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Performance of honeycomb double exposure solar still

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ABSTRACT

A honeycomb double exposure solar still has been designed to enhance the productivity throughout the day. Experiments have been carried out to predict the performance of the proposed still in October 2009, Karpagam University, Coimbatore, India. The concept of transparent honeycomb structure with thin walled glass tube of small aspect ratio (H/D ≈ 1.7) in the basin and also planar reflector for east, west and south facing walls from the outer surface is implemented in this modification. The emphasis is to study the effect of the transparent honeycomb in the basin on the productivity of the still. It has been found that the still receives large amount of radiation and daily output increased by 25% than ordinary double exposure solar still.

Keywords: Passive solar still; Honeycomb; Double Exposure; Thermal analysis

1. Introduction

Fresh water is the essence of life and is the most important constituent of the environment. Solar distillation is a fascinating process which uses solar energy as the source for distillation of saline or brackish water. Solar distillation system can be classified under two categories, passive and active systems. The review work on passive solar distillation has been done by Malik et al. [1] and further reviewed by several researchers [2–6] which includes work on active distillation. In any design of solar still the large temperature difference between evaporative and condensing surface enhances the productivity of the still and have been explained by the researchers [7–13]. The use of external reflectors on the still has increased the input solar insolation and thereby increases the distillate output to some extent [14]. El-Swify [15] has suggested that the solar radiation captured by the still is maximum when its aspect ratio is in the order of 2.0 i.e., length is twice the width. Moreover El-Swify and Metias [16] have shown that reflectors on the east, west and south facing walls from outer surface of L-type solar still which acts as an insulating material on the glass increased the amount of solar energy gain in the basin. The double exposure solar still has the limitation of small amount of distillate yield in the night due to the absence of thermal storage.

In the present study in order to increase the night time collection of distillate output, an attempt has been made by introducing the transparent honeycomb structure in the basin of double exposure solar still which serve as thermal storage during peak sunny hour. Experimental analysis is carried out to explore the effects of aperture, aspect ratio and other factors of the honeycomb on the performance of the proposed still.

2. System description

Fig. 1a shows L type honeycomb double exposure solar still. The length is 1m width is 0.5 m with aspect ratio L/W = 2.0. The upper glass cover is tilted at an angle 26°. The south facing, east facing and west facing surfaces of the still are covered with highly reflecting material from the outer surface that help to gain

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additional energy through the reflection of sun rays to the still basin and reduce emissivity. The basin of the still are closely packed with thin walled transparent honeycomb structure with small aspect ratio (H/D = 1.7). The reflectors pasted from outside have also served as thermal insulation for the walls of the still and also the emissivity of the glass walls. The same aspect ratio of L/W = 2.0 have been used to fabricate the L-type solar still without the honeycomb structure in the basin.

The presence of the thin walled transparent honeycomb structure in the basin restricts the water natural convection, obstruct the infrared radiation heat loss and reduce conduction heat loss through the walls. The transparent honeycomb structure traps the total incident radiation inside the basin by means of total internal reflection. For the assessment of the influence of honeycomb structure in the basin on the performance, another double exposure solar still without honeycomb structure is constructed as shown in the Fig. 1b. The photograph of the honeycomb double exposure solar still is depicted in Fig. 2.

2.1. Analysis

It is necessary to estimate the reflected energy from south, east and west-facing reflectors and also the transmittance of the glass tube honeycomb unit in the basin.

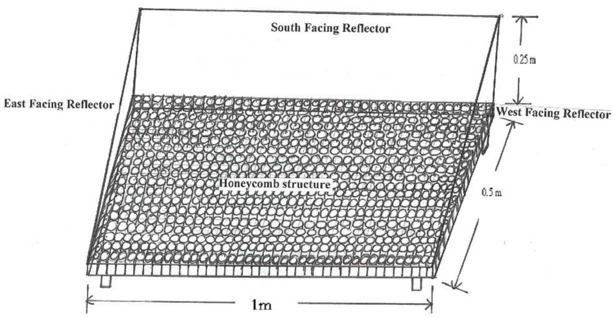

Fig. 1a. Schematic diagram of the honeycomb double exposure solar still.

