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Experimental Investigation of the Combined Effect of Fin, Phase Change Material and External Condenser on the Yield of Solar Still

S. S. Tuly[#1], M. R. I. Sarker[#2], Suman Saha[*3]

[#1]*Assistant Professor, Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi – 6204, Bangladesh*

[#2]*Professor, Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi – 6204, Bangladesh*

[*3]*Instructor (Power), Rajshahi Polytechnic Institute Sopura, Rajshahi – 6203, Bangladesh*

Abstract

The present work focuses on improving the still solar productivity by integrating fin, phase change material (PCM), and an external condenser. Two double slope solar stills (modified and finned solar stills) have been designed and constructed, and their thermal performances have been analyzed. Modified solar still consists of solid rectangular fins, paraffin wax as latent heat storage material, and an external condenser with an extra condensation surface of 1824.15 cm^2. Paraffin wax stores heat energy and continue the distillation process during the off-sunshine period. Each absorber plate (2 in number) used in the modified solar still contains thee fins, whereas finned solar still consists of six fins attached to the basin plate. Fins provide greater surface area and facilitate the evaporation rate, thus provides higher productivity. Experimental results revealed that the accumulated freshwater yields for the modified and finned solar stills are 2100 ml/m^2 and 1620 ml/m^{2,} respectively, for the experimental day. The modified solar still produces 22.8 % higher accumulated distillate output throughout the day than finned solar.

Keywords — *Double slope solar still, fin, Phase change material, external condenser, accumulated distillate*

I. INTRODUCTION

The scarcity of pure drinking water is a significant problem nowadays in developing countries and mainly in the coastal areas where salinity is a major concern. The supply of freshwater is becoming an increasingly significant issue in many areas of the world [1]. To solve the challenge of freshwater demand, saline or impure water is converted into potable drinking water by applying various techniques. Reverse osmosis (RO), multi-effect distillation (MED), multistage flash distillation (MSFD), freezing, vapor compression distillation (VC), electro-dialysis, and humidification-dehumidification are the available water purification processes. All these techniques consume a large amount of energy to provide pure drinking water. In this regard, solar desalination is an effective method to convert saline water into freshwater using renewable energy sources. The apparatus used in the solar distillation process called solar still is a very simple and economical device for producing potable water from brackish water, using solar thermal energy, which is freely and profusely available on our planet [2]. A simple solar still can provide freshwater in the range of 2–5 l/m^2/day only [3].

Researchers around the world have conducted numerous experiments to augment the productivity of solar still. Various design and climatic parameters affect the productivity of solar stills, such as glass cover inclination [4], depth of water [5], the temperature difference between water and glass cover surface [6], solar intensity [7], and wind velocity [8]. Energy storing material, phase change material, fin, nanofluid, reflector, condenser, solar collector, and vacuum technology is also integrated with solar to enhance the freshwater yield.

The distillate output of a solar still improves with the increase of the free surface area of water. The use of fin, sponge, wick material, jute cloth in the still basin provides a larger surface area for water evaporation. Alaian et al. [9] used pin finned wick in the design of solar still, and the productivity increased by more than 23%. Velmurugan et al. [1] experimented with purifying industrial wastewater using five solid rectangular fins, black rubber, pebbles, sponges, and sand in single basin solar still and obtained enhanced productivity of 75%. Square and circular hollow fins were integrated into a single basin double slope solar still. The productivity was 54.22%, 38.49%, and 43.86% higher for circular fins than square fins at basin water depths of 10 mm, 20 mm, and 30 mm, respectively [10]. Experiments were also performed using porous and robust solid fins [11], strip fins [12, 13] to improve productivity.

