THERMAL INVESTIGATION OF A TUBULAR SOLAR STILL

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ABSTRACT

In the present work performance of a Tubular Solar Still is tested in active and passive mode. A 4W fan is used inside the still to enhance the evaporation and condensation rate in the active mode. The experiments were conducted in the month of October (winter season) in Indian climatic conditions in the Solar Energy Laboratory of SHUATS, Allahabad, (U.P.) India. Exergy destruction in the basin water is calculated and it is found more in passive system than in the active system. Results show that exergy efficiency of tubular solar still with fan is 133% higher than the tubular solar still in passive mode.

Key words: Tubular solar still, Exergy efficiency, Exergy Destruction.


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1. INTRODUCTION

Water is essential for life on the earth. Three fourth of the earth surface is also covered with water. This water in its original form cannot be consumed. This water should be desalinated first to make it potable water. Among the known desalination processes, solar distillation is one of the simplest and cheapest techniques to purify the available sea water. The basic drawback of these systems are it’s low productivity. Different solar stills are developed by the researchers to get the pure water with improved productivity. Single basin solar still is one of the simplest designs. Many attempts have been made to improve the daily productivity of the still. Vel murugan et al. (2008) have fabricated a single basin solar still integrated with fins to increasing the daily yield output by use of sand, black rubber and pebbles. Kumar and Tiwari (2008) have investigated a passive solar still performance which is coupled with a PV system. They observed that PV coupled still is 3.5 times more efficient than passive solar still. Gude et al. (2011) have presented theoretical and experimental analysis of ARS system which is powered by solar and PV energy and they also compared the GHG emissions with other
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desalination processes. Kabeel et al. (2011) have developed a solar still which is cost effective and increase the daily distillate of still. They increase the productivity of still 24 to 36%. Kianifar et al. (2012) have conducted the comparative experimental study of an active and passive pyramid shaped solar still. They have used a small fan (2W) to increase the distillate production 20% in active system in seasons (summer/winter). They also examined the cost of the distillate and found that 8-9% production cost of distillate is reduced in the case of active system. Rai et al. (2013) have attempted to improve the performance of solar still by changing the condensing cover material. It was reported that use of polyvinyl chloride as condensing cover gives 64% more distillate than when the glass cover is used. They also preformed the cost analysis and payback period of single slope solar still. Rai et al. (2013) have conducted the experimental studies in the month of April 2013 in the premises of SHUATS Allahabad to find the performance of a Tubular solar still. It was observed that the Tubular solar still gives 166% better performance than that the Double slope solar still of the same basin area.

Rai et al. (2015) have used PCM (stERIC acid) in the basin of Tubular solar still to enhance the productivity of the Tubular solar still. It was observed that the use of the PCM further increases the daily productivity of Tubular solar still by 20%. They have also calculated the energy and exergy efficiency of the system and daily exergy of 0.857% was obtained. Ranjan et al. (2013) proposed the thermal model of a solar still. Energy and exergy efficiencies of passive solar still are found as 30.42% and 4.93% respectively. The exergy destruction in different components of still i.e. basin liner, brackish water and glass cover were also evaluated as 3353, 1633 and 362 W/m² respectively. Sivakumar et al. (2015) have attempted to develop a mathematical model, to investigate the thermal performance of a single slope solar still and also evaluate the exergy destruction in the single slope solar still. They have observed that the maximum total exergy destruction of 3,642.23 W/m² is found in the still basin the minimum exergy destruction of 290.2 W/m² in the glass cover.

In this paper the thermal performance of a TSS is predicted in the terms of exergy efficiency. A comparison is made between the exergy destruction in the water when TSS is equipped with a fan and when there is no fan.

2. EXPERIMENTAL SETUP

![Figure 1 Photograph showing the experimental setup](image)
Tubular solar still TSS is shown in fig.1. It consists of a water basin made of G.I. sheet of thickness 0.5 mm. Basin area is 0.77 m$^2$. Proper sealing is made to avoid water leakage. Tray is painted black to absorb maximum solar radiation. Still cover is made of PVC sheet in a tubular shape with help of two iron rings provided at the two rings. Two circular discs are used to cover both ends. Silica gel and M-seal are used to provide leak proof arrangement. One fan of 4 W provided at side of Tubular Solar Still to enhance evaporation and condensation rate. Tray is filled with water up to 2 cm height. K-type thermocouples are used to measure temperature. To collect the distillate, a beaker is used in the lower end of the still cover.

Observations were taken in the month of October, winter season of Indian climatic conditions in 2017 at SHUATS, ALLAHABAD (U.P.) India. Observations are taken between 8.30 AM to 5.00 PM.

3. EXERGY ANALYSIS

Exergy is defined as large amount of work which can be produced by a system or energy as it comes to balance with surrounding conditions. Exergy analysis is derived from the second law of thermodynamics and serves as a measure of the ability of energy to do work; it is equal to the maximum amount of work that can be extracted from a given quantity of energy. The second law of thermodynamics deals with the exergy destruction of every stage in the TSS, which cannot be utilized or transferred to the working medium.

