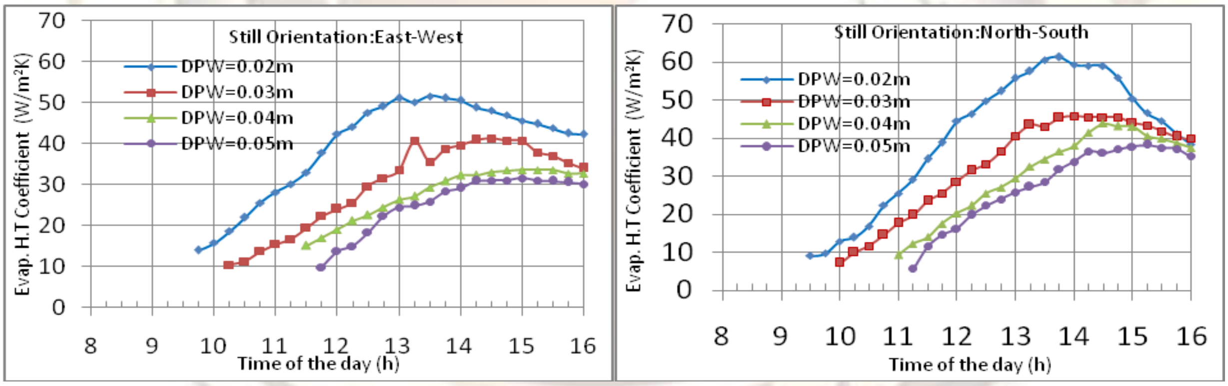


Fig.4.3. Variation in evaporative heat transfer coefficient

The actual distillate collected during the experiment through the drainage channels at bottom of the two inclined glass covers of the solar still for the various conditions have been plotted and shown in Fig.4.4. From the graphs, it is clear that the distillate output decreases with increase in the depths of water. The maximum distillate collected were 1030 ml, 785 ml, 655 ml and 305 ml for the water depths of 0.02 m, 0.03 m, 0.04 m and 0.05 m, respectively at the East-West orientation of the still. However, they were 1160 ml, 890 ml, 715 ml and 395 ml for the water depths of 0.02 m, 0.03 m, 0.04 m and 0.05 m, respectively at the North-South orientation of the still.

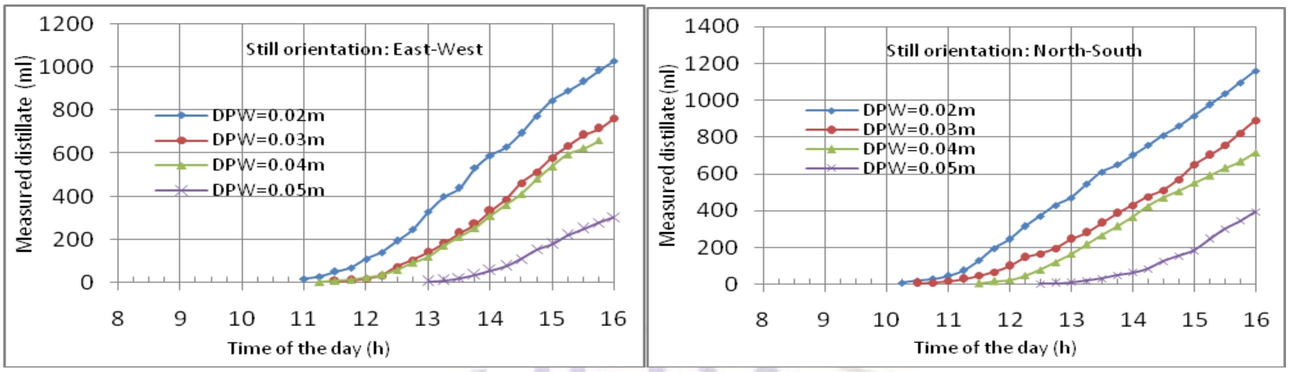
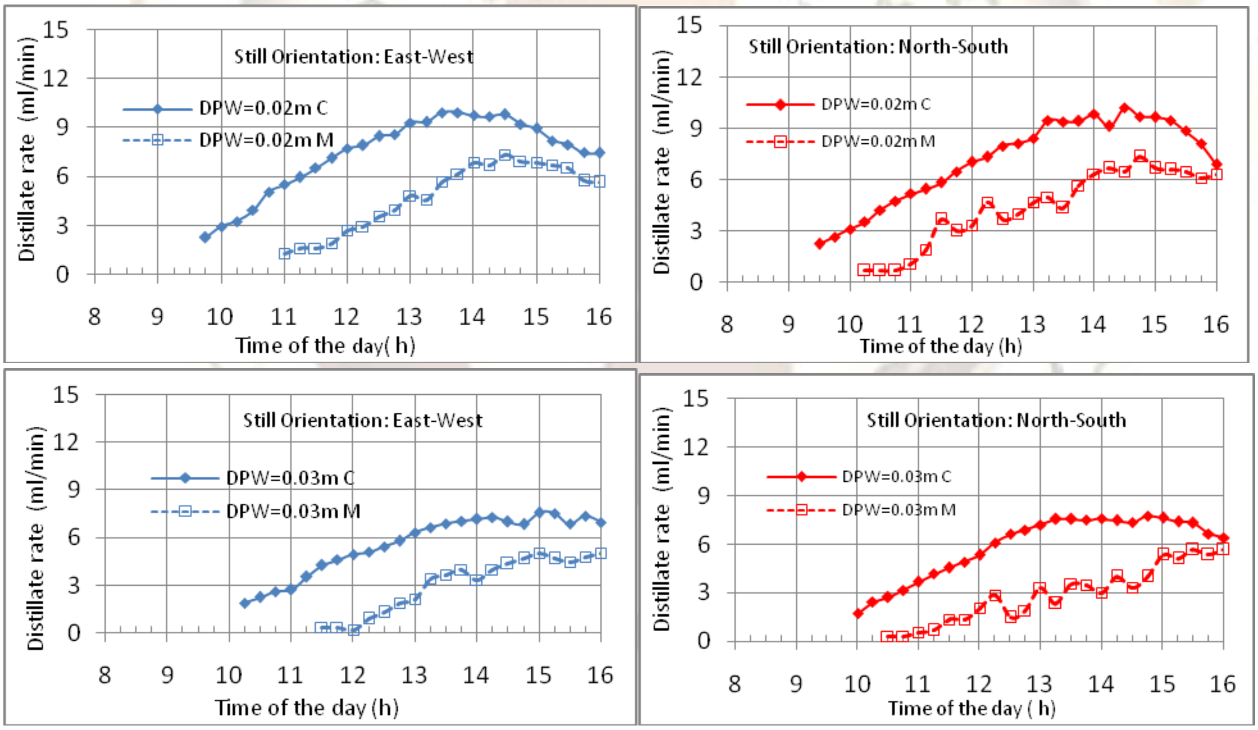


