Heat Mass Transfer and Thermophysical Analysis for Pyramid Type Solar Still

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Abstract: ***In this communication, an attempt has been made to find out the heat transfer coefficients such as internal and external heat transfer modes and thermophysical properties such as dynamic viscosity, density, thermal conductivity, latent heat of evaporation and saturated vapor pressure for active solar distillation system. It is observed that water temperature plays a vital role in the distillate output (the yield) since it increases significantly with the rise of basin water temperature. Double slope step type solar still of area 1 m^2 is constructed using a glass pieces. Top Glass cover with 10° slope ensures a very good transmission of solar radiation inside the still. The distillate water productivity is in the range of 2.758 litres to 2.805 liters per day for still performance study. Similarly the instantaneous efficiency for still performance study is in the range of 17.84% to18.25%. Dimensionless numbers such as the Nusselt number (Nu), the Grashof number (Gr), the Reynolds number (Re) and the Prandtl number (Pr) were also estimated. Heat transfer coefficient were estimated for the present system since the system overall efficiency depend on heat transfer modes. Internal (convection, evaporation and radiation) and external (convection, conduction and radiation) heat transfer modes were calculated for the present system and it is found that because of rise in water temperature, evaporative heat transfer coefficient value rises significantly.***

Keywords: Solar Still, Heat Transfer Modes, Radiation, Acrylic, Distillate Yield, Efficiency

1. Introduction

It is a well known fact that fresh water is necessary for the continuity of all life. The global fresh water shortage, particularly in remote areas, presents an international problem. The problem is more severe in desert countries, particularly in India, where water shortage is a serious problem. In India, the urgent need for fresh water is concentrated in the coastal regions, which constitutes a considerable development area. Since the transportation of fresh water to these areas is difficult and not economic, desalination systems are essential. Many of these countries, however, enjoy an abundant and free solar energy with high intensity so that solar distillation is a promising way of supplying these regions with fresh water.

H.P. Garg and H.S. Mann [1] indicated that about 26% of the heat input to the basin-type solar still is lost through its base. Abdel-Salam *et al.,* [2] studied the effect of insulation on the performance of unsymmetrical solar stills and found that its productivity rate is increased by 16.5%. Several research results were published where heat transfer coefficients are calculated theoretically for various operating conditions by M. A. S. Malik et al., [3] and Baum and Bairamov [4] and Ahmed Omri et al., [5]. They concluded that heat flows inside the still are calculated generally by assuming that transfer mechanisms such as convection and mass diffusion take place simultaneously and the total heat transfer rate is calculated by adding the individual quantitie

2. Construction of Pyramid Type Solar Still

Pyramid solar still with total evaporation area of 0.5625 m^2 is made using single piece of stainless steel with dimension 0.75 m x 0.75 m x 0.20 m. Acrylic sheet of 3mm thickness is used as top cover. A slope of 10° is provided from the center of the basin to the end of basin to receive the direct solar radiation more nearly perpendicular to the absorbing surface. Water collecting segment are provided beneath the sliding segment of top cover. Diagonally opposite pipes are used for collecting the distillate yield. Base of the still are blackened with paint for good absorption of solar radiation. The outer cover is made up of wood of thickness 0.015 m. The dimension of outer cover box is 0.80 m x 0.80 m x 0.25 m respectively. Saw dust and glass wool makes the bottom and side insulation. Water collection segment of dimensin 0.80 m x 0.03 m x 0.04 m is placed at the end of top cover on all sides of the stepped basin. . A cross sectional view of pyramid type solar still is shown in Fig (1).

Figure 1: Pyramid Type solar still

3. Experimental Arrangement

The performance of the still has been studied for number of days and its readings on clear sunshine days have been recorded. The experimental study is started from 9am. The basin is filled with water of 15 litre of saline water. The pre-calibrated thermocouples are fixed at the appropriate places and it is connected to the digital thermometer to measure the air temperature (T_a), water temperature (T_w) inside the still and top acrylic cover temperature (T_g). A thermometer with an accuracy of 0.1 °C is used to measure the ambient temperature (T_{amb}). Amount of total solar insolation (H) and the amount of distilled water collected at the outlet are recorded at regular intervals. A measuring jar is kept at the distilled water outlet and the collection is recorded at the regular intervals.