The performance of a solar still can be improved using thermal storage materials. Latent heat storage materials such as phase change materials (PCM) are incorporated in the solar desalination process to continue the distillation process during the

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off-sunshine period. Paraffin wax as PCM was used by Arunkumar et al. [14] in concentrator-coupled hemispherical basin solar still, and the distillate output was enhanced by 26%. The solar efficiency still with and without PCM was 27% and 25.19%, respectively, when Bitumen was used as phase change material [15]. Stearic acid was used in single basin solar still to improve productivity [16]. The distillate output from the still was 9 kg/m^2/day and 5 kg/m^2/day for the PCM and without PCM, respectively. Another productivity improvement technique for solar still is to integrate external or internal condenser. Solar still with condenser is a very efficient and effective design and provides a faster evaporation rate of water [27]. Khalifa et al. conducted an experiment using an internal passive condenser in a conventional solar still, which was 58% efficient. External passive condensers [18-20], built-in passive condensers [21-24] have also been employed in many experiments to augment solar performance still.

The present work's objective is to enhance the solar's freshwater productivity still with the integration of fin, phase change material as a thermal energy storage medium, and an external condenser (modified solar still). The combined effect of these three modifications is also investigated, and a comparative analysis of the modified and finned solar performances still is performed.

II. EXPERIMENTAL WORK

A. Design and Construction of Solar Still

In this experiment, two double slope solar stills (Modified and finned solar still) are designed and fabricated to investigate the effect of a fin, phase change material (PCM) as a thermal energy storage medium, and external condenser on the yield of solar still. The modified solar still consists of a solid rectangular fin, paraffin wax as PCM below the absorber plate, and an external condenser placed at the top of the solar still. The schematic diagram of the modified solar still is shown in Fig.1. The areas of the modified and finned solar stills are 1.6 m^2 and 1.3 m^2, whereas the heights of the front and back walls are 0.41 m and 0.13 m, respectively. The modified solar still consists of two absorber plates with an effective area of 0.5 m^2. Finned solar still contains one absorber plate with a 1m^2 area. The still solar bodies and the absorber plates are made of 6 mm thick galvanized iron sheets. Absorber plates are blackened to absorb maximum solar radiation. The bottom and sidewalls of the solar stills are insulated using a 1.5 cm thick cork sheet to prevent heat energy dissipation from the stills to the atmosphere. A commercial glass of thickness 3.5 mm is used as a solar still cover, which is inclined at 25^o with the horizontal. Glass cover and solar still edges are sealed together using M-seal to prevent any leakage of vapor maintain an airtight environment. To supply water in the still basin, the feed water tank is positioned 1 m above the still.

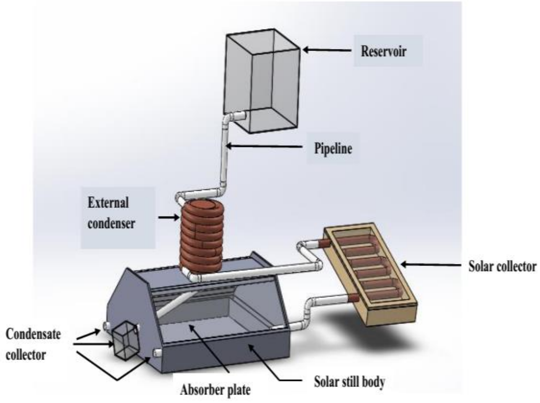

Fig 1: Schematic Diagram of Modified Solar Still

In finned solar, direct feed water is still used; however, in the modified solar still feed water after two-stage preheating in the flat plate solar collector and an external condenser is supplied to the solar still basin, the condensation process faster. Fig.2. Shows a photograph of the experimental setup. Two PCM storage tanks of 3 cm height are fabricated and placed beneath the absorber plates and welded. A total of 15 kg of paraffin wax is used as PCM to fill the absorber plates. Paraffin wax is selected as PCM depending on the operating conditions' features and due to its low cost, high latent heat of fusion, uniform melting, nontoxicity, reliability, and safety. The thermophysical properties of paraffin wax are presented in Table 1.

