Performance comparison of solar stills with different fin materials coupled with PCM energy storage

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Abstract. Low productivity is a major issue to be addressed in solar still which is considered to be an economical and viable gadget used to convert brackish water into potable water in remote and rural regions of developing countries. In the present work, an attempt has been made to improve the productivity of solar still by incorporating fins and energy storage materials. Two identical single slope single basin solar stills were fabricated with an effective basin area of 0.5 m² (1000 mm x 500 mm) and glazing inclination of 12° with the horizontal. Experiments were conducted to compare the performance of conventional solar still with finned solar still attached with paraffin wax as phase change material (PCM). Two different materials; Galvanized iron and Aluminium were used to fabricate the basin and tubular fins. The experimental results showed that the productivity and the daily efficiency of the solar still with fins and energy storage were higher compared to solar still with mere fins and solar still with mere energy storage. Further, solar still with Aluminium fins exhibited superior performance compared to the solar still with galvanized iron fins.

1. Introduction

While more than two-thirds of our planet is surrounded by water and the rest is land, all over the world, people's access to clean water is shrinking and dwindling day by day. In recent decades, freshwater shortages have become increasingly serious due to increasing world population, excessive waste, and increasing contamination of natural water sources. Remote and arid regions in developing and under developed countries are facing serious demand of fresh water for drinking. In addition to food and energy, potable water is an essential thing to sustain all living beings on our earth. Due to increased rate of consumption of potable water and rapid industrialization, most part of the world is facing an increasing demand of fresh water. Desalination of saline or brackish water is identified as an effective solution to overcome the demand of fresh water. Water salinity below 500 ppm has been considered as potable as per the report of the World Health Organization (WHO). But in most part of our planet, the salinity of available water is observed to be greater than 10,000 ppm [1]. A simple as...
As well as cost-effective device used to convert saline or brackish water into fresh water using the energy received from the sun is known as solar still. This economic and portable solar distillation system can be classified into two types; passive solar still and active solar still. Passive stills utilize only the energy received from the sun for its operation but active stills are supplied with additional energy from external sources to improve the output of the system. Proven desalination techniques such as multistage flash distillation (MSF), membrane distillation (RO), and electro dialysis (ED) are being used in developed countries to handle their demand of fresh water [2]. The major disadvantage in employing these techniques is the use of fossil fuel which increases global warming and poses other environmental threats. Hence, the use of solar stills which utilizes renewable energy to produce fresh water would be an ideal solution to meet out the needs of potable water in developing countries like India.

Many previous researches have been carried out to improvise the productivity, mainly from the following aspects: improving the structure, using auxiliary equipment, or using special materials. Ansari et al. [3] have performed an theoretical investigation on enhancement of a passive type solar still coupled with PCM as a thermal storage. They concluded that using a PCM material relies ultimately on the peak temperature of saline water. Kumar and Bharathi studied the effect of basin water depth over the distillate output of the still by doing an experimental modification on solar still with black gravel powder as energy storage medium and observed an increase of 9% in the efficiency of the modified still [4].

Kumar et al. has reviewed the various types of PCM and concluded that, using Lauric acid as a PCM material can increase the overall productivity by 13% and paraffin wax with aluminium powder can increase the productivity by 25% [5]. El-Sebaii et al. experimentally investigated single basin solar still with a thin layer of stearic acid as a PCM to store energy. The addition of energy storage material has produced an increased output of 9.005 lit/day against the output of conventional still which yielded 4.998 lit/day [6].

The major portion of the incoming solar radiation is absorbed by basin liner which requires tremendously high absorptance for the solar radiation [7]. Metals sheets of copper, aluminium, iron and steel are commonly used to fabricate the basin of a solar still. Every solar engineering application has thermal conductivity as its key property of the metals [8]. Copper and aluminium have a very high amount of thermal conductivity which is comparatively higher than the galvanized iron and hence used for most of the solar applications. Many researchers have investigated solar stills with fins of different configurations over the basin liner to increase the productivity of still by increasing the absorbance of solar radiation [9-11].

