Chapter 9

Experimental Study on a Compound Parabolic Concentrator Tubular Solar Still Tied with Pyramid Solar Still

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/49995

1. Introduction

Water is a nature's gift and it plays a key role in the development of an economy and in turn for the welfare of a nation. Non-availability of drinking water is one of the major problem faced by both the under developed and developing countries all over the world. Around 97% of the water in the world is in the ocean, approximately 2% of the water in the world is at present stored as ice in polar region, and 1% is fresh water available for the need of the plants, animals and human life [1]. Researchers have been carried out in this method by Nijmeh, et al., [2], they have been investigated the regenerative, conventional and double-glass-cover cooling solar still theoretically and experimentally. Several system parameters were also investigated with respect to their effect on the productivity, namely, water with and without dye in the lower basin, basin heat loss coefficient, and mass of water in the basins and mass flow rate into the double-glass cover. Thermal performances of a solar still coupled with flat plate heater along with an evaporator-condenser have been analyzed by Réné Tchinda, et al., [3]. They reported that the theoretical solar still productivity is in reasonably good agreement with the experimental distillation yields. Thermal performances of a regenerative active solar distillation system working under the thermosyphon mode of operation have been studied by Singh and Tiwari for Indian climatic condition. It is concluded that (i) there is a significant improvement in overall performance due to water flow over the glass cover and (ii) the hot water available due to the regenerative effect does not enhance the output. They derived expressions for water and glass temperatures, hourly yield and instantaneous efficiency for both passive and active solar distillation systems [4]. Chouchi et al., [5] have designed and built a small solar desalination unit equipped with a parabolic concentrator. The results show that, the maximum efficiency corresponds to the maximum solar lightning obtained towards 14:00. At that hour, the boiler was nearly in a horizontal position, which maximizes the offered heat transfer surface. Thermal analyses of a concentrator assisted regenerative solar distillation unit in forced circulation mode were studied by Kumar and Sinha [6]. It is concluded that the yield of the concentrator assisted regenerative solar still is much higher than any other passive/active regenerative or non-regenerative solar distillation system and the overall thermal efficiency increases with an increase in the flow rate of the flowing cold water over the glass cover. Thermal evaluations of concentrator assisted solar distillation system have been studied by Sinha and Tiwari [7]. It was observed that the instantaneous and overall efficiency of the concentrator assisted solar still is significantly improved compared to a collector cum distillation unit due to reduced heat loss in the concentrator. Tube-type solar still integrated by a conventional still and a water distribution network suitable to the concept of desert plantation was studied by Murase, et al., [8]. Experimental data measured using infrared lamps which showed the effectiveness of the method for productivity, the design of the basin tray and thermal efficiency. Tiwari and Kumar [9] have experimentally studied the tubular solar still. The still consists of a rectangular black metallic tray placed at the diametric plane of a cylindrical glass tube. It was concluded that the daily yield of distillate in the tubular solar still is higher than that of the conventional solar still. The purity of the product in the tubular solar still is higher than that of the conventional one, and could be used for chemical laboratories, etc.

A new heat and mass transfer for tubular solar still was studied by Islam and Fukuhara [10]. The heat and mass transfer coefficients were expressed as functions of the temperature difference between the saline water and the cover. A quasi steady heat and mass transfer tubular solar still taking an account of humid air properties inside the still was analyzed by Islam and Fukuhara [11]. It was found from the production experiment that the analytical solutions derived from the present model could reproduce the experimental results on the saline water temperature, the humid air temperature, the cover temperature and production and condensation fluxes. Ahsan et al., [12] has experimentally studied the evaporation, condensation and production of a tubular solar still. They found that the relative humid of the humid air was definitely not saturated and the hourly evaporation, condensation and production fluxes were proportional to the humid air temperature and relative humidity.

This paper covers an experimental study on a compound parabolic concentrator tubular solar still coupled pyramid solar still with and without top cover cooling has been investigated.

