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An Experimental Study of a Simple Solar Still using a Suspended Non-Metallic Perforated and Non-Perforated Absorber Plates

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Abstract—*Experiments to study the effect of perforated and non-perforated absorber plates on the performance of a simple solar still have been carried out. Two identical simple solar stills having basin size of 1.0m x 0.7m were constructed. Absorber plates of three different non-metallic materials, i.e. wooden-mica, acrylic, and fibre-glass (fibre-reinforced plastic), all having low thermal conductivity, were used for the experimentation. Non-metallic absorber plates were selected as they are free from the problem of corrosion observed in the metallic absorber plates. First, the performance of the solar still was studied for each absorber plate without perforations. Subsequently, perforations were made in acrylic and fibre-glass absorber plates and the effect of perforated absorber plates on the performance of the solar still was studied.The wooden-micaabsorber plate couldn't be used with perforations as it couldn't withstand the impact of water and soon was bent and swelled after it was wetted by water.*

The experimental results show that the productivity of solar still strongly depends on the amount of water present in the solar still. The highest productivity of 3160 ml/d was obtained for acrylic absorber plate without any perforation which was 22.96 % higher than the solar still without any absorber plate (2570 ml/d). It was observed that the use of absorber plate without perforation increases the total output by 22-26 % whereas, after perforation, productivity increased only by 6-14 %. The problem of swelling and bending was observed in wooden-mica absorber plate, which makes it unfit for the use.

Keywords: *Solar Still, Solar Distillation, Non-Metallic Absorber Plate.*

Introduction

Water plays an important role in the economic development and well-being of a nation. However, in India, with ever-rising population and improvement in the level of our life, we are losing precious and limited fresh-water resources very quickly. The solution to this ever-worsening problem of fresh-water is to use the available resources of fresh-water judiciously and develop eco-friendly techniques to convert unusable water into potable water. A number of desalination techniques have been developed to convert unusable water into potable water. However, most of the desalination techniques are energy-intensive. The use of solar desalination is an important eco-friendly alternative to attain the objective of economic development. In solar desalination, both renewable energy and desalination methods are coupled to provide a viable method to fulfil the need of the freshwater.

A number ofsolar still plants and individual stills have been built around the world for quite some time [1].Many innovative methods have been used to improve the efficiency of the stills on one hand and on the other hand, many experiments have been done to fine-tune the design and operational parameters to enhance the efficiency of solar stills.

Tiwari and Tiwari [2] suggested that the highest output and efficiency are obtainedat lower depths of water in solar still basin.

Omara et al. [3] experimented with two modifications in solar stills, one having iron fins and the other one having corrugated shaped basin instead of a flat basin. The results showed that distillate outputs for finned and corrugated solar stillwere 40% and 21% higher than that of conventional still for 30 L quantity of water.

Omara et al. [4]used a double-layer wick and internal reflectors together to improve the performance of corrugated solar still. For 1 cmof water depth, the productivity of the modified corrugated solar still with wick and corrugated solar still with wick& internal reflectors, was found to be 90% and 145.5% higher than the conventional solar still, respectively.

Panchal and Patel [5] experimented with different energy storage materials (black ink, black rubber matt, and black dyes) and concluded that use of black dye as energy storage material give significantly higher productivity than other two materials. Further black naphthylamine was found better than dark green dye and red carmoisine dye.

Srivastava and Agrawal [6]analyzed the effect of thermal conductivity of floating insulation on distillate output by using porous absorbers having low thermal inertia made of blackened jute cloth. The results show that higher output was achieved for floating insulation with lower thermal conductivity. The distillate output was very less dependent on the quantity of water for experiments with floating insulation.

El-Sebaii[7] compared the performance of a single-slope solar still with and without a floating absorber. Metallic and non-metallic floating absorbers made up of mica, stainless steel, aluminium, and copper were used. It was found that for all the investigated quantities of the mass of water above the floating absorber; the productivity of solar distiller with a floating absorber was found to be higher than that of the single basin solar distiller. He observed that floating absorber plate having the lowest value of thermal conductivity, i.e. a non-metallic material, mica gave the best performance.