4. Internal Heat Transfer Rate at Inside the Still

4.1 Internal Convection Loss

The heat transfer per unit area per unit time due to convection is given by $Q_{ci} = h_{ci} (T_w - T_g)$ W/m^2 (1)
where

$$h_{ci} = 0.884\left((T_w - T_g) + \left(\frac{(P_w - P_g)(T_w + 273)}{268.9 \times 10^3 - P_w}\right)^{1/3}\right)(T_w - T_g) \quad W/m^2$$

4.2 Internal Evaporation Loss

Heat transfer mode inside the still due to evaporation is given by

$Q_{ei} = h_{ei} (T_w - T_g)$ W/m^2 (2)
where $h_{ei} = (16.276 \times 10^{-3}) \times h_{ci} \times R_1$

here R_1 is the constant evaluated by fitting the saturation vapor pressure data in the range of interest to a straight line.

4.3 Internal Radiation Loss

In the usual analyses of solar stills, the water surface and the glass cover are considered as infinite parallel planes. Using Stefan Bolzmann's constant, heat transfer per unit area per unit time due to radiation is given by

$Q_{ri} = h_{ri} (T_w - T_g)$ W/m^2 (3)
where $h_{ri} = \varepsilon_w \sigma [(T_w + 273)^4 - (T_g + 273)^4] / (T_w - T_g)$ W/m^2

The ratio between the heat of evaporation to the total heat transferred from the water to the cover, depends upon T_w and T_g. Computation of this ratio (S) is given by

$S = h_{ei} / (h_{ei} + h_{ci} + h_{ri})$ (4)

5. Heat Transfer Rate Outside the Still

The external heat transfer modes are convention and radiation. Due to the small thickness of the glass cover, it is assumed that the lamp of the cover is uniform.

5.1 External Convection Loss

The external convention loss from glass to the outside atmosphere is given by

$Q_{ca} = h_{ca} (T_g - T_a)$ W/m^2 (5)

where, h_{ca} is a function of wind velocity and is given by J.A. Duffie and W.A. Beckman [30] as $h_{ca} = 5.7 + 3.8$ V (6)

5.2 External Radiation Loss

The external radiation loss from the top cover to the atmosphere is given by,

$Q_{ra} = \varepsilon_g \sigma [(T_g + 273)^4 - (T_{sky} + 273)^4)]$ W/m^2 (7)
$T_{sky} = (T_a - 12)$ is the apparent sky temperature for long wave radiation. ε_g for glass is $\cong$0.85

5.3 External Conduction Loss

The value of conduction heat loss through the base Q_{be} is given by $Q_{be} = h_{be} (T_w - T_a)$ (8)

6. Efficiency and Dimensionless Numbers

The efficiency of the still is calculated using the formula
$\eta = (M \times L) / (H_s \times A \times t)$ (9)

The convective heat transfer is considered in terms of dimensionless parameters, viz. the Nusselt number (Nu), the Grash of number (Gr), the Reynolds number (Re) and the Prandtl number (Pr); the expressions for these numbers are

$Nu = (h_{ci} L / k)$ (10)
$Gr = (x_i^3 \rho_i^2 \beta g \Delta T') / \mu_i^2$ (11)
$Pr = (C_p \mu / k)$ (12)

7. Results and Discussion

The performance of pyramid type top cover solar still is analyzed on normal sunny days. The radiative heat transfer (Q_{ri}), convective heat transfer (Q_{ci}) and evaporative heat transfer (Q_{ei}) for internal heat transfer rates inside the still are predicted. Similarly heat transfer rates outside the still by conduction heat transfer (Q_{be}), external heat transfer through radiation from the top glass cover (Q_{re}) and heat transfer from the top glass cover to atmosphere by convection (Q_{ce}) are also estimated. The instantaneous efficiency and overall efficiency are calculated for all the studies. Heat transfer coefficients predicted under internal and external heat transfer modes for still performance is shown in Table (1) below

Table 1: Heat Transfer Values

	Internal Heat Transfer Mode			*External Heat Transfer Mode*		
	Q_{ri} W/m^2	Q_{ci} W/m^2	Q_{ei} W/m^2	Q_{be} W/m^2	Q_{re} W/m^2	Q_{ce} W/m^2
Still Performance	118.52	43.13	501.89	10.52	106.20	73.20

The thermal conductivity of water is analyzed and it is observed in the range