2. Fabrication Details

The inner and outer tubes are positioned with a 5 mm gap for flowing cold water to cool the outer surface of the inner glass tube. A circular basin of dimension 2m length and a diameter 0.035 m was designed and coated with black paint using a spray technique. Pyramid solar still of area 1 m x 1 m is designed. The bottom of the still is insulted using saw dust. The solar still is insulated with saw dust reduces the cost of fabrication. Consequently, the cost for fresh water production is less. In the view of eco-friendly material, saw dust would be a good alternative for glass wool. The pyramid solar still is coupled with a non-tracking CPC with help of insulated pipes. The top cover is cooled by flowing cold water at a constant flow rate of 10ml/min. It is adjusted by using a pressure head. It is adjusted for maintaining constant water level in the water storage tank initially during the experiment. A graduated measuring jar is used to measure the flow rate. The process is repeated many times until steady cold water flow in between the tubular cover. The following parameters were measured every fifteen minutes of interval. Water temperature (T_w), interior humid air temperature (T_a), ambient temperature (T_{amb}), outer cover of the tubular temperature (T_{oc}), total radiation (I_{diff}) and direct solar radiation (I_{dir}), and distillate yield. The radiation is measured by a Precision Pyranometer and Pyrheliometer.

3. Experimental Setup

The experimental setup of the system is shown in Figs. 1-3. The distilled yield extracted from both CPC tubular solar still and pyramid solar still. The pyramid solar still is directly coupled with compound parabolic concentrator (CPC) through an insulated pipe. The cold water from the water tank is passed to cool the tubular cover of the still through inlet. The heat energy gained from the top cover cooling process is extracted through outlet and stored in the basin of four sloped solar still. The basin water temperature is raised to a maximum level within a short period, the operating temperature of the still becomes higher and distillation has been started. As well as the radiation falls on the surface of the pyramid solar still which keeps the temperature at a constant level than it reduces through convection. The condensate yield is started to increase due to the temperature difference between water in the basin and top cover of the pyramid still top cover temperature is decreased by cold water flow over it. Thus the temperature difference is wider and produces a distillate yield to a larger quantity.

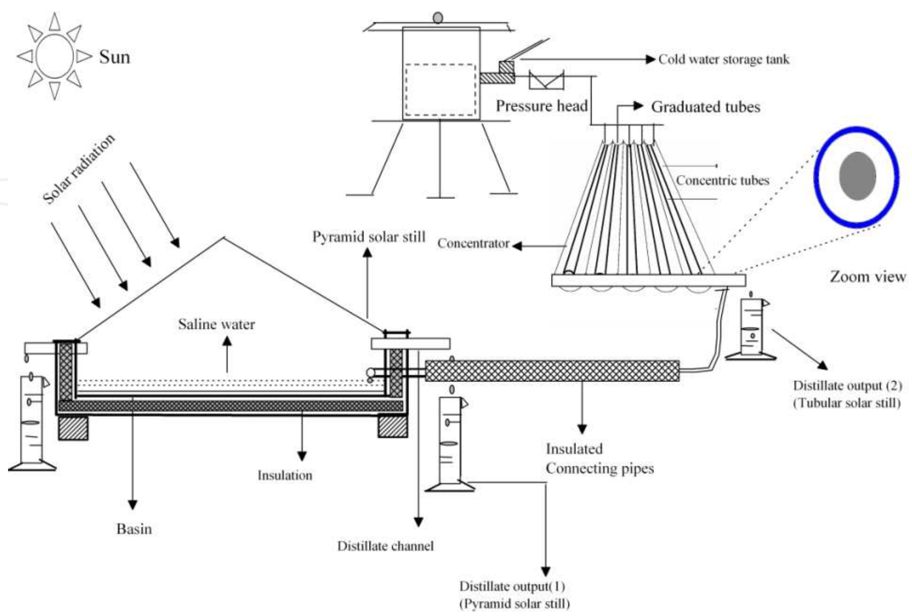

Figure 1. Cross sectional view of compound parabolic concnetrator tubular solar still coupled with pyramid solar still.

Figure 2. Pictorial view of compound parabolic concnetrator tubular solar still coupled with pyramid solar still.