Shalaby et al.[8]studied a new design of corrugated solar still in which a net of tubes containing paraffin wax as phase change material (PCM) was installed under the corrugated base to enhance the heat storage capacity of the basin. The experimental results show that the use of PCM beneath the corrugated plate reduces the daylight output while there was a considerable increment in the overnight distillate output. The total daily distillate output increased by 12% after installation of PCM in the corrugated solar still.

Working of a solar still

In solar distillation processes, solar energy enters the solar still through a clear glazing surface such as a transparent glass or a plastic sheet. A part of the radiations falling on the solar still is reflected back by the cover, another part of the radiations falling on the cover is absorbed by the cover itself and the remaining part of the solar radiations enters the still. The radiations entering the still are absorbed either by water, sidewalls or blackened bottom surface of the still.A part of the thermal energy entering the basin of the still is also lost to the atmosphere through the sidewalls and the bottom of the still through conduction. The part of thermal radiations absorbed by the basin water leads to a rise in temperature of the basin water and the basin water starts evaporating. Warm vapours of water rise-up leaving all the impurities behind in the basin. These vapours condense on the underside of the cover. The condensed water vapours formwater droplets which remain attached to the cover plate due to surface tension and slidedown because of gravity to atrough located at the lower end of the cover plate. Water from the trough flows into a storage tank. The water thus collected is as pure as distilled water. The heat of condensation released by water vapoursis lostto the atmosphere through the glass cover.

Experimental setup

Two simple solar stills (conventional stills) were used simultaneously for a comparative study of the solar stillswith and without non-metallic absorber plates. The basin area of both the solar stills was 0.7 m^2 (1 m length x 0.7 m width). Two sidewalls of the still formed a trapezium with larger vertical side of 510 mm and the smaller vertical side of 150 mm. Solar still frame wasmade up of double walls of the galvanized iron sheet (22 gauge, i.e. 1.311 mm). Thermocol sheet (thickness = 25.4 mm, and thermal conductivity = 0.0314 W/m K) was sandwiched between the two sheets of the double-walledside and bottom walls to reduce heat loss to the ambient. The top of the solar still was covered by an ordinary plane and transparent glass of 5 mm thickness (0.94 m × 1.04 m). It rested on the sidewalls of the solar still at an inclination of 26º (latitude of Jaipur). The orientation of the solar still was fixed such that its smallest sidewall was facing southso as capture maximum solar radiation. In order to increase the absorptivity, the inner surfaces of the solar still and upper side of absorber plates were painted black using synthetic black paint. Bio-foam sheet was used between the glass cover and the frame in order to prevent leakage of water vapour from the solar still. The absorber plate was placed at a height of 10 mm from the bottom. Wooden-mica plate, fibreglass plate, and acrylic plate were used as non-metallic absorber plates to augment the performance of the solar still. For the experiments with perforated absorber plates, the holes having a diameter of 2 mm and 3.5 mm were drilled at a pitch of 1 inch in both the directions. Experimentswere performed simultaneously on the two solar stills, one having non-metallic absorber plate and the other without any absorber plate.Some relevant properties of the absorber plates are shown below in table 1.

Table 1: Properties of various non-metallic plates

Property	Absorber plate material		
	Wooden-mica	Fibreglass	Acrylic
d (mm)	2	3	3
ρ (kg/m^3)	2883	2600	1190
k (W/m-K)	0.7	0.04	0.2
C_p (J/kg-K)	880	700	1470

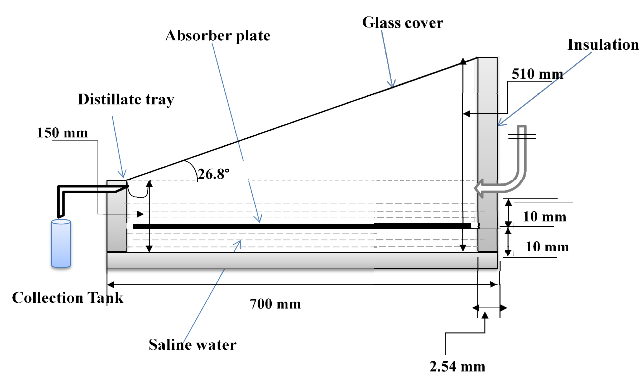

Figure 1. Schematic diagram of solar still with suspended absorber plate.