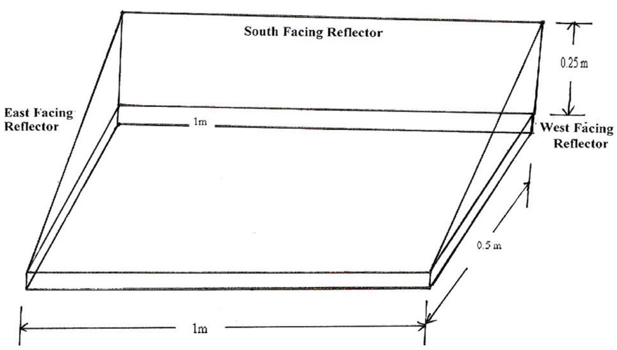

Fig. 1b. Schematic diagram of double exposure solar still.

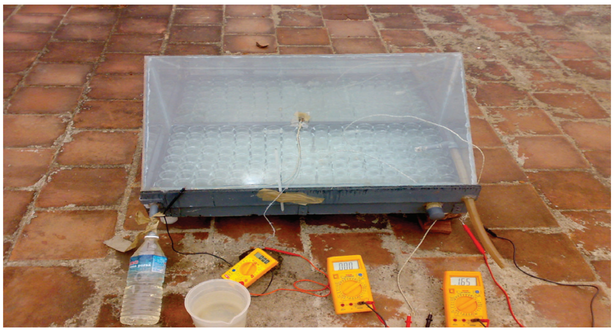

Fig. 2. Photograph of the honeycomb double exposure solar still.

Energy input to the honeycomb unit in the basin includes the global solar radiation falling directly on the still glass window and the reflected energy from the reflectors.

The energy input to the basin with honeycomb structure can be estimated by the equation derived by El-Swify and Metias [16] and it is given by

$$I_H = \tau\tau_1 I_T + \sum (I_r)_{S,E,W} \tag{1}$$

where

$$(I_r)_{S,E,W} = (I_B)_e \Sigma f_{S,E,W} \tag{2}$$

The fraction of reflected solar energy form South East and West reflectors are given by El-Swify and Metias [16]

$$f_s = \text{Cos}\gamma\text{Cos}\alpha S^{-1}(1 - \frac{1}{2}\text{Tan}\alpha) \tag{3}$$

$$f_E = 0.25\ \text{Sin}^2\gamma\frac{\text{Cos}^2\alpha}{\text{Sin}\alpha} \tag{4}$$

$$f_W = 0.25\ \text{Sin}^2\gamma\frac{\text{Cos}^2\alpha}{\text{Sin}\alpha} \tag{5}$$

The response of each glass tube in the closely packed honeycomb structure with water to the reflected rays from the reflectors in addition to the solar radiation transmitting through the top glass cover remains the same. Consider a single glass tube in the honeycomb unit and beam of parallel rays irradiate in to the glass tube openings at an arbitrary angle. The following assumptions have been made to simplify the analysis. The single glass tube in the honeycomb unit and the corresponding path of solar radiation is shown in the Fig. 3.