Figure 3. Pictorial view top cover closed pyramid solar still coupled with compound parabolic concentrator tubular solar still.

4. Results and Discussion

Total radiation with respect to time is shown in Fig. 4. Hourly variation of solar radiation is in the range of 520-1036 W/m^2 for CPC-CCBTSS –during top cooling at the tubular solar still and the average solar intensity is 791.72 W/m^2. Similarly the radiation measured as 495-1060 W/m^2 for CPC-CCBTSS-Pyramid solar still top cover without cooling and the average radiation is 793.42 W/m^2. The radiation measured in the range of 579-1050 W/m^2 during the study of effect of top cover cooling in pyramid solar still and the average radiation is 790.27 W/m^2.

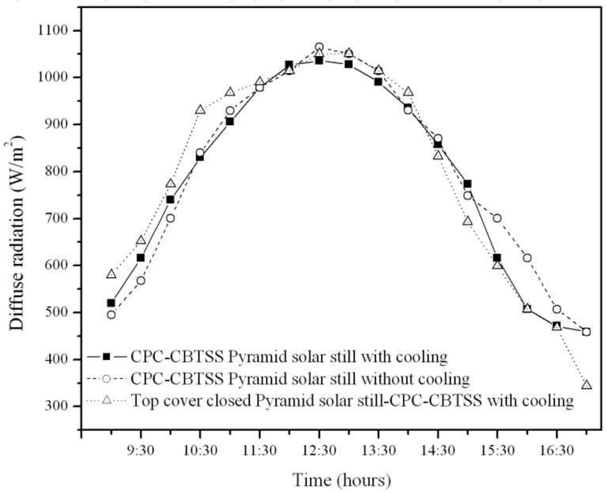

Figure 4. Hourly variation of diffuse solar radiation with respect to time.

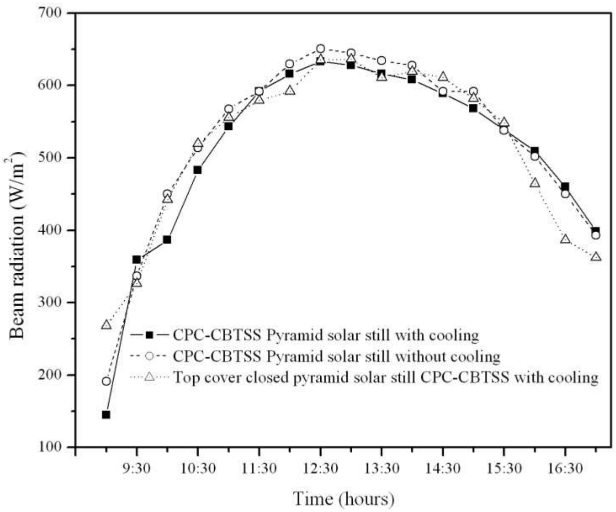

Figure 5. Hourly variation of beam solar radiation with respect to time.

Direct radiation with respect to time is shown in Fig. 5. Hourly variation of direct radiation is in the range of 244-735 W/m^2 for CPC-CCBTSS with Pyramid solar still's top cover cooling process and the average solar intensity is 610.20 W/m^2. Similarly 291-751 W/m^2 for CPC-

CCBTSS-Pyramid solar still top cover without cooling and the average radiation is 623 W/m^2, and 268-739 W/m^2 for top cover closed pyramid solar still with CPC-CCBTSS and the average radiation is 613.90 W/m^2. Hourly variation of ambient temperature is shown in Fig. 6. The recorded ambient temperature is in the range of 29°C to 36°C for cooling. All the analyses are carried out in almost same atmospheric effect same during the study and it is more compatible for comparison. Similarly, 28°C to 35°C for CPC-CCBTSS pyramid solar still top cover cooling and 28°C to 36°C for top cover closed CPC-CCBTSS with cooling.