Observations

The experimental work was carried out simultaneously on two solar stills – the first solar still having non-metallic absorber plate and the second solar still without any absorber plate. The experiments were first done with the non-perforated absorber plates and thereafter with the perforated absorber plates.

The temperatures at various points, such as the inner and outer surface of the glass, vapour, basin water, water above absorber plate, water below the absorber plate and the inside bottom surface of the still, were measured with the help of twelve J-type thermocouples which were connected to a data logger. The solar intensity and hourly measured ambient temperature data were taken from MNIT weather station. Before the experiment, the measured quantity of 15 L of water was poured into the basin and the glass cover of the solar still was cleaned. Distilled water output was measured with 1-litre measuring flask. Hourly distillate output was measured during the daytime from 9 a.m. to 7 p.m. and night output was measured on the next day at 8 a.m. using a calibrated flask.

Results & discussion

Results obtained for solar still without any absorber plate, with non-metallic absorber plates without perforations and non-metallic perforated absorber plates were compared on the basis of temperature rise and productivity.

It was observed that the bottom temperature of the solar still without any absorber plate was high from 8 AM to 2 PM as compared to that of the solar still with non-metallic absorber plate. The reason for this enhancement can be attributed to the fact that the non-metallic sheet does not allow heat to pass through it to the bottom. It was also observed that the bottom temperature of the solar still with non-metallic absorber plate was high as compared to the solar still without any absorber plate after 2 PM. The reason for this increase can be attributed to the fact that non-metallic plate works as a thermal resistor and does allow the water below it to cool; as a result temperature below the non-metallic absorber plate remains high for a long time during the night (or after the sunset).

It was also observed that the temperature of the water above the absorber plate in the solar still with an absorber plate was higher than that of the solar still without any absorber plate for all the time. This happened because the absorber plate provides maximum solar energy to the water above itself by restricting the irradiation to go to the water below it. The higher water temperature leads to a high rate of evaporation which results in higher distillate output.

Figure 2 shows the sunshine productivity, nocturnal productivity, and the total distillate productivity for the solar still with non-perforated wooden-mica plate and the solar still without any absorber plate. It was observed that sunshine productivity increased significantly by using a wooden-mica absorber plate. This happens because thermally insulating nature of wooden-mica plate resists the irradiation to reach to the bottom and the maximum amount of heat was utilised by the lesser quantity of water above the absorber plate which leads to a higher rate of evaporation. Perforation in wooden-mica plate was quite difficult due to its brittle nature. Wooden-mica plate also started bending and swelling due to regular contact with water. Therefore, no experimentation was done with perforated wooden-mica absorber plate.

Figure 3 shows the productivity for the solar still with non-perforated fiberglass plate and the productivity of the solar still without the absorber plate. It was found that daytime output increased by 26.89%, overnight output increased by 13.79% and overall distillate output increased by 25.31% when non-perforated fiberglass plate was used as an absorber plate.

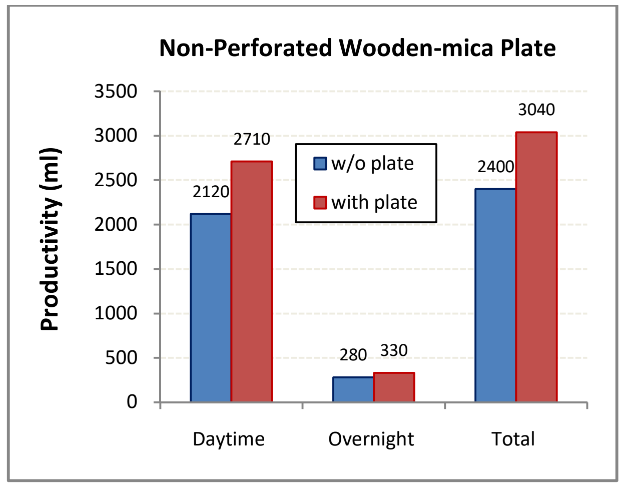

Figure 2.Productivity of solar still with non-perforated wooden-mica absorber plate and without absorber plate.