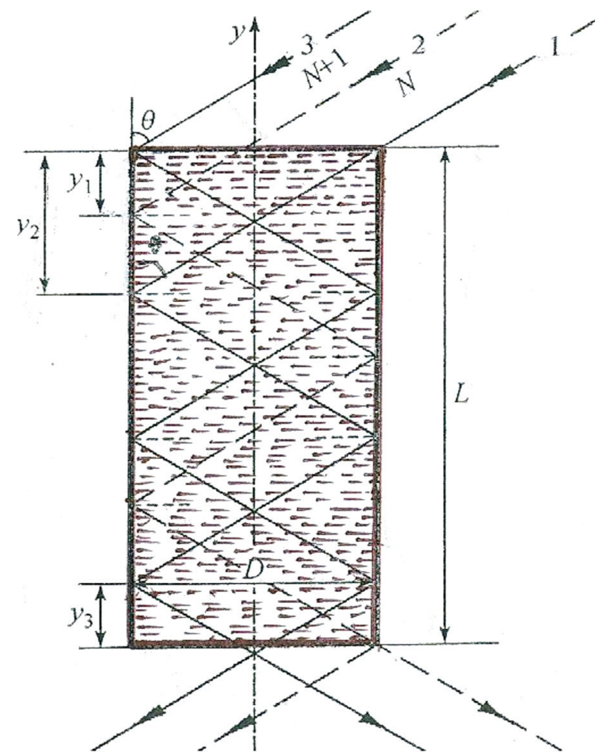

Fig. 3. Single glass tube in honeycomb unit.

1. The solar radiation reflected from the side wall reflectors in addition to the radiation transmitted directly through the top glass cover will be considered as parallel lines entering the top of the transparent honeycomb structure.
2. The radiation transmitted through the water surface and glass tube but transmitting to another glass tube will be converted in to reflected light with in it.
3. The transmittance of the water surface and glass tube will be a constant for all incident angles.

When light is transmitted through the water surface and glass tube, each time the intensity decays by a fraction τ_e, which is effective transmittance and can be written as

$$\tau_e = \tau_2\tau_3\tau_4 = 0.61 \tag{6}$$

On the account of the transmitted light which results from Eq. (6), the total fraction of reflected light inside the basin, or effective reflectivity will be

$$\rho_e = \tau_e + \rho = 0.64 + 0.05 = 0.69 \tag{7}$$

With the above assumptions, in Fig. 3, the ray represented by line 1 be incident on a point at an angle θ in the glass wall, after transmission through the water with distance 'Y_α ' from the opening of the glass tube can be derived as

$$Y_\alpha = D/\tan\theta \tag{8}$$

If the height of the honeycomb is 'N' time the distance 'Y_α', then the length of the glass tube will be $L = Ny_\alpha$ and hence the fraction of rays undergoes n times reflection before coming out of the glass tube.

The height of the tube is fixed, though the incident angle of the sunlight changes with time. Thus we have $\frac{L}{Y_2} = \frac{L}{D}\tan\theta$, which is not an integer. Among these light lines coming out of the glass tube, small fraction of lines experience one more reflection through the bottom wall section Y_3. Since the Ray 2 and 3 experiences $N + 1$ times reflection before emerging out of the tube, it is considered that $Y_1 = Y_2$. The fraction of rays which undergoes $N + 1$ times reflection can be obtained as $X_1 = \frac{Y_1}{Y_2} = \frac{L - NY_2}{Y_2} = \frac{L}{D}\tan\theta - N$. The fraction of rays which undergoes N times reflection can be written as $X_2 = 1 - X_1 = 1 + N - \frac{L}{D}\tan\theta$. The sum of above two fractions of rays gives the total transmittance of the glass tube with water. Therefore, the effective transmittance through the honeycomb unit with water can be expressed as a simple formula as

$$\begin{aligned}\tau_e &= \left[X_1\rho_e^{N+1} + X_2\rho_e^{N}\right]\\ &= \left[\left[\frac{L}{D}\tan\theta - N\right]\rho_e^{N+1} + \left[1 + N - \frac{L}{D}\tan\theta\right]\rho_e^{N}\right]\\ &= \left[1 + \left(N - \frac{L}{D}\tan\theta\right)(1 - \rho_e)\right]\rho_e^{N}\end{aligned} \tag{9}$$