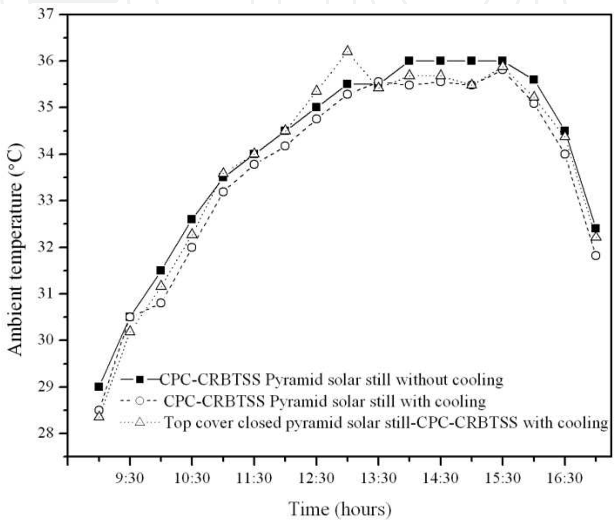

Figure 6. Hourly variation of ambient temperature with respect to time.

Fig. 7 shows the variation of water temperature, air temperature, and outer cover temperature with respect to time in the pyramid solar still. The maximum rise in water temperature is observed as 68°C. Similarly the maximum air temperature inside the pyramid still as 60°C and outer cover temperature is 43°C. Fig. 8 shows the variation of water temperature, air temperature, and outer cover temperature with respect to time for tubular solar still with circular basin. The maximum rise in water temperature is observed as 95°C, the maximum air temperature as 80°C and maximum outer cover temperature as 54°C are obtained from this study. Fig. 9 shows the variation of water temperature, air temperature, and outer cover temperature with respect to time for pyramid solar still top cover cooling. The maximum rise in water temperature is observed as 77°C. Similarly the maximum air temperature of 69°C and the outer cover temperature of 42°C are obtained. Fig.10 shows the variation of water temperature, air temperature, and outer cover temperature with respect to time for tubular solar still circular basin with water cooling. Similarly, the maximum rise in water temperature, air temperature and outer cover temperature are measured as 77°C, 67°C and 50°C respectively. Fig. 11 shows the variation of water temperature, air temperature, and outer cover temperature with respect to time for top cover closed pyramid solar still coupled tubular solar still. The maximum rise in water temperature is observed as 60°C. Similarly the maximum air temperature of 49°C is measured and the maximum outer cover temperature as 37°C is measured.

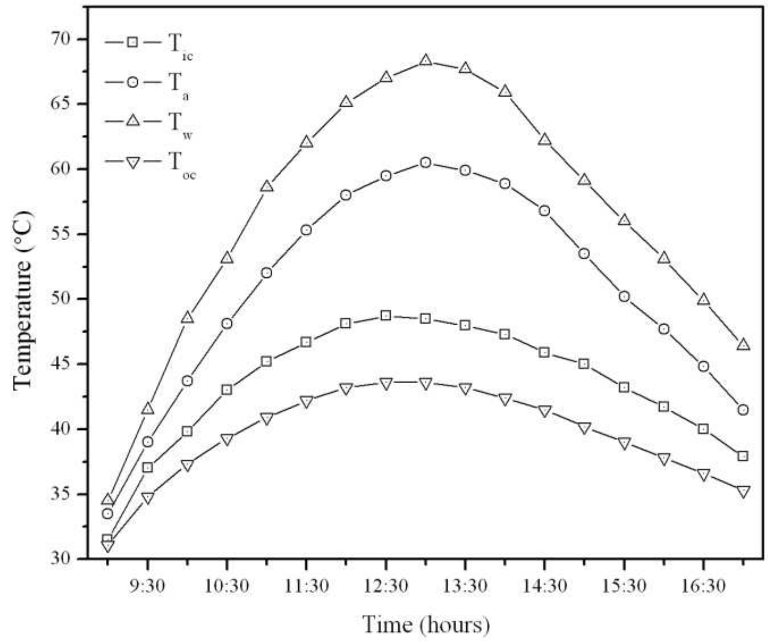

Figure 7. Hourly variation of temperatures with respect to time in pyramid solar still.

