Performance investigation on solar still with plate fins and latent heat energy storage

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Abstract: Solar still is a cheap and portable solar distillation system that can purify brackish water into potable water and is ideal for domestic use. Low productivity is a major issue that needs to be addressed in solar stills. In the present work, the efficiency of the fabricated single slope single basin solar still was enhanced by the incorporation of plate fins over the basin liner of the still. The daily productivity was further increased by attaching a latent heat energy storage unit to the still. Paraffin wax was used as phase change material (PCM) in the energy storage unit. Experiments were conducted on modified solar still for the following two cases (i) with mere plate fins and (ii) with plate fins and PCM. A 40.6% increase in productivity was observed for the solar still with mere fins and the productivity is increased by 94.51% for the solar still incorporated with both fins and PCM when compared with that of conventional still.

Keywords: solar still, distillation, fins, energy storage, paraffin wax

1. Introduction

About 70% of the planet is covered with water sources and it is obvious to believe that it will always be abundant. However, freshwater that we drink, wash and utilise is extremely rare. Around 2.8 billion people are facing water-shortage for at least a month due to the water that is unable to be consumed because it is either cloistered in glaziers or inconvenient for usage, which comprises two third of the available water in the world [1]. In dense populated countries like India and China, shortage of fresh water for various needs affects the development of the country [2]. Research states that an individual requires at least 2-5 litres of water per day [3]. To meet out the mentioned problem, desalination process is implied to generate fresh water from sea water through large plants which is expensive, as it uses fossil fuel for its energy requirement. On contrast, solar distillation process requires utilization of energy received from the sun which is sustainable and inexpensive. The device used to carry out the solar distillation process is termed as solar still.

The two principles behind a solar still are evaporation and condensation processes. Initially, the abundantly available saline or brackish water is filled into a basin coated black with paint. Solar still is
then exposed to the sun where the water inside the basin gets evaporated due to the thermal energy received from the sun. The evaporated vapour settles at the glass ceiling, which is inclined at an appropriate angle. The temperature difference between the basin water and glazing inner surface acted as a driving potential to condense the vapour hitting the glass cover. The droplets slide down the glass cover and gets collected separately through the collecting duct [4]. Varun et al. experimentally inferred that the internal and external heat transfer primarily depends on the amount of water mass present in the solar still basin [5]. In some cases, solar stills are coupled with fins in the flat plate basin which increases the surface area of the fins thus; the rate of heat transfer is increased. Velmurugan et al. performed experiments using wick materials, fins and sponges engrossed in the brine of a finned solar still and observed an increase in productivity has by 29.6 % 45.5 % and 15.3 % respectively [6]. Ramadan et al. concluded from their experiment that there was an increase in productivity when the height of the fins were increased and they observed a decrease in productivity upon increasing the thickness of the fins. Further, it was studies that, the increased number of fins would hinder the daily yield of the still since the shadow area has increased due to the introduction of fins [7-9].

Sathish et al. [10] and Badran et al. [11] has conducted experiments which have resulted in increased productivity by decreasing the depth of the water. Paraffin wax is employed as a phase change energy storage material for capturing the excess energy received from the solar radiation during the peak sunshine hours as it has large storage density [12]. During the nocturnal period, the stored energy is delivered back to the basin water [13]. Thus, it is evident that the performance of the solar still can be improved using thermal energy storage material [14]. Since, many previous research works were reported on solar still performance annexed with various fin configurations and various energy storage materials separately, hence in the present work, it is proposed to study the performance of solar still with both fins and energy storage material.

2. Materials and methods

2.1 Experimental Setup

The fabricated experimental setup consists of a finned basin, glazing, the outer chamber, thermocouple, temperature indicator and a measuring jar. A finned basin of area 0.5 m² was fabricated using mild steel sheet of thickness 16 gauge; the dimensions are 1000 x 500 mm; depth 92 mm. Within the surface area 7 fins were integrated at a pitch distance of 120 mm. The height and thickness of the fins were 35 mm and 1 mm respectively. The basin is divided into two parts, the upper region and the lower region and fins were introduced on both upper and lower side of the basin exposing its area to both basin water and thermal energy storage medium. Brackish water was filled into the upper part and the thermal energy storage material like paraffin wax was loaded into the lower part. Fins at the lower part helped in transferring the energy to the paraffin wax at a faster rate during daytime. The basin liner separated both the regions. The entire basin is coated with black paint.

The glazing was made up of tempered glass of thickness 4 mm. Varying the thickness of the glass can result in the poor transmissivity of solar incident radiation. The glazing was fitted over the top of the outer chamber using 3 hinges. The hinges were fitted at an equal distance between each other. The glazing is inclined at 12° since the geographical latitude of Coimbatore; the experimental location is 11.0168°N [15].