Based on the equation, we can obtain the effective transmittance of the honeycomb unit with water in the basin. The total radiation trapped within the basin can be estimated by using the effective transmittance of honeycomb with water and rays reflected from the east, west and south facing reflector in addition to direct one falling from glass windows. Hence the equation can be written as

$$I_{Tot} = I_H\tau_e \tag{10}$$

2.2. Experimental procedure

The honeycomb double exposure still and ordinary double exposure solar still have been oriented towards south direction. The latitude of the location (Coimbatore) is 11 °N and it has a tropical climate and does not witness much temperature fluctuations between summers and winters. During the summers, the average weather conditions are hot with mercury rising to as high as 39 °C whereas the minimum temperature in summer is around 21 °C. During the winters, the weather remains mild with the maximum temperature around 30 °C and the minimum temperature remaining around 15 °C. The various temperature components of the still have been measured with respect to time. The ambient temperature, global solar radiation intensity and beam solar insolation for the corresponding daylight hours were measured using digital thermometer, Eppley Pyranometer (EPLAB-PSP model) with Sensitivity: approximately 9 μV/Wm^2, and Pyreheliometer respectively. The daily total productivity of both the stills has collected with graduated flask which includes the night and day time collection.

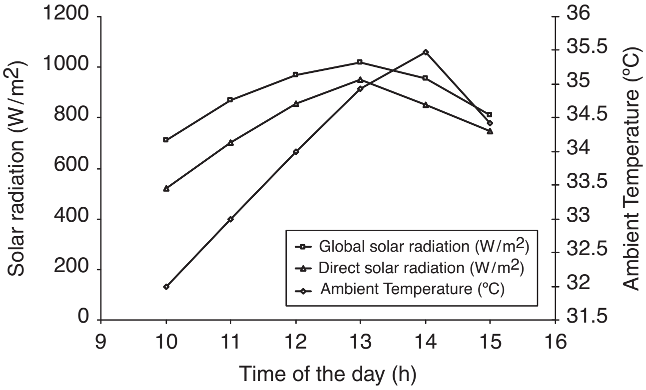

Fig. 4. Variation of solar radiation and ambient temperature.

3. Result and discussions

The variation of solar radiation and ambient temperature in one of the clear sunny days in October is shown in Fig. 4. The augmentation energy ratio (AER) for honeycomb double exposure solar still and ordinary double exposure solar still are depicted in the Fig. 5. It is found that the energy gain for honeycomb double exposure solar still is higher than the ordinary double exposure solar still. The hourly water basin temperature for both the stills is drawn in the Fig. 6. From the graph it is seen that the maximum water basin temperature inside the honeycomb double exposure solar still is about 59.0 °C and 54.0 °C in ordinary double exposure solar still and also found that there is an increase of water basin temperature inside the still due to the presence of honeycomb, which traps energy to certain extent as expected.

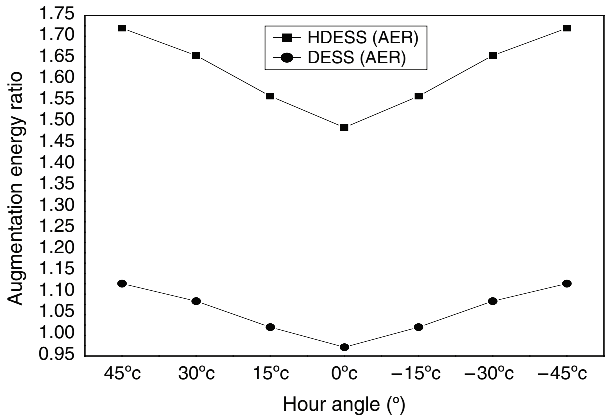

Fig. 5. Augmentation Energy ratio for HDESS and DESS.

