An Experimental investigation on Hemispherical Basin Solar Still coupled with Heat Pipes, Evacuated Tubes& Paraboloid Concentrator

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Abstract: This paper elaborates on the changes in the solar still efficiency when heat pipes, evacuated tubes and paraboloid concentrator are added to the solar still. The solar still setup is tested for efficiency in four different modes of operation. They are (i) solar still with concentrator, (ii) solar still coupled with heat pipes and evacuated tubes, (iii) solar still coupled with concentrator, heat pipes and evacuated tubes, (iv) solar still coupled with concentrator, heat pipes and evacuated tubes (without insulation). The efficiencies of solar still are found to be 26.009%, 24.708%, 27.72%, and 23.164% respectively in each case. The efficiency of solar still has increased from 24.708% in case of solar still coupled with heat pipes and evacuated tube to 27.72% in case of solar still coupled with heatpipes, evacuated tubes and paraboloid concentrator.

1. Introduction
A solar still is a very economical device that can be used to obtain distilled water. The working principle of solar still is the simple evaporation followed by condensation of water. Solar still, as it is has a basin to contain water which is normally brackish and a glass plate on which the evaporated water condenses which is pure and drinkable. The shape of the glass, basin and the coupling of the solar stills with efficiency enhancing devices like heat pipes, evacuated tubes, concentrators, etc. allow us to obtain different configurations.

Performance of a single slope solar still was studied by [1] by using different low cost materials for the basin, collector plate. The experiment was conducted in a hot area Chennai (Latitude 13°00'29" Longitude 80°'13'06")$. The area of the basin used was 1m² and the slope of the collector was kept constant at 13°. And also different types of feed water were used. It was found that Aluminium as the material for the basin has the highest productivity of all the low cost materials. Experimental study on the single basin solar still coupled with evacuated tubes was conducted by [2]. The evacuated tubes were used in order to reduce the losses thus increasing the productivity. The evacuated tubes were connected on the lower side of the basin with a base area of 1m². Also several experiments were
conducted by using different configurations of the setup like the still alone and still coupled with evacuated tubes. The experiment was conducted at one of the hotter locations Coimbatore (77°E, 11°N), Tamil Nadu. The results showed an increase of 49.7% in the productivity when evacuated tubes were used. Also economic analysis done depicted a payback period of this setup as 235 days. The effect of coupling the single basin solar stills with heat pipes in evacuated tubes was studied by [3]. Other parameters like depth of water in the basin, sun direction and the intensity of solar radiation were studied in order to get the maximum productivity. And the results showed that when these are done, the productivity increased by an amount of 32%. It was also proved that greater the depth of water, lower the productivity and solar insolation is directly proportional to the productivity. Parametric modelling and experimental evaluation of hemispherical solar still was done by [4]. Various parameters like the temperature of water, cover temperature, air temperature, ambient temperature and distillate were studied and the results were studied. Performance study on Heat pipes with different working fluids and different fill ratios has been studied by Harikrishnan et.al [5] and they found that acetone exhibited more efficiency compared to water and methanol and 30° inclination has been found to be optimum. Ganesh A et.al [6] studied the different configurations of Pyramid type solar still coupled with evacuated tubes. They found that the percentage of output distilled water from still coupled with evacuated tubes and reflector are 90.47% and 114.28% more than that of the output from still alone.

2. Experimental Setup:
The test setup is fabricated and introduced at Amrita School of Engineering, Bangalore (Latitude: 12.97°N, longitude: 77.59°E and an altitude of 900m above sea level), Karnataka, India. The schematic diagram and the pictorial view of the hemispherical basin solar still are shown in the figure 2.1 and 2.2 respectively.

![Fig: 2.1 2D Diagram of Solar still](image1)

![Fig: 2.2 CAD model of Solar Still](image2)

The solar still is fabricated using the Aluminium sheet of 2mm thickness, as Aluminium is one of the metal which has high conductivity. The top surface of the Solar Still is covered with a borosilicate glass of thickness of 4mm. This glass is inclined at 15°. A half cut PVC pipe of 0.75 inch is used to collect the desalinated water from the condensed glass. It is connected to the 0.75 inch PVC pipe from which the desalinated water is collected. A hole of diameter 140mm is made in the base of the solar still and the base is brazed with a hemispherical basin made of Aluminium.

The second major part of the experimental setup is installation of heat pipes and evacuated tubes. The evacuated tubes have inner diameter and outer diameter as 0.037m and 0.047m. Two evacuated tubes are used in this setup. Inside the evacuated tubes, the heat pipes are placed and the condenser part of the heat pipes are placed inside the PVC pipes of 1.5 inch Diameter. These evacuated tubes are placed at an angle of 20° to the horizontal. The final setup includes the concentrator which is of Paraboloid shape.
3. Results and Discussion
The efficiency of heat pipe is calculated by inclining the heat pipe at 20° and measuring the temperature of water in the closed chamber surrounding the condenser section. The variation of Solar Intensity and Temperature of water with respect to Time is measured and shown in the following graphs 3.1 and 3.2.