Each absorber plate used in the modified solar still consists of three solid rectangular fins with 88.9 cm, 3 cm, and 0.4 cm in length, height, and thickness. Fins are also made of galvanized iron sheets, and the pitch between two consecutive fins is 18 cm. The finned solar still contains six solid rectangular fins of the identical dimension of modified solar. Fins are used to enhance the free surface area and also the heat transfer rate.

Table 1: Thermophysical Properties of PCM (Paraffin Wax) [25]

Property	Value
Melting temperature	56 – 58 °C
Density of liquid/solid	760/818 kg/m^3
Specific heat of liquid/solid	2510/2950 J/kg °C
Latent heat of fusion	226000 J/kg
Thermal conductivity of liquid/solid	0.24/0.24 W/m °C

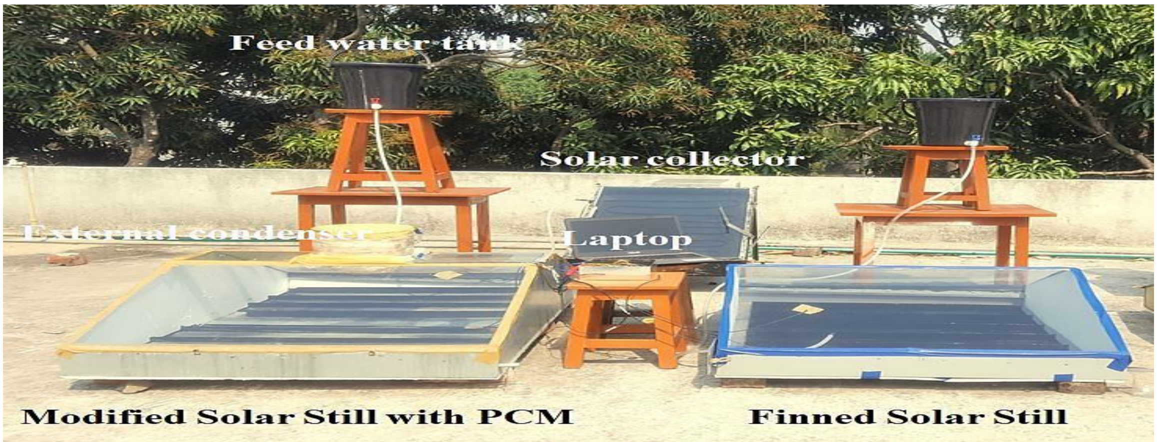

Fig 2: Photograph of the Experimental Setup

An external condenser with dimensions of 25.4 cm diameter and 22.86 cm height is placed at the top of the modified solar still and works as a heat exchanger. The condenser is made by a copper tube of 0.64 cm in diameter, wounded at a shape of a compressed coil of 25.4 cm. The external condenser's outer surface is insulated with cotton, and the bottom portion is insulated with a cork sheet to prevent heat loss. This external condenser provides an extra condensation surface of 1824.15 cm^2.

B. Measurements

Hourly solar radiation was measured using a pyranometer with a measurement range from 0 to 1280 W/m^2 over a spectral range of 300 to 1100 nm. DS18B20 temperature sensors were used to measure the temperatures at different solar portions, such as basin, basin water, inner glass cover, PCM, and ambient temperature. Outer glass cover surface temperature and condenser inner surface temperatures were measured using a digital infrared thermometer. Mercury thermometer was used to determine the temperature of preheated water at the solar collector outlet. In both solar stills, the depth of water was kept constant at 3 cm throughout the experiment. Readings were taken after every 1hour interval, and the amount of freshwater yield was also measured using a calibrated flask. All the temperature sensors were connected to a data logger. A record of all the measured values was maintained every hour from 10 am to 7 pm. All the experiments were conducted in the outdoor condition at Rajshahi University of Engineering & Technology (RUET), Bangladesh (Longitude/Latitude: 88.6241° E / 24.3636° N).