The hourly glass cover temperature for honeycomb double exposure solar still and ordinary double exposure solar still is shown in the Fig. 7. From the figure it is found that in honeycomb double exposure solar still, the glass cover temperature i.e., the condensing surface is lower than the ordinary double exposure still. The temperature difference between the evaporating and condensing glass cover surface of honeycomb double exposure solar still is much larger and the rate of evaporation increases as compared to ordinary double exposure solar still. The honeycomb structure in the basin traps the energy within the basin due to total internal reflection and the thermal energy stored in the honeycomb structure in the basin increases the rate of evaporation in night. The effective transmittance of the honeycomb unit convects a large amount of energy to the raw water in the basin and decreases the temperature of the condensing surface with the increase of cooling effect.

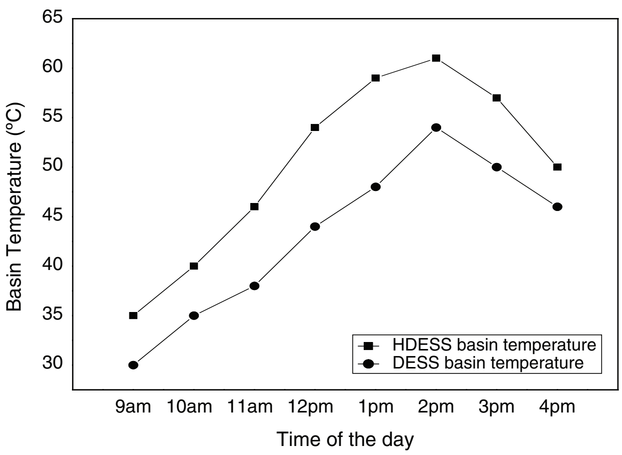

Fig. 6. Variation of Basin Temperature of HDESS and DESS.

Fig. 8 shows the hourly productivity of both the stills respectively. From the Figure it can be seen that the

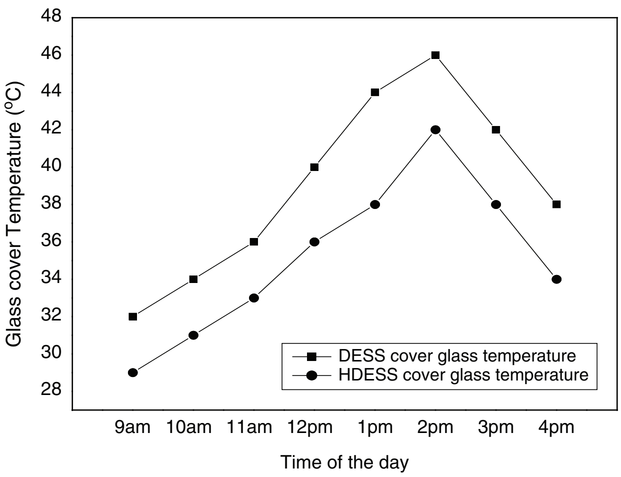

Fig. 7. Variation of glass cover temperature of HDESS and DESS.

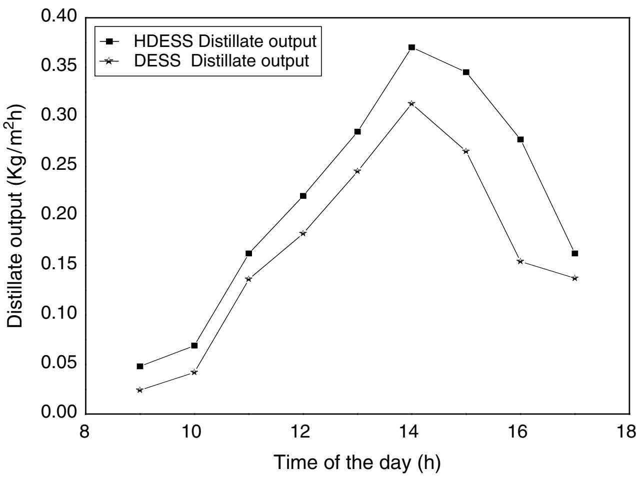

Fig. 8. Distillate yield of HDESS and DESS.