![Graph 3.1 Local Time vs Solar Intensity](image1)

![Graph 3.2 Local Time Vs Temperature](image2)

- The water input is 250ml, weight of water, $m = 0.25Kg$, change in temperature, $\Delta T = 69-32 = 37 \text{ K}$

  \[ \text{Efficiency of concentrator, } \eta_{T.C.C} = \frac{m \cdot c \cdot p \cdot \Delta T}{I \cdot A \cdot t} \]

  From the above data, the efficiency of the heat pipes used is calculated to be 26.34%.

3.1 Efficiency Calculation for the solar still:

\[ \text{Efficiency of solar still, } \eta_s = \frac{m_o \cdot L}{\text{Energy input from [(Direct sun) + (Heat Pipes) + (Concentrator)]}} \]

Where $m_o$ is the output distilled water, $L$ is the Latent heat of water at the average temperature.

3.2 Efficiency of solar still coupled with Paraboloid concentrator

- Total Water output obtained is 200ml, total weight of output water is 0.20 Kg, average water temperature $T_{avg} = 37.88^\circ \text{C}$, Latent heat of water at $T_{avg} = 2210.992 \text{ KJ/Kg}$, Average Intensity of solar intensity = 629.745 W/m²
3.3 Efficiency of solar still coupled with Heat pipes and Evacuated tubes

![Figure 3.5 Local Time Vs Solar Intensity](image1)

![Figure 3.6 Local Time Vs Output distilled water](image2)

- Total Water output obtained is 240ml, total weight of output water is 0.240 Kg, average water temperature $T_{avg} = 43.11^\circ$C, Latent heat of water at $T_{avg} = 2199.467$ KJ/Kg, Average Intensity of solar intensity $= 566.77$ W/m$^2$

3.4 Efficiency of solar still coupled with Heat pipes, Evacuated tubes and Paraboloid concentrator

![Figure 3.7 Local Time Vs Solar Intensity](image3)

![Figure 3.8 Local Time Vs Output Distilled Water](image4)

- Total Water output obtained is 295ml, total weight of output water is 0.295 Kg, average water temperature $T_{avg} = 43.11^\circ$C, Latent heat of water at $T_{avg} = 2199.467$ KJ/Kg, Average Intensity of solar intensity $= 620.89$ W/m$^2$
3.5 Efficiency of solar still coupled with Heat pipes, Evacuated tubes and Paraboloid concentrator without insulation

![Time vs Intensity(W/m^2) 15th May 2017](image1)

![Time vs Output 15th May 2017](image2)

**Fig 3.9 Local Time Vs Solar Intensity Fig 3.10 Local Time Vs Output (ml)**

Total Water output obtained is 250ml, total weight of output water is 0.25 Kg, average water temperature \( T_{avg} = 43.11^\circ C \), Latent heat of water at \( T_{avg} = 2199.467 \) KJ/Kg, Average Intensity of solar intensity = 691.64 W/m^2

From the above data, using the Efficiency of Solar Still formula, the efficiencies of above combinations are calculated and tabulated as shown below in **Table 3.1**:

| Hemispherical basin solar still coupled with | Efficiency     |
|--------------------------------------------|----------------|
| Paraboloid concentrator                     | 26.009%        |
| Heat pipes and evacuated tubes              | 24.708%        |
| Concentrator & Heat pipes with evacuated tubes (Without insulation) | 23.164%        |
| Concentrator & Heat pipes with evacuated tubes | 27.72%        |

**Table 3.1 Efficiency of solar still with different configurations**

4. Conclusion

Integrating the evacuated tubes and heat pipes with hemispherical basin solar still increases the water temperature and distilled output. Further adding the paraboloid concentrator helps in increasing the efficiency. Four different configurations are tested for the same basin area of 0.04m^2. It has been found that for the first mode, with all attached & with insulation, the maximum distilled output is 295ml, second mode the whole still setup without insulation, the maximum distilled output is 250ml, third mode the whole still setup without heat pipes, the maximum distilled output is 200ml and fourth mode the whole still setup without concentrators, the maximum distilled output is 240ml reached for a water quantity of 4000ml. The thermal efficiency of the solar still is observed to be 27.72% with insulation, heat pipes, concentrator and the whole still set up without insulation is 23.164%, the whole still set up without concentrators is 24.708% and the whole still set up without heat pipes is 26.009%. In hemispherical basin solar still coupled with concentrators, evacuated tubes and heat pipes, the productivity of distilled water range has increased 32.20%- 15.25% when compared to all other individual possibilities where any one of the part is missing from distillation unit.
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