Productivity Enhancement of A Single Slope Solar Still Using Parabolic Concentrating Dish Collector

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Abstract: The performance of coupling a parabolic concentrating type dish collector with a single slope solar still is investigated experimentally. The incident solar energy on the concentrating collector is transferred to the basin water stored in the solar still by heat exchanger imbedded in the solar still. The heat exchanger is fabricated from copper tubes. The experiments are conducted at summer and winter times for two systems; conventional solar still and solar still with parabolic concentrating type dish Collector for constant 20 mm saline water depth in the basin. The results illustrate that the solar still coupled with concentrating collector has higher basn water temperature and productivity as compared to conventional solar still. The freshwater productivity of solar still coupled with concentrating collector is higher than that of conventional solar still by about 75% at saline water depth 20 mm in summer and 92% higher in winter. Freshwater productivity is about 1750 ml per day and 1250 ml per day for solar still coupled with concentrating collector in the summer and winter respectively. The results also illustrate that the performance of solar still in winter is smaller than summer for both systems. In summer and at saline water depth 20 mm, the daily efficiency of the solar still coupled with concentrating collector in summer and winter season is 34% and 28% respectivelyDue to carbonization concern, generation resourc

Keywords: Distillation, parabolic collector, productivity, solar still

1. INTRODUCTION

Water is the vital for all forms of life on the earth. Human, animals and plants. Water is one of the most valuable resources on the earth that covers 71% of its total surface. About 97% of the earth's water is present in oceans and seas as salty water, 2% is reserved in Polar Regions as ice and the rest 1% is presented as freshwater in the form of lakes, ground water, and rivers[1], [2]. The availability of freshwater from the natural resources of water shrinks daily because of rapid growth of world population and poor management of water[3]. There are many people living in remote areas where electricity and potable water is scarce and it needs high cost to supply these entities at these places. Due to water related diseases, in the earth, 3.575 million people die each year[4]. So, it is important to explore alternative methods to produce potable water at low cost. The solar energy is available everywhere and it is abundant, free and renewable source of energy. Therefore, it is valuable to use solar energy in the desalination of salty water to overcome this problem. Many solar desalination systems were developed over the past years. The solar still is most simple and conventional solar desalination device as compared to the other distillation devices using conventional sources of energy (mostly electricity)[5]. Solar still uses saline water and works on the principle of evaporation and condensation. The saline water inside the basin of the solar still is evaporated by using the solar energy and it condenses on the solar still cover plate. The condensate is collected and stored as potable water. The solar stills are mainly classified into two types: passive and active solar still. For passive solar still, the incident solar radiation on the solar still is the only parameter which causes the evaporation process. For active solar still, besides the incident solar radiation, the evaporation is also caused by using supplementary devices like fan, pump, solar collectors or any other devices. The main problem encountered by the solar still is its low productivity of potable water, which is within the limit 2.5–5 L/m2 day[6]. To improve the productivity of the solar still, many researches were carried out up till now. Elango et al. [7] analyzed the effect of different nano-fluids on the efficiency of single basin, single slope solar still. Al_2O_3, ZnO, and SnO_2 nano-fluids of 0.05 % and 0.1 % concentration were analyzed to improve the rate of heat transfer which significantly improved the efficiency of the still. Using Al_2O_3 nanofluid, the rate of production was maximum which was about 29.95 % higher as comp[ared to the conventional system. The production was increased by 12.67 %

and 18.63 % respectively, as compared to conventional solar still. These production rates were attained using 0.1% concentration of nanofluids. The result of 0.05 % concentration was not reasonable. Sodium dodecyl benzene sulphonate (SDBS) was used to maintain stable and homogeneous suspension of nanofluids.