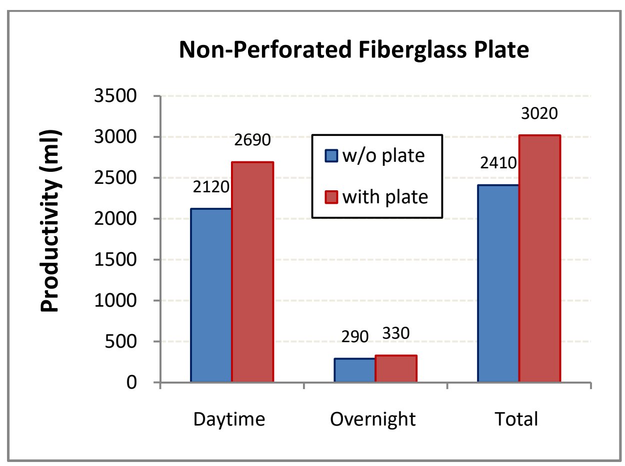

Figure 3. Productivity of solar still with non-perforated fibreglass absorber plate and without absorber plate.

Figure 4 shows the productivity for the solar still with a non-perforated acrylic plate and the productivity of the solar still without an absorber plate. The daytime output increased by 23.68%, overnight output increased by 17.24% and overall distillate output increased by 22.96% for non-perforated acrylic absorber plate as compared to that of the solar still without any absorber plate.

Figure 5 shows the productivity of the solar still with a perforated acrylic plate (perforations ϕ=3.5mm)and the productivity of the solar still without an absorber plate.

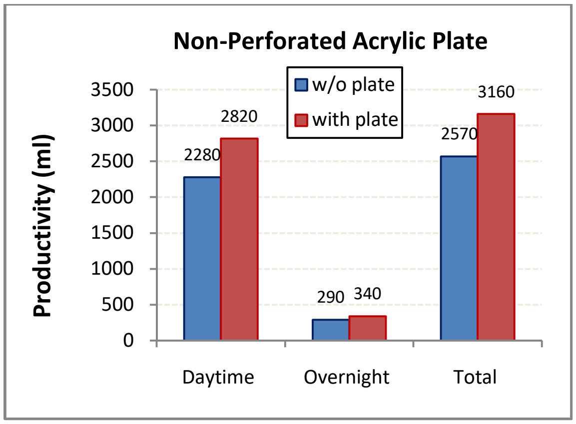

Figure 4: Productivity of solar still with non-perforated acrylic absorber plate and without absorber plate.

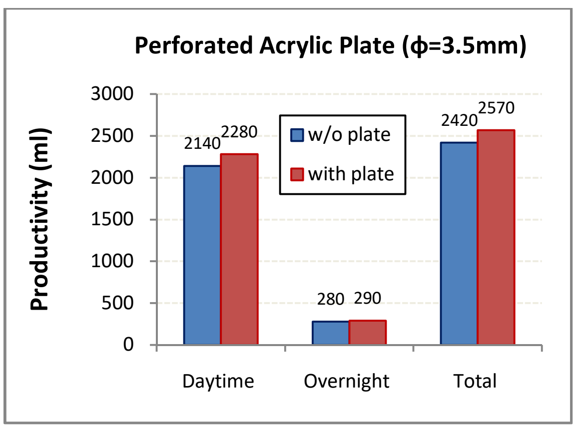

Figure 5: Productivity of solar still with perforated acrylic absorber plate (ϕ=3.5mm) and without absorber plate.

After perforations, the temperature gap between both water layers decreased due to the mixing of the two layers of water which leads to lesser evaporation. Subsequently, the increment in productivity also gets reduced after perforation and total productivity increased only by 6.20%.