In the present work, an attempt has been made to improvise the efficiency and productivity of the solar still embedded with tubular fins and thermal energy storage materials (PCM). Additionally, performance comparison for both galvanized iron and aluminium material was experimentally investigated in different test cases and also the modified still was compared with the conventional still. All the trials were conducted at the same climatic conditions.

2. Materials and Methods

2.1 Materials

Two similar solar still; conventional and modified solar stills were designed and fabricated with identical dimensions. Two basins of same dimensions were made up of galvanized iron sheet and the other with aluminium sheet of thickness 18 gauge each and with an area of 0.5 m². The basin of modified stills were integrated with square tubular fins of dimensions 25.4mm x 25.4mm x 50 mm and these dimensions were chosen in such a way to avoid the shadow of the fins falling in the basin [12]. There are 32 fins attached to the basin. Tempered glass cover of thickness 5mm was used as the condensing surface and the inclined angle of the glazing has been fixed as 12° which was equal to the
latitude of the experimental location (11.0168°N). Lowering the glazing angle would increase the chances of dribbling condensate to fall back into the solar still basin [13]. Toughened glass has been used for its high transmissivity and it can withstand the effects of wind, sunlight, rain etc. The outer box is made up of mild steel of dimension 1050 mm x 550 mm. Thermocol of thickness 2 cm was used as an insulating material which is packed between the basin surface and outer enclosure. Each still was incorporated with paraffin wax as thermal energy storage; it emits the stored heat energy to basin water during off-sunshine hours and increases night productivity [14]. K-type thermocouples were used to measure the ambient temperature, temperatures of the water, the inner and the outer glass surface and the ambient temperature which was placed in different location the of the still.

2.2 Working
The solar still was placed facing south to receive the maximum solar radiation. The brackish water was loaded to the required level into the solar still basin during the trial days before the start of the experimentation. The entire still was enclosed in a completely airtight surface. The basin liner coated with black has absorbed the incident solar thermal radiation which in turn was converted into heat due to its opaque nature. The heat generated in the basin has evaporated the brackish water and lifted the pure water molecules, leaving the dirty parts in the basin. The evaporated water vapour molecules have been turned into water droplets by condensation process after hitting the glazing inner surface. Then, the water droplets start to fall on the bottom surface of the glass due to the effect of gravity and get collected in the outlet.

![Figure 1. Photograph of the experimental set-up](image)

In this present work, experiments were conducted for water depth of 2cm to the solar still made up of galvanized iron. A modification is made in the still by adding a number of fins and hence the effective absorber area has been increased in turn increasing the heat content of the basin due to increased amount of absorbed solar radiation. To improve overnight productivity, the galvanized iron basin was coupled with thermal energy storage. The trials performed on modified stills with galvanized iron basin have been repeated on modified still with the aluminium basin. The readings are taken from 9.00 hours to 18.00 hours and the overnight productivity has been noted before starting the next day trail. The measurements were taken hourly to study the effect of temperature, solar radiation intensity, and productivity of the still.
The instantaneous efficiency of the solar still has been determined with the aid of the following correlations [15],

$$\eta_{i} = \frac{q_{ew}}{I_{e}} = \frac{h_{ew}(T_{w} - T_{g})}{I_{e}}$$

(1)

$$h_{ew}(W m^{-2}) = 16.273 \times 10^{-3} \times h_{ew} \left[ \frac{p_{w} - p_{g}}{T_{w} - T_{g}} \right]$$

(2)

Where,

$I_{e}$ is the intensity of hourly solar isolation, $W m^{-2}$,

$h_{ew}$ is the evaporative heat transfer coefficient, $W m^{-2} K^{-1}$,

$p_{w}$ is the partial saturation pressure corresponding to basin water temperature, $N m^{-2}$,

$p_{g}$ is the partial saturation pressure corresponding to glazing inner surface temperature, $N m^{-2}$

3. Results and Discussion

3.1 Comparison of Productivity

The variation of the productivity and efficiency of conventional and modified solar stills made up of galvanized iron and aluminium basins incorporated with fins and energy storage has been discussed using various plots as shown below.