Sain et al. [8] enhanced the performance of single slope, single basin solar still by mixing Al_2O_3 nanoparticles with the black paint. Using Al_2O_3 nanoparticles, production achieved and efficiency of solar still at optimum water depth of 1 cm was found 3.48 liters and 38.45% respectively. Gnanadason et al. [9] analyzed the effect of nanofluids in a modified vacuum single basin solar still. In the study, the copper basin was used instead of the GI basin, and the glass cover thickness used was 4 mm inclined at 32°. The amount of distillate collected in the still made of copper was higher and the increment in efficiency was 60 % when compared with still made up of GI for the same basin area. Hansel et al. [10] analyzed the performance of a solar still with the inclined absorber surface using different wick materials and wire mesh. To maintain a equal thickness of water on inclined absorber surface, wick was used. In this study, wick materials were wood pulp paper, water coral fleece, and polystyrene sponge. It was found that the best wick material was water coral fleece with porosity 69.67 %. Sandeep et al. [11] analyzed a modified single slope, single basin active solar still using secondary condensing cover. The yield of the new solar still was 3.015 kg/m2/day, which was about 25.4 % more than that of a conventional solar still running in parallel. Ahmad et al. [12] analyzed the performance of single slope solar still at different inclination angles of the glass cover. The results showed that maximum yield was obtained from the condensing cover inclined at an angle of 45° and minimum yield was obtained from the condensing cover inclined at an angle of 15°. Aboul-Enein et al. [13] investigated the thermal performance of the solar still both experimentally and theoretically. A decrement was seen in the productivity of the still with an increase in heat capacity of basin water during day, and it was reversed during the night. The optimum tilt angles of the still cover were found to be 10° and 50° during the summer and winter seasons respectively. Estahbanati et al. [14] investigated the effect of stages on multi-effect active solar still. The maximum productivity of 22.9 liters/day and 27.1 liters/day was achieved for non-continuous and continuous modes respectively with 4 stages. Panchal et al. [15] gave a comparative result of single slope solar still coupled with flat plate collector and passive solar still. It was seen that Solar still coupled with flat plate collector increased the productivity of solar still by 35%. Al-Garni et al. [15] analyzed the effect of glass tilt angle and water depth on the productivity of double slope solar still. It was observed that maximum yield was obtained at glass tilt angle of 35□. The productivity of the still was 4.64 l/m2 in summer and 2.1 l/m2 in the winter season. Valsaraj [16] conducted an experiment on a single slope basin solar still in which one-fourth portion of perforated and ‘V’ shaped aluminum sheet was floating over the water surface. At a water depth of 9 cm, the increment was found in yield more than 43% and at a water depth of 3 cm, negligible yield was observed. Nafey et al. [17] used black rubber and black gravel materials within a single slope solar still as a storage medium. The results showed that black rubber of 10 mm thickness improved the productivity by 20% under the conditions of 60 liters/m2 brine volume and 15° glass cover tilt angle.

In spite of the large number of studies on the solar still, there is a scope of work to improve its performance and productivity. A very few studies have been noticed on the performance of single slope solar still coupled with parabolic concentrating type dish collector During the literature review, majority of the solar still related studies were presented for summer seasons and few studies were addressed for winter days. Moreover, not much literature has been noticed for seasons comparison between the performance of active solar still for variety of seasons.

So, in this work, an experimental work has been presented on the effect of coupling parabolic concentrating type dish collector with a single slope solar still. The collector produces high temperature on its focus. The concentrating collector is used as an extra heating source to the saline water in solar still basin. A comparison between the solar still coupled with parabolic concentrating type dish collector and the conventional solar still is presented. Also, a comparison between the performance of the solar still for summer and winter is performed in this study. The study is carried out at constant saline water depth and the measurements are carried out during summer and winter. The collected solar radiation on the collector is transferred to the solar still by using a coil made up of copper tubes forming a heat exchanger inside the solar still basin.

2. MATERIALS AND METHODS

The experimental setup consists of single slope solar still coupled with parabolic concentrating type dish collector. The solar still is composed of saline water basin of 900mm length, 780 mm length and 600 mm height as illustrated in Figs. 3.1 and 3.7. The basin walls are made from a galvanized iron sheet of 0.81 mm thick. All inside surfaces of the basin are coated with black paint materials to increase the basin absorptivity of solar radiation. The basin is fitted inside a wooden frame of 19 mm thick and 650 mm height and outer dimensions of 950 mm length and 829 mm width. The space between the basin and the wooden frame is filled with an insulating saw dust and thermocole to reduce the heat loss from the basin to the surrounding. The used solar still is covered with a clear glass sheet of 4 mm thickness inclined with an angle of 26° with the horizontal which is the latitude angle of Jaipur (26°55′ N latitude, 75°52′ E longitude), Rajasthan, India. The solar still was oriented to the south direction because this is the direction of maximum incident solar energy falling on the cover plate of solar still [18]. Bonding silicon and clay sand were used to prevent any leakage between the basin box and the glass cover. A channel made of GI sheet was installed inside the solar still at the bottom end to collect the condensed freshwater. This channel was tilted with enough slope to collect efficiently the condensed water vapour at glass cover plate. A supply line is connected to the solar still to compensate the daily condensed freshwater by saline water in the basin at the start of each daily experiment.