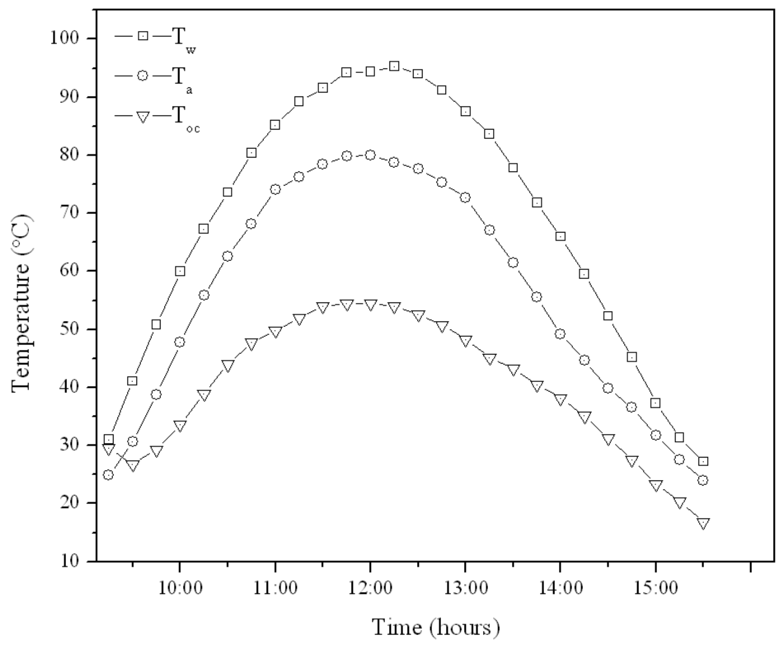

Figure 8. Hourly variation of temperature in tubular solar still in CPC assembly.

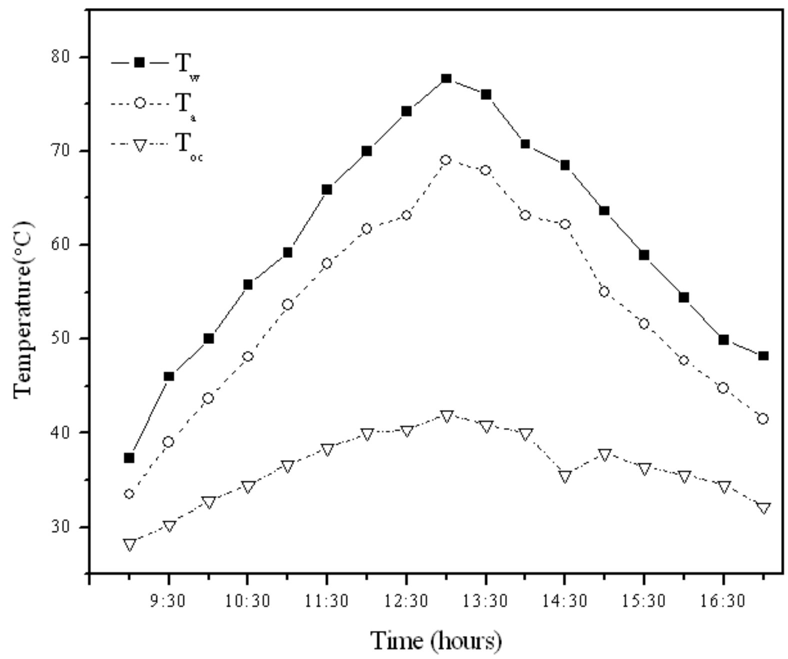

Figure 9. Hourly variation of temperature with cooling in pyramid solar still.