The exergy efficiency is defined by Hepbalsi A (2008) as:

$$\eta_{Ex} = \frac{\text{Exergy Output of Solar Still}}{\text{Exergy input to Solar still}} = \frac{\text{Ex}_\text{evap}}{\text{Ex}_\text{input}}$$

(1)

$$\text{Ex}_\text{evap} = \frac{m_L}{3600} \times \left(1 - \frac{T_a+273}{T_w+273}\right)$$

(2)

Where $m_L$ is hourly yield of Tubular solar still (litre/h), $L$ is the latent heat of vaporization (J/kg), $T_a$ is the ambient temperature in ($^0$C) and $T_w$ is water temperature ($^0$C).

The exergy input can be determined as:

$$\text{Ex}_\text{input} = \text{Ex}_\text{sun(solar still)} + \text{Ex (fan)}$$

(3)

Where $\text{Ex}_\text{sun(solar still)}$ is the exergy contribution to solar still through radiation and can be obtained from the following equations.

$$\text{Ex}_\text{sun (solar still)} = A_b \times I(t)_h \times \left[1 - \frac{4}{3} \times \left(1 - \frac{T_a+273}{T_w+273}\right) + \frac{1}{3} \times \left(\frac{T_a+273}{T_s}\right)^4\right]$$

(4)

Where $A_b$ is the basin area into tubular solar still (m$^2$), $I(t)_h$ is solar radiation on the slanted glass surface of solar still (W/m$^2$) and $T_s$ is the sun temperature 6000 K. Additionally, Ex(fan) is identified with power utilization by the fan (4 Watts) in the Tubular solar still.

4. EXERGY DESTRUCTION

The exergy destruction into TSS for saline water is

$$\text{Ex}_{des} = m_w \times C_w \times (T_w - T_a) \times \left(1 - \frac{T_a+273}{T_w+273}\right)$$

(5)

Where $m_w$ is mass of water filled into basin of TSS, $C_w$ is specific heat of water.

The 2$^{nd}$ law of efficiency given as:

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\[ \eta_{Ex} = \frac{E_{\text{output}}}{E_{\text{in}}} = 1 - \frac{E_{\text{des}}}{E_{\text{in}}} \]  

(6)

5. RESULT AND DISCUSSION

Fig. 2 and Fig. 3 show the variation of solar intensity and variation of wind velocity with respect to time of the day (hours).

![Figure 2](image2.png)

**Figure 2** Variation of Solar intensity (w/m²) w.r.t. time (hour)

![Figure 3](image3.png)

**Figure 3** Variation of the wind velocity (m/s) with respect to time in month of October

It has been observed that the maximum solar intensity observed at 11:00 AM and after that it continuously decreases with respect to time. Weather condition is partially cloudy. The average solar intensity of the day was 564.44 W/m². In figure 3 it was observed that at 12:30 PM, wind velocity was maximum and was 1.6 m/s. Figure 4 shows the variation of Ambient temperature \( (T_a) \), PVC Cover Temperature \( (T_c) \), Basin water temperature \( (T_w) \), Basin water surface Temperature \( (T_{ws}) \), Temperature of humid air inside the solar still \( (T_{ci}) \), \( T_b \) Basin temperature w.r.t. to time of the day. It is observed that trend of variation of different temperatures are approximately same. Lowest temperatures are the environmental temperature followed by outside cover temperature throughout the day. Inside the solar still, as expected, cover temperature is at lower temperature than the water temperature and basin temperature after 10:30AM, because by this time the sufficient heat is trapped inside the still.
Figure 4 Variation of different temperatures of Tubular solar still w.r.t. time of the Day

Figure 5 Variation of exergy efficiency of TSS w.r.t. to time of the day

Figure 5 shows the variation of exergy efficiency w.r.t. the time of the day of Tubular solar still. The maximum exergy efficiency of the still with fan is 4.45% and without fan 1.25% at the time of day 4:30 PM and 12:30 PM respectively. Exergy efficiency of the still with fan is more after 12:30 PM because of increased distillate output. Average exergy of the still with fan and without fan are 1.86%, 0.80% respectively.

Figure 6 Variation of exergy destruction in water w.r.t. time of day
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Figure 6 shows the variation of exergy destruction w.r.t. the time of day of Tubular solar still. The maximum exergy destruction calculated for with fan and without fan is 71.66 W/m² and 122.46 W/m² at the time 11:00 AM and 11:30 AM respectively. Average of the exergy destruction of still with and without fan is 47.86 W/m² and 60.92 W/m² respectively.

![Figure 7](image_url)

**Figure 7** Variation of Distillate output w.r.t. time of the day

Figure 7 shows that the variation of distillate output of with and without fan. It shows that maximum distillate output measured at with fan and without fan is 0.168 litres and 0.78 litres at the time 2:00 PM and 12:30 PM respectively. The total distillate output with and without fan are 1.566 and 0.809 litres respectively. The reason behind low distillate output is poor solar intensity and small basin area.

6. CONCLUSIONS

In this paper the exergy efficiency and exergy destruction in the basin water of a Tubular Solar Still with and without fan are obtained experimentally. The results show that the daily distillate output of the active system is 52% more than passive tubular solar still. The maximum instantaneous exergy efficiency of 4.44% is obtained for the tubular solar still with fan. The exergy destruction of with fan is lower as comparison to the without fan. Distillate output greater than with fan as compare to without fan. The productivity of with fan is 48.33% more than without fan.

REFERENCES


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