The used collector is parabolic concentrating type dish collector used as a reflector which concentrates solar radiation on the receiver coil. The concentrator is manufactured from reflective plastic sheet of 0.4 mm thickness. The receiver coil of the concentrator consists of an absorber copper tube which is 2.43 m long and 9.52 mm diameter. The concentrator is oriented to the south with a tilt angle equal to the latitude of Jaipur, Rajasthan.

The absorbed solar radiation by the copper absorber tube is transmitted to thermal oil passing inside this tube. This oil is used to transfer the heat gain to the saline water in the solar still basin. Copper tubes are used to transmit the heated thermal oil from the receiver copper tube to the inlet of the solar still and vice versa

The heat carried by the oil at the inlet to the solar still transmits its heat to the basin saline water by using oil heat exchanger. The heat exchanger pipe is fabricated from copper tube of 9.52 mm diameter and 8 m length and it is installed in the bottom of the basin. All the heat exchanger tubes are painted with black paint material to maximise their absorptivity. A small pump is used to pump the hot oil through the tubes of the used system (solar still with concentrating trough collector) at a flow rate of 7 L/min. The pump used is an gear pump which is driven by a DC motor which is powered by a battery. The battery is charged by the solar panels which makes the setup run solely on solar energy. The fabricated experimental setup as shown in Fig. 3.1 which was installed on the terrace of Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur (26°55′ N latitude, 75°52′ E longitude). The solar still was kept directing towards South direction to receive the maximum solar intensity

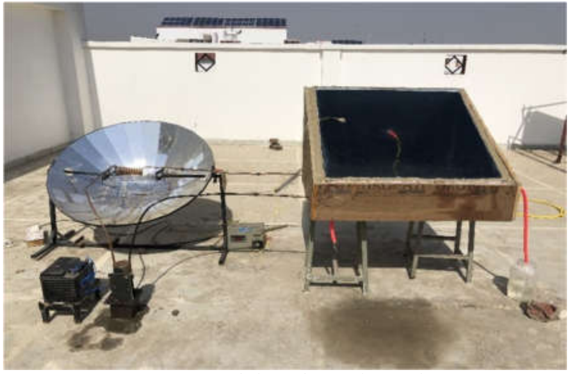

Figure 3.1: Fabricated experimental setup

In this study, the experiments were performed on different days of different seasons. The conventional solar still was compared with the solar still integrated with parabolic concentrating type dish collector. The experiments were carried out for 5 days in each season. Experiments were carried out from 9:00 AM in the morning till 5:00 PM in the evening. The experiments were carried out on 8th to 11th of August, 2018 and 11th to 14th of February, 2019.

The concentrating collector was used to add external heat to the working fluid. The working fluid used is synthetic mineral oil. This oil flows through the receiver coil which is placed at the focal point of the concentrating collector. Due to high temperature at the focal point of the concentrator the oil flowing inside the coil gets heated up. This oil then flows to the solar still basin where it transfers its heat to the saline water which is stored in it. The water inside the basin is already heated by the direct solar radiation which is incident onto the glass cover plate of the solar still. When the hot oil carrying the heat form concentrator passes through the heat exchanger coil placed inside the saline water in the still basin, it adds external heat to the water.

This external heat enhances the rate of evaporation and thus increases the productivity of the conventional solar still. The oil which is cooled after transferring its heat to the saline water, comes out of the still and is pumped back to receiver coil placed at the focal point of the concentrator. A pump is used to circulate the oil through the whole circuit. The pump used was a gear pump, operated by a DC motor.