III. RESULTS AND DISCUSSIONS

A. Effect of Solar Radiation Intensity on the Performance of Solar Still

The productivity of a solar still majorly depends on the solar radiation intensity absorbed by

e efficiency and productivity of the solar still improve with the increase in solar intensity [26]. Fig.3. Shows the basin's hourly temperature variations, basin water, inner and outer glass cover surfaces, PCM, and ambient temperature for the solar still with fin, PCM, and external condenser. The fluctuation of solar radiation intensity with time is also presented in the same figure. It is observed that all the temperature values follow an upward trend as the time increases and reaches the maximum value at 1 pm. The intensity of solar radiation is also maximum by this time and then gradually decreases. The maximum temperatures for a basin, basin water, inner glass cover, outer glass cover, and PCM are 66.5° C, 63.75° C, 59.75° C, 59.6° C, and 60.75° C, respectively. The highest value of ambient temperature is 48° C, and the peak solar radiation is 866 W/m^2. At the starting of the experiment, PCM takes heat from the absorber plate, and its temperature gradually enhances with time. After completing the melting process of PCM, its temperature starts to decrease, and by this time, solidification of PCM occurs. PCM provides its stored heat to basin water and keeps the water warm during the off-sunshine period, and the distillation process continues.

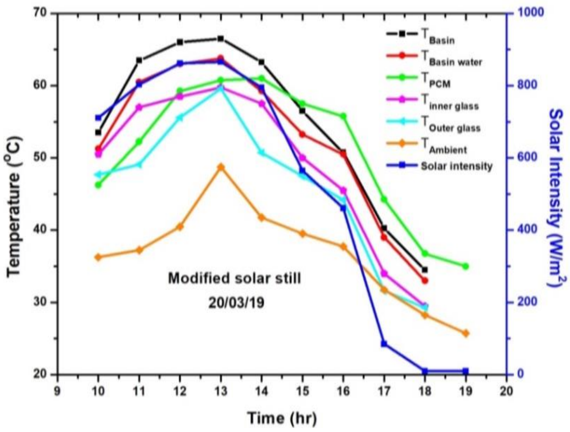

Fig 3: Hourly Solar Radiation and Temperature Variations for the Solar Still with Fin, PCM and External Condenser (Modified Solar Still)

Fig.4. Represents the similar former parameters of Fig.3. But for finned solar still. Fig.4. Means that, for the solar still with fin, the maximum basin water temperature is 62° C, while the inner and outer glass temperature ranges from 29.5° – 62.5° C and 27.2° – 58.9 ° C respectively. All the parameters gradually decrease with the decrease in solar radiation intensity. For finned solar still, freshwater is productivity is related to the presence of solar intensity. On the other hand, in modified solar still, the presence of PCM helps to continue the distillation process even though no sunshine is present and, as a result, provides a higher distillate output compared to finned solar still.

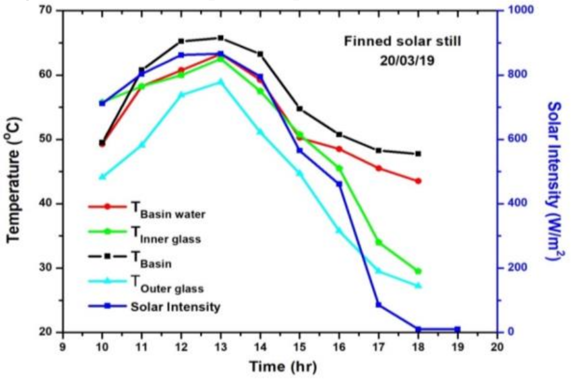

Fig 4: Hourly Solar Radiation and Temperature Variations for Finned Solar Still

B. Fresh Water Productivity

a). Effect of Fin, PCM and External Condenser on the Hourly Distillate Output of Solar Stills

Fig.5. Represents the hourly freshwater yield for both the modified and finned solar still. It is seen from the figure that the rate of hourly distillate output for modified solar still is higher than the finned solar. During the early period of the experiment, the freshwater productivity is nearly similar for both stills. However, as time progresses, modified solar productivity still increases due to the combined effect of a fin, PCM, and external condenser.