productivity of honeycomb double exposure still is much improved as compared to the ordinary double exposure still especially when diffuse radiation intensity is more in winter time. Fig. 9 shows the efficiency of both the stills and the honeycomb double exposure solar still is more efficient in trapping solar energy. The daily productivity of the honeycomb double exposure solar still is found to be 2.650 l/m^{2}d which includes both day and night time collection of distillate output for a 24 h cycle. The night time output is increased in the still, as honeycomb stored the solar energy within the basin due to effective transmittance. It is found that the overall efficiency of the honeycomb double exposure solar still is 39.74%.

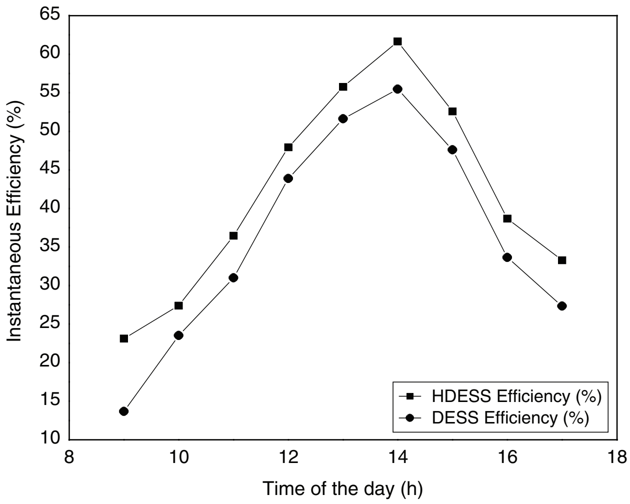

Fig. 9. Instantaneous efficiency of HDESS and DESS.

4. Conclusion

The presence of honeycomb structure with small aspect ratio (H/D = 1.7) in the basin along with internal reflectors increases the productivity of fresh water. The honeycomb unit in the basin leads to:

1. Increase the rate of evaporation without the increase of condensing water temperature.
2. Increase the difference between evaporating and condensing surface which is expected.
3. Increase the large convection of solar energy to the water in the basin.
4. Increase the night time distillate output due the storage of energy by the honeycomb unit in the basin as compared to ordinary double exposure solar still.
5. The theoretical analysis of honeycomb structure is found to be in good agreement with the experimental observations.

The average distillate yield of the honeycomb double exposure solar still is found to be 2.650 l/d out of which 1 l of distillate yield is approximately collected during night. It is also found that the average efficiency of the honeycomb double exposure solar still is 39.74%. and 25% increase in distillate output when compared with the ordinary double exposure solar still.

Symbols

H	—	Height of the honeycomb glass tube (m)
D	—	Diameter of the honeycomb glass tube (m)
L	—	Length of the still (m)
W	—	Width of the Still (m)
I_H	—	Total solar radiation to the basin with Honeycomb structure (W/m^2)

τ	—	Transmittance of the top glass covers (0.85)
τ_1	—	Transmittance of the condensing water drop (0.85)
I_T	—	Total solar radiation on the top glass covers (W/m^2)
$(I_r)_{S,E,W}$	—	Fraction of solar radiation reflected from south, east and west facing reflector (W/m^2)
ρ	—	Reflectivity of the reflectors
γ	—	Solar azimuth angle with respect to the horizontal plane (°)
α	—	Solar altitude angle with respect to the horizontal plane (°)
f	—	Fraction of reflected sunlight intercepted by the still basin
τ_2	—	Transmittance of glass wall (0.85)
τ_3	—	Transmittance of water (0.85)
τ_4	—	Transmittance of second glass wall (0.85)
τ_e	—	Transmittance of honeycomb (0.85)
ρ_e	—	Reflectivity of the honeycomb
I_H	—	Total radiation trapped inside the honeycomb
I_{total}	—	Total radiation trapped with in the basin

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