The DC motor was operated by a 12V battery which was charged using the solar panels, making the whole setup run on solar energy only. Distillate output of conventional solar still was compared to that of the still integrated with parabolic concentrating type dish collector.

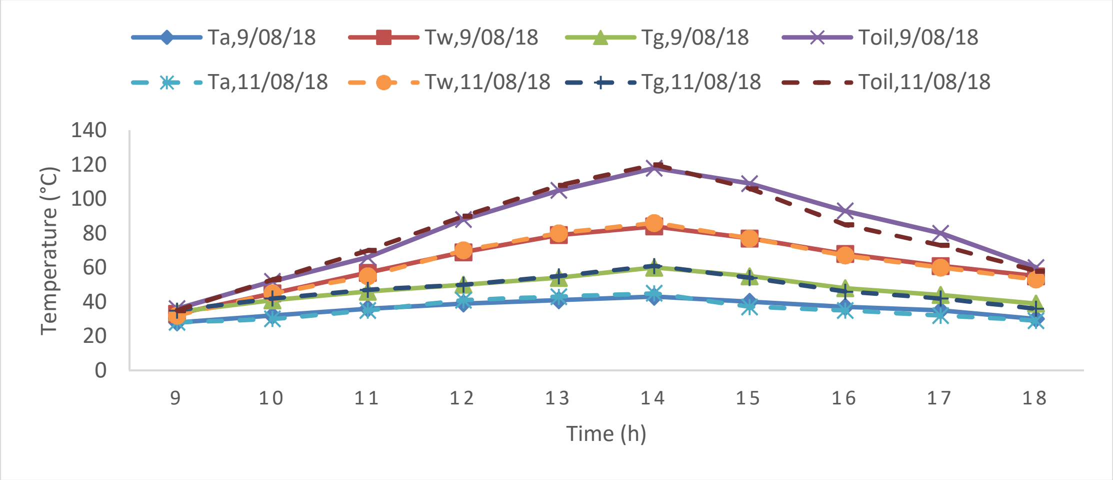

Figure 4.1: Variation in temperatures of various components of still integrated with dish collector in summer

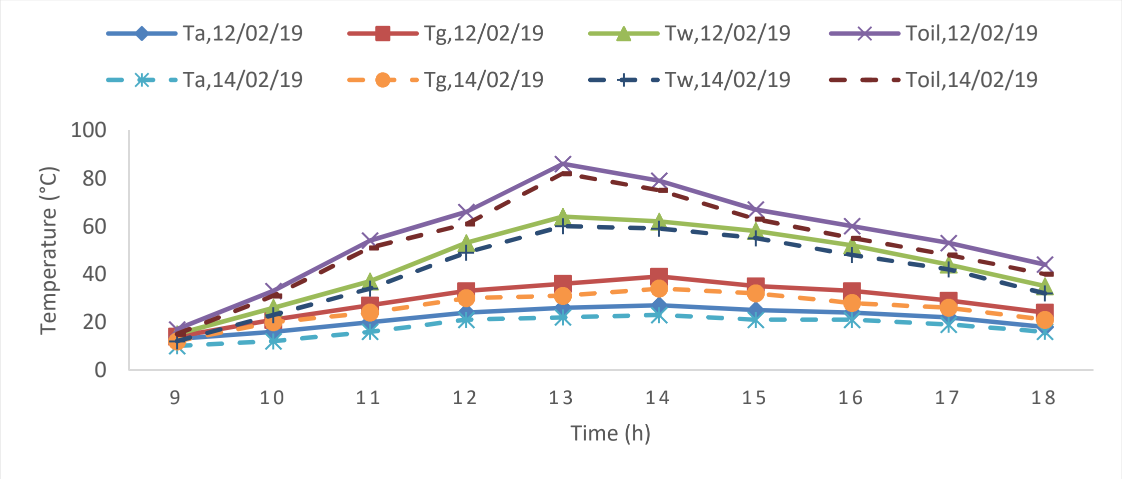

Figure 4.*2*: Variation in temperatures of various components of still integrated with dish collector in winter

3. RESULTS AND DISCUSSIONS

The results of the present experimental work are carried out for the studied two solar still systems (conventional single slope solar still and single slope solar still integrated with parabolic concentrating dish collector) for 20 mm depth of saline water in the basin. The measurements are measured and recorded each hour from 9 AM to 6 PM and are carried out in summer from 8 to 11 August 2018 and in winter from 11 to 14 February 2019. The productivity of the solar still increases with increase the rate of evaporation of the saline water in the basin and the rate of condensation of the evaporated water at the inner surface of the solar still. So, in this work, efforts are made to enhance the evaporation rate of the saline water by adding external heat supplied by concentrating dish collector coupled with the solar still.