The outer chamber or casing is fabricated using a mild steel sheet of thickness 16 gauge, of dimension 1050x550 mm. Once the basin was placed the excess region surrounding the basin was perfectly insulated using thermocol. At the shorter side of the chamber, a collecting duct was fixed along the width of the chamber to collect the droplets sliding from the glass. Thermocouples were placed at the appropriate parts of the experimental setup and connected with the 12-point temperature indicator to measure the temperatures.
2.2 Experimental Procedure

The brackish water was filled in solar still basin till the depth of water reached 2 cm. Incident radiations was partially absorbed by glazing and leaving the rest of the radiation to pass through which reaches the water body. Again water absorbed certain radiation and rest of the radiation reached the basin water. The opaque basin liner got heated up and transferred the heated up and transferred the heat to the basin water. The evaporated hot water settled at the glass ceiling which was at a temperature below the saturation temperature of the vapour touching it making it to condense on its surface as water droplets. An inclination of 12° was offered to the glazing placed over the enclosure. The droplets at the glass ceiling slides down to the collecting duct which was connected with the measuring jar at the outlet pipe of the still. The finned solar still has 5kg mass of paraffin wax which was employed as the latent heat energy storage medium placed below the basin liner that stored the energy when the basin was heated during the daytime and delivered the same to the brackish water present in the basin during the night time. The daily yield was observed and noted for 2 cm water depth. The entire experimentation was carried out for 2 cm water depth since the hourly distillate yield obtained was observed to be optimum for incorporating thermal energy storage in the still when compared to other water depths.

2.2.1 Instantaneous efficiency

The expressions used to determine the instantaneous energy efficiency of the still [15] are:

\[
\eta_i = \frac{q_{ew}}{I_t} = \frac{h_{ew}(T_w - T_g)}{I_t}
\]

(1)

\[
h_{ew}(Wm^{-2}) = 16.273 \times 10^{-3} \times h_{cw}\left[\frac{P_w - P_g}{T_w - T_g}\right]
\]

(2)

where \(I_t\) is solar radiation measured every hour, \(Wm^2\), \(h_{ew}\) is the evaporative heat transfer coefficient, \(Wm^{-2}K^{-1}\), \(P_w\) and \(P_g\) are the partial saturation pressures with respect to water and glass temperatures, \(Nm^2\).
3. Results and discussion
In this section, various conditions affecting productivity and efficiency of the conventional still and modified stills are compared with the help of various plots.

![Figure 2. Schematic of the experimental set-up, Solar still](image)

The hourly solar insolation received during the experimental days was compared in Figure 3. It was observed from the graph that the intensity of hourly solar radiation received on both the days was similar and hence the reading taken on these days can be taken for analysis and comparison.

![Figure 3. Comparison of Solar Insolation during the experimental trails](image)
3.1 Effect of fins on productivity

The comparison of the productivity of CSS and SSWF has been shown in the Figure 4. It was observed that the increase in productivity of CSS and SSWF was almost similar till 12.00 hours and thereafter, the productivity of CSS has started to decline but SSWF has continued its increasing trend till 15.00 hours. This was due to the excess heat energy gained by the fins attached over the basin liner which obviously increased the overall productivity of the still.

3.2 Effect of both fins and thermal energy storage material on productivity

The productivity of CSS and SSWF+TES has been compared in Figure 5. It was observed that the hourly productivity of both the stills started to vary after 12.00 noon. The productivity of SSWF+TES was on the higher side even after the decline of solar radiation. This was due to the presence of TES material which supplied the thermal energy required for evaporation to the basin water after sunshine hours.
3.3 Variation of water and glazing temperatures

The difference between the basin water temperature and the glass inner surface temperature is an influencing parameter on productivity of the solar still. Figure 6 and Figure 7 illustrate the variation on the basin water and glass cover inner surface temperatures in CSS, SSWF and SSWF+TES. It was observed that the variation between CSS and SSWF+TES was on higher side when the solar radiation started to decline i.e., after 13.00 hours. This has leaded to increase in the hourly productivity of SSWF and SSWF+TES.

Figure 6. Variation of basin water temperature and glass cover temperature of CSS and SSWF

Figure 7. Variation of basin water temperature and glass cover temperature of CSS and SSWF+TES
3.4 Comparison of Cumulative distillate output

Figure 8. Comparison of cumulative yield of CSS, SSWF and SSWF+TES with respect to time

Figure 8 compares the cumulative yield of all the stills and it was observed that the CSS has stopped its output by 18.00 hours i.e., once the input solar radiation becomes zero. Similarly, SSWF has ended its yield just after 18.00 hours but has exhibited an increased yield from 13.00 hours onwards when compared to CSS. But the cumulative distillate of SSWF+TES was on increasing trend even 20.00 hours since the input energy required for the distillation process was being supplied by the TES material placed beneath the basin liner. Further the fins extended below the basin liner onto the TES region has increased the storage efficiency of the PCM used which was the main cause of extended productivity in case of SSWF+TES.

3.5 Comparison of instantaneous efficiencies

Figure 9. Comparison of instantaneous efficiency of CSS, SSWF and SSWF+TES

The instantaneous efficiency of the CSS, SSWF and SSWF+TES has been compared in the Figure 9. It was observed that the efficiency of the CSS has started to decline from 16.00 hours due to its very low productivity. But the efficiencies of SSWF and SSWF+TES were on increasing trend till dusk. This was
due to the excess energy gained through fins in the case of SSWF and excess energy gained through fins and TES material in case of SSWF+TES. It was also observed that the difference between the efficiencies of SSWF and SSWF+TES has started to widen after 15.00 hours due to the presence of TES material which supplied the excess energy required for evaporation which it has gained during the peak sunshine hours.

4. Conclusion
Two similar solar stills were fabricated and experiments were conducted on CSS, SSWF and SSWF+TES on two different days with similar climatic conditions. The following conclusions were derived through the experimentation and analysis;

1. The daily efficiency of CSS, SSWF and SSWF +TES is recorded as 37.47%, 52.66% and 65.95%.
2. An enhancement of 40.6% on productivity has been observed due to the introduction of only tubular fins over the basin liner.
3. An enhancement of 94.51% on productivity in case of incorporating both fins and energy storage medium to the solar still.

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