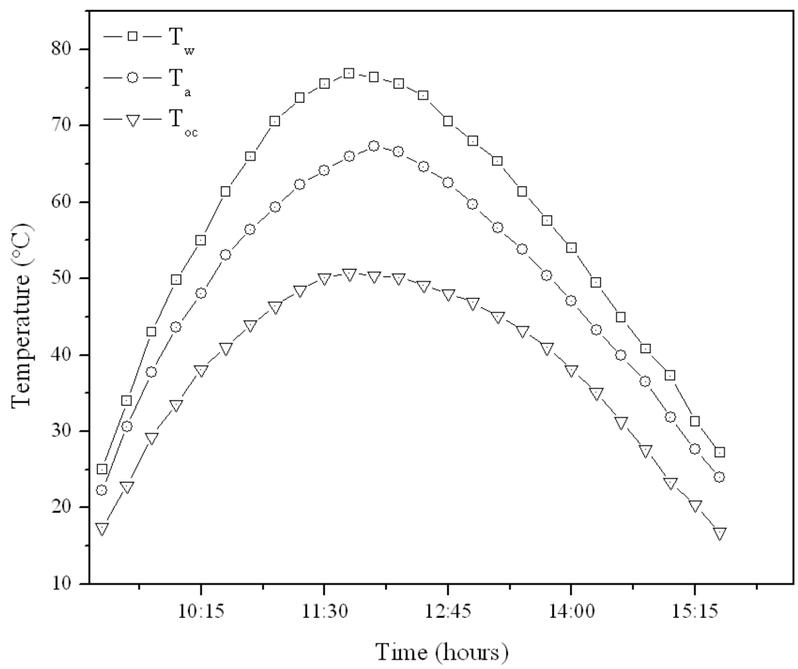

Figure 10. Hourly variation of temperature with cooling in CPC assembly.

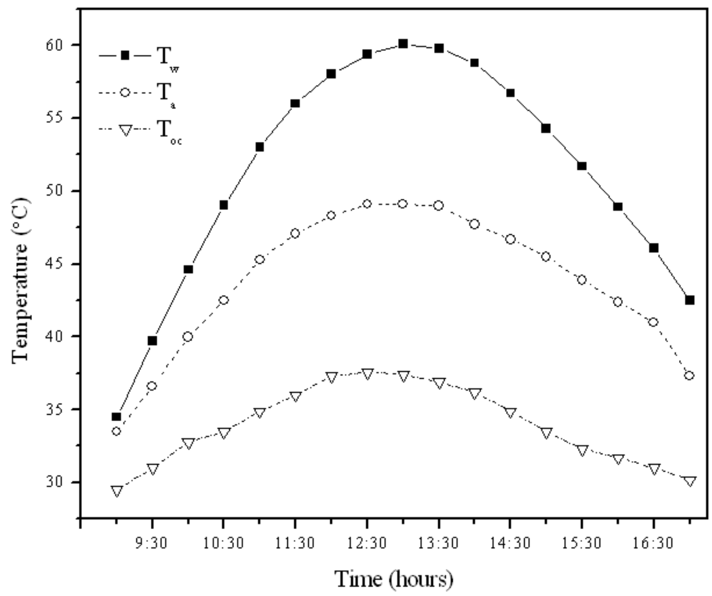

Figure 11. Hourly variation of temperatures for top cover closed pyramid solar still in CPC assembly.

Fig. 12 shows the variation of hourly production in the system. The distilled water collection is in the range of 160-625 ml for CPC-CCBTSS coupled with pyramid solar still without cooling and the total yield is collected as 6528 ml/m^2/day (Pyramid solar still 2818 ml/m^2/day and tubular solar still 3710 ml). Similarly, 160-650 ml for CPC-CCBTSS pyramid solar still with cooling and the total yield of 6928 ml/m^2/day (Pyramid solar still 3218 ml/m^2/day and tubular solar still 3710 ml) 40-470 ml for top cover closed pyramid solar still with CPC-CCBTSS and the total yield of 5243 ml/m^2/day (Pyramid solar still 1533 ml/m^2/day and tubular solar still 3710 ml are obtained from the above studies). The pyramid solar still operation is active mode when the heat extraction of water from CPC-CCBTSS is fed up into the pyramid solar still. Also the effective heat gained by the water in the pyramid solar still is estimated by top cover closed mode of operation. The yield rate is more than that of pyramid solar still alone. The productivity of the pyramid solar still is 2500 ml/m^2/day only. But it's yield rate is improved by coupling system with concentrator. A further increasing in yield rate is also observed from the extraction. In conventional solar still, the evaporation takes place after one hour from the beginning of experiment. This draw back has improved here. The warm-up period is reduced and supports for quick evaporation. The initial water temperature in the pyramid solar still is high as 55°C due to the heat extraction from the CPC-CCBTSS. Additionally, the heat extraction of water in the pyramid solar still temperature is further increased by the incoming solar radiation. So the water temperature is increased within a short interval of time. The sudden rise in water temperature is induced the evaporative heat transfer in the still. So the distilled yield increases more than conventional solar still. A further increase in yield rate is also observed for the cooling over the pyramid solar still under same mode of operation. Thus this result conformed that the assistance of concentrator certainly increased the yield rate of distilled water.