![Figure 2. Comparison of productivity of CSS and SSWPF for galvanized iron and Aluminium basin solar stills](image)

Figure 2 compares the productivity of CSS and SSWPF with galvanized iron basin and aluminium basins. It was observed that the use of aluminium basin has revealed an appreciable increase in the productivity of the still right from the start of the experimentation. Use of fins has shown superior productivity due to increased absorption area and increase in total heat content of the basin. Compared
to finned galvanized iron basin, aluminium basin with fins has exhibited increased productivity till 14.00 h and also delivered maximum distillate output compared to all other cases. The aluminium basin still has increased productivity of 33% compared to galvanized iron solar still due to its superior thermal conductivity.

![Figure 3](image1)

**Figure 3.** Hourly variation in productivity of CSS and SSWPF+TES for galvanized iron and aluminium basin solar stills

Figure 3 differentiate the variation of productivity of both conventional solar still and modified solar still incorporated with thermal energy storage for both galvanized iron and aluminium basin solar stills with respect to time. The incorporation of energy storage in both galvanized iron basin and aluminium basin has increased the productivity of the still appreciably. The raise in productivity in aluminium basin has started to increase steeply even during the early part of the day since the heat received from the incident solar radiation has been effectively conducted by the aluminium basin due to its high thermal conductivity to the water stored in the basin. As a result, the productivity of solar still with aluminium basin and energy storage has increased by 36% compared to the conventional still.

3.2 Comparison of Instantaneous efficiency

![Figure 4](image2)

**Figure 4.** Hourly variation of instantaneous efficiency of CSS and SSWPF with galvanised iron basin
Figure 5. Hourly variation of instantaneous efficiency of CSS and SSWPF with aluminium basin

Figure 4 and 5 compares the hourly variation of instantaneous efficiency of galvanized iron basin and aluminium basin solar stills. In both the cases, the efficiency for conventional and modified stills is almost equal at the start of the day. Between 11.00 h and 13.00 h, the modified stills displayed higher efficiency compared to the conventional stills and after 14.00 h, the efficiency of modified stills with TES started to increase steadily. This is due to the constant distillate output even during the decline in the solar radiation input. The reduction in the direct input from the solar radiation is compensated by the energy received from the thermal energy storage medium.

Figure 6. Hourly variation of instantaneous efficiency of SSWPF+TES with galvanised iron and aluminium basins

Figure 6 compares the hour-to-hour variation of instantaneous efficiency for the solar stills integrated with fins and energy storage of galvanised iron and aluminium basins. The variation in the efficiency of the solar still with galvanized iron was constant and it was gradually increasing. Though the instantaneous efficiency is on higher side for the aluminium basin still, during the major part of the day, the fluctuation in efficiency was more due to its rapid response to the variation in the input solar
radiation since the thermal conductivity of aluminium is more than twice the thermal conductivity of galvanized iron.

3.3 Comparison of Cumulative distillate output

![Figure 7. Comparison of cumulative yield of CSS and Modified solar stills](image)

Figure 7 compares the cumulative yield of the conventional and modified solar stills with both galvanized iron and aluminium basins. For both the materials, the cumulative output of solar still integrated with fins and solar still with both fins and TES delivered more yield in increasing order respectively. But, compared to solar still made of GI basin with fins and TES; solar still made of aluminium with fins only produced more distillate output. Compared to all other cases, solar still made of aluminium basin with TES has superior productivity.

4. Conclusion

The present work has studied the performance enhancement on solar still with tubular fins and energy storage with both galvanized iron basin and aluminium basin, the vital findings are furnished below,

a. The cumulative yield of the solar still with aluminium basin embedded with fins is 12% compared to the solar still with galvanized iron basin embedded with fins.

b. The productivity of the solar still with aluminium basin, aluminium basin with fins and aluminium basin with both fins and TES has increased by 18%, 33% and 36% respectively when compared to solar still with galvanized iron basin.

c. Addition of energy storage unit to the still has improved the nocturnal productivity by 13%.

d. The overall efficiency of the solar still with aluminium basin is higher than the solar still with galvanized iron basin.

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