It can be concluded from figure 6 and figure 7 that, for experiments with perforated fibreglass absorber plate, overall distillate output was still higher by 12-14% than that of the solar still without absorber plate but this was lesser as compared to that of the solar still with non-perforated fibreglass absorber plate (25.31%). It was also found that the effect of the size of the holes was not predominant. With an increase in the diameter of holes from 2 mm to 3.5 mm, the total output reduced slightly from 13.98% to 12.20%.

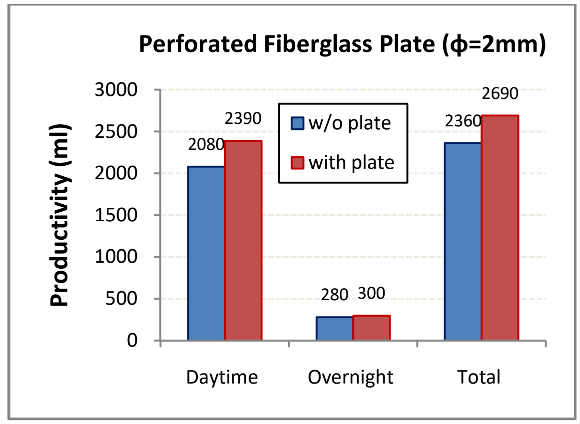

Figure 6: Productivity of solar still with perforated fibreglass absorber plate (ϕ=2mm) and without absorber plate.

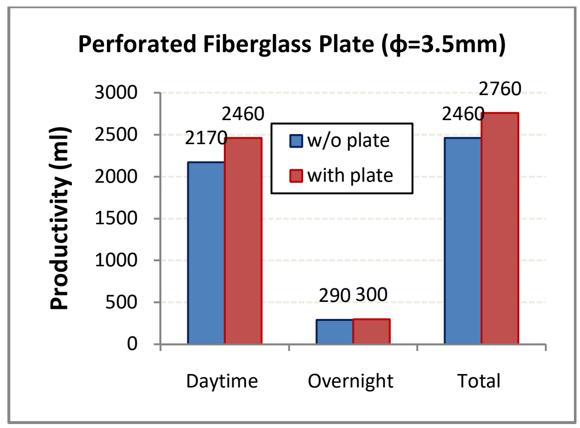

Figure 7: Productivity of solar still with perforated fibreglass absorber plate (ϕ=3.5mm) and without absorber plate.

Conclusions

The experiments were carried out for simple solar still without any absorber plate, with non-metallic perforated suspended absorber plates and with non-perforated suspended absorber plates. Comparison for non-perforated absorber plates with perforated absorber plates was also carried out on the basis of temperature rise and productivity. Following conclusions can be made from the study:

1) The temperature of the bottom surface of the still was found to be lower when non-metallic absorber plate without perforation was used. This leads to lower heat losses through the bottom and higher distillate output.

2) The temperature of water above the absorber plate was significantly higher than the temperature of the basin water in the solar still without the absorber plate. High temperature leads to a higher rate of evaporation and higher distillate output

3) Due to regular contactwith water for a long time, wooden-mica absorber plate started swelling and bending. Thus

wooden-mica absorber plate was found unsuitable for this application.

4) Absorber plates without perforation give better performance as compared to the perforated absorber plates because perforation reduces the temperature difference between the upper and the lower water. The use of the absorber plate without any perforation increases the total output by 22-26 % whereas, after perforation, productivity increased only by 6-14 %.

5) Highest productivity of 3160 ml was obtained by using acrylic absorber plate without perforation which was 22.96 % higher than solar still without absorber plate (2570 ml).

The results were also compared with the results of the experiments done at MNIT with metallic absorber plate [9].

6) The use of non-metallic absorber plates overcome the problem of corrosion which was observed in metallic absorber plates.

7) Temperature gap created between water above and below the absorber plate is higher for non-metallic (low thermal conductivity) absorber plate as compared to metallic (high thermal conductivity) absorber plate.

8) Maximum temperature of water above the plate was higher in the case of non-metallic plates by 14 °Cas compared to that for metallic plates by 10 °C.

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