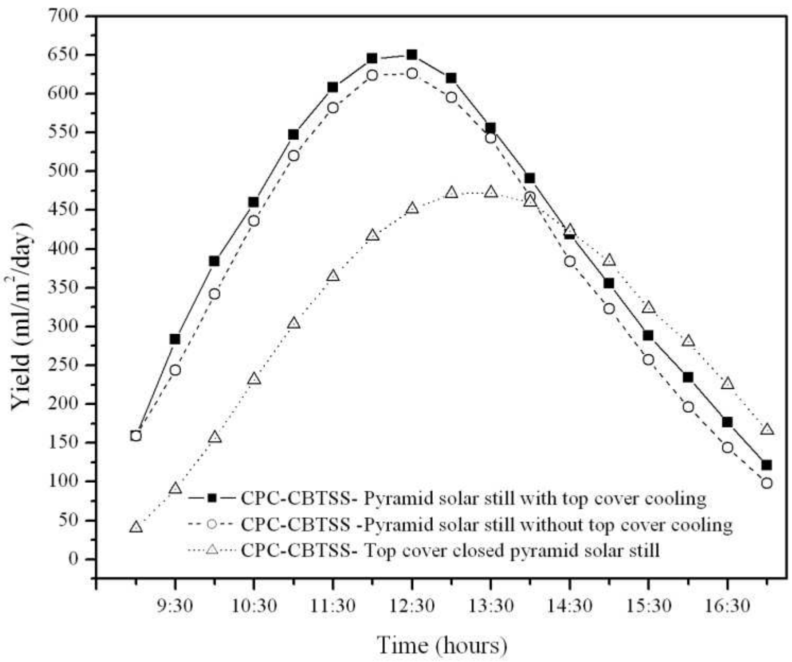

Figure 12. Hourly variation of yield with respect to time.

The temperature difference between the water in the basin and the glass cover are increased in the early hours from the beginning of the experiment due to the heat extraction of water from the CPC-CCBTSS which is directly coupled with pyramid solar still. The sum of yield has been taken into the calculation part. Also top cover cooling water from the CPC-CCBTSS is improved the operation of the solar still. So the energy loss of heat during cooling in the CPC-CCBTSS is further utilized by the pyramid solar still and increased the overall system efficiency. The overall efficiency of the system is calculated as 17.01% for without cooling and 21.14% for with cooling.

5. Conclusion

The temperature of the saline water in the basin can also be increased through the addition of external heating. These effects may be created by integrating with solar concentrator, flat plate collector. These type of behavior is studied by using of a pyramid solar still directly coupled with compound parabolic concentrator – tubular solar still in this work. It is completely different than that of other substitution effect to increase the temperature of basin water. CPC acts as a heat collecting unit and produces the distillate yield through circular basin cooling water from tubular cover serves as a further evaporation in the pyramid solar still. It can extract not only solar radiation incident on the saline water but also the other sources of heat loss. This type of utility of heat loss as a additional source will be suitable only at high temperatures. These results showed that the maximum output extracted from the proposed system as 6928 ml/m^2/day for with cooling.

http://dx.doi.org/10.5772/49995

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