3.1 Solar Still TemperatureS

Measuring the temperature at different positions of the solar still gives good information and explanation on the still performance. So, the temperatures of ambient air (Ta), glass cover plate (Tg), saline water in the basin (Tw), and oil at the inlet to the solar still (Toil) are measured. Fig. 4.1 shows the evolution of the temperatures of the saline water (Tw), glass cover plate (Tg), ambient (Ta) and oil (Toil) for modified solar still at saline water depth 20 mm. Fig. 4.1 and Fig 4.2, indicate that the temperatures increase with time from the morning until about 2 PM in summer season and 1 PM in winter season and then fall with increasing time. It is noted that the maximum value of temperature is around 2 PM in summers and 1 PM In winters as shown in Fig. 4.1 and Fig. 4.2

3.2 Freshwater Production

The variation of the hourly production of potable water (freshwater) with time for both studied solar still systems in summer and winter are shown in Figs. 4.3 and 4.4 respectively. Figs. 4.3 and 4.4 indicate that the hourly production of freshwater increases with time from 9 AM to about 2 PM in summers and from 9 AM to 1 PM in winters, and then it decreases with time until the end of the reading time. It is noted that the evolution of the freshwater productivity in summer with time has the same trend in winter The maximum potable water is produced by the still is in summers when it is coupled with a parabolic concentrating type dish collector. The maximum potable water produced by the modified still in summers was 1750 ml per day and the maximum potable water produced by the conventional still was 1000 ml per day. In winters the maximum potable water produced by modified and conventional stills was 650 ml and 1250 ml respectively.

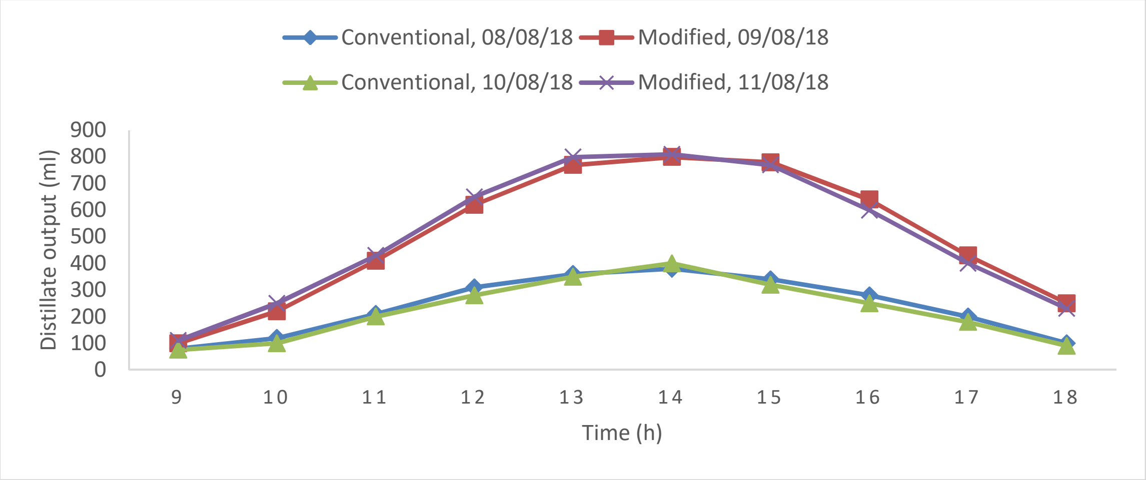

Figure 4.3: Hourly production of potable water by both solar still systems in summer