Fig.4.4. Variation in the measured distillate output

The distillate output calculated on the basis of the heat of distillation Q_{dl} is presented and compared with the measured distillate. Figure 4.5 shows variations of the calculated and measured distillate outputs with the passage of time for different water depths at two orientations (East- West and North-South). There seems to be difference in the measured and calculated values especially at the start-up time, although they become close after a certain period of heating. The difference in their values at the start-up time is obvious, because the real evaporation starts immediately when there is rise in temperature of the water even up to a few degrees. This difference may be due to the time lag between the distillation process and the collection. Also, there may be possible errors like, minute leakages in the drainage channels, trapping of some distillate in the channels itself that may not be reaching the end point of collection or some distillate may fall down in the basin water before reaching the drainage channels through the glass covers. However, the calculated distillate output and the measured distillate both show similar trends of variation.



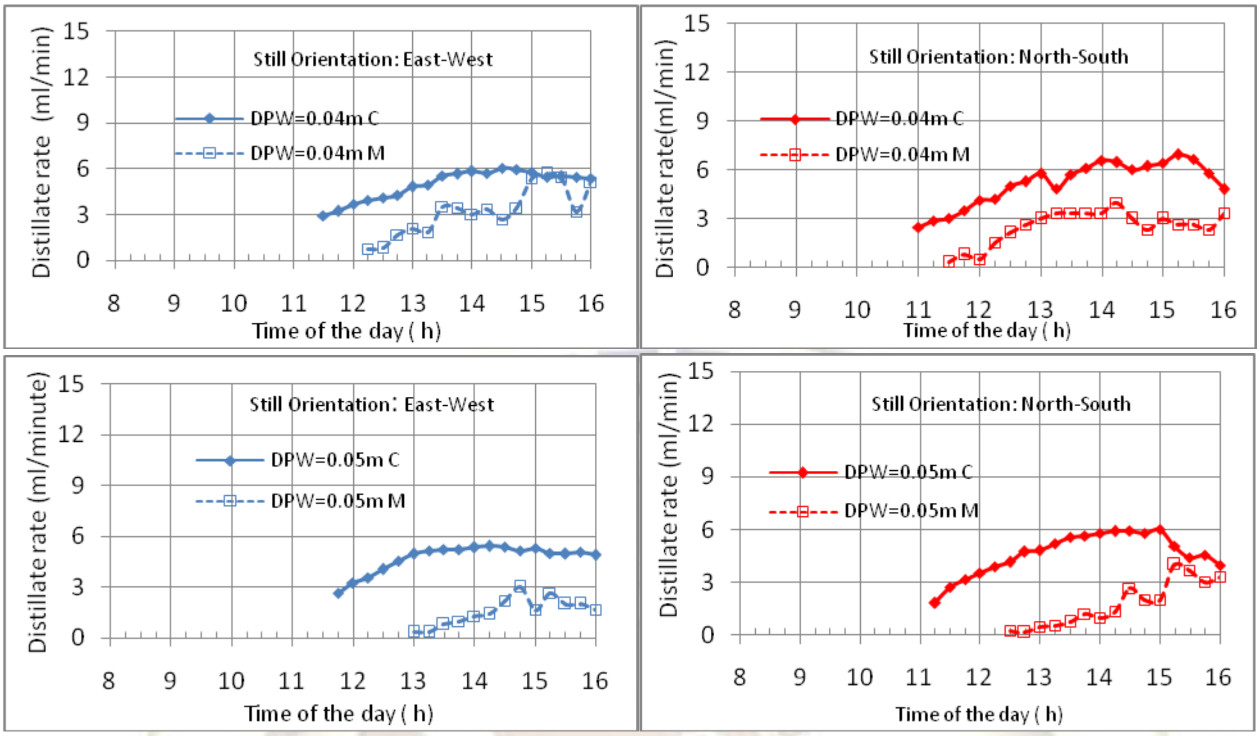


Fig.4.5. Comparison of calculated and measured distillate output

5. CONCLUSION

It was observed that The average water mass temperature remains high for low water depths due to faster rate of heating of the shallow water mass. The variation in the water temperature is almost same in both orientations of the solar still. For almost all the water depths, the distillate output is more for the North-South Orientation of the solar still when the two glass covers face east and west directions. Further, distillate output is maximum for shallow water depth in the basin and it goes on decreasing with the increease in depths of water in the basin. The calculated distillate output and the measured distillate, both show similar trends of variation. They are generally high for the North-South orientation as compared to the East-West orientation of the distiller.

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