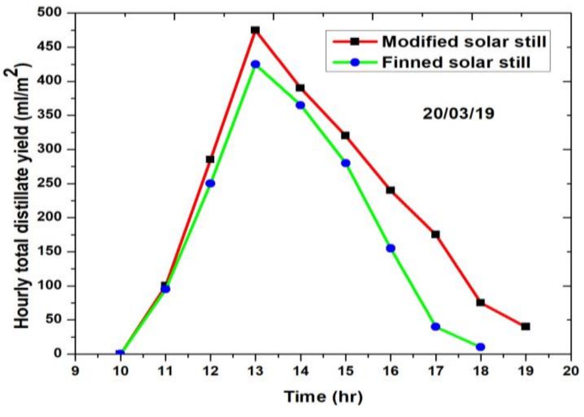

Fig 5: Hourly Fresh Water Productivity for Modified and Finned Solar Stills

The integration of fins enhances the free surface area of water and thus increases productivity. External condenser enhances the distillate output by providing an extra condensation surface. Also, it picks up the latent heat of condensation of vapor condensed on its surface and preheats the water. It is also observed from the figure that the distillation process stops for finned solar still after 6 pm; however, modified solar still fresh water production continues due to paraffin wax as PCM. PCM provides nightlong distillation and augments productivity.

b). Accumulated Distillate Output of Solar Stills

The accumulated freshwater productivity for both solar stills is shown in Fig. 6. It is found that the total accumulated distillate output from 10 am to 7 pm of the experimental day is higher for the solar still with fin, PCM, and external condenser (modified solar still) as compared to finned solar still. The freshwater productivity continues for modified solar still during the sunshine period, which provides a higher distillate output. For the experimental day, the total accumulated freshwater yields for the modified and finned solar stills are 2100 ml /m^2 and 1620 ml /m^{2,} respectively. The accumulated freshwater yield for the modified solar still is 22.8 % higher than that of the finned solar along the day.

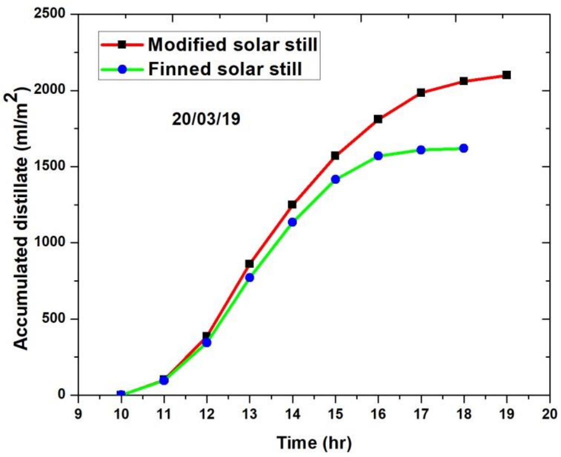

Fig 6: Accumulated Fresh Water Yield for Modified and Finned Solar Still

IV. CONCLUSIONS

In the present experimental work, the performances of two double slope solar stills (modified and finned solar stills) have been analyzed to increase productivity. In the modified solar still, a solid rectangular fin, paraffin wax as PCM, and an external condenser have been incorporated as modifications. Fins provide a larger surface area for evaporation. PCM works as the thermal energy storage medium, and external condenser leads to a faster condensation rate with an extra condensation surface of 1824.15 cm^2. The combined effect of a fin, PCM, and an external condenser is also investigated, and a comparative analysis has been performed between the performances of modified and finned solar still. The experimental results show that the total accumulated distillate output for the modified solar still is 2100 ml /m^2 day. In contrast, for the finned solar still, the value is 1620 ml /m^2 day. The modified solar still provides 22.8 % higher accumulated freshwater output throughout the day compared to finned solar due to the presence of fins, PCM, and external condenser.

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