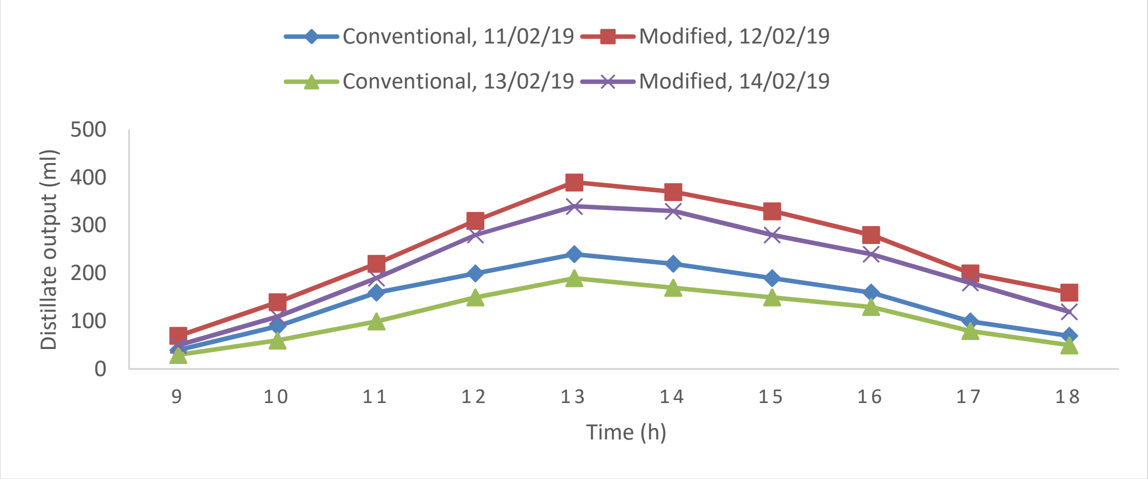

Figure 4.4: Hourly production of potable water by both solar still systems in winter

3.3 STILL EFFICIENCY

From the previous results, it is found that coupled PTC with conventional solar still increases solar still production of freshwater. So, it is important to study the efficiency of using PTC with the solar still compared with conventional solar still

The distillate output can be calculated as:

$$M_{ew} = (q_{ew}/L) \times 3600 = [h_{ew}(T_w - T_g)/L] \times 3600$$

[19]

Where,

Mew = Distillate output from the still, L/m2/day

qew = Evaporative heat transfer from water to cover, W/m2

L = Latent heat of vapourisation, J/Kg

hew = Evaporative heat transfer coefficient from water to cover, W/m2 °C

Tw = Temperature of basin water.

Tg = Temperature of glass cover plate.

The efficiency of the solar still system can be obtained by $\eta_i = q_{ew}/I(t) \times 100$

[43]

Where,

ηi = Instantaneous efficiency

I(t) = Total solar radiation, W/m^2

Heat added by concentrator to the basin water can be calculated as:

Q = mcdt

Where,

Q = Heat added by conduction, J

M = Mass flow rate

C = Specific heat capacity, J/Kg °C

dt = Temperature difference, °C

The efficiency of conventional solar still and modified solar still was 26% and 35% respectively in summers and 22% and 28.16% respectively in winters. Hence, the efficiency of solar still was increased by 34% in summers and 28% in winters by the use of parabolic concentrating type dish collector.

4. CONCLUSION

An experimental study on productivity enhancement of a solar still by integrating with parabolic concentrating dish collector was presented. The effects of external heat addition by the concentrating collector on the distillate output were analyzed. The following conclusions were obtained.

- From the study, it was observed that the maximum basin water temperature at water depth of 20 mm for conventional still in summer is 64°C and 52°C in winter. Whereas for the still coupled with the concentrating collector basin water temperatures for summer and winter are 85°C and 64°C.
- An average increment of 79 % and 94 % in output has been noted for the observation duration for summer and winter respectively
- The efficiency of solar still was increased by 34% in summers and 28% in winters by the use of parabolic concentrating type dish collector.

From the above experimental analysis, positive effect on the efficiency and distillate output was seen by integrating a parabolic concentrating type dish collector with the conventional solar still. Higher distillate output by using the external heat provided by the concentrating collector proves that the productivity of the still can be enhanced by adding external heat to the basin water. The very less value of the PPM of dissolved salts in the output water was the proof of good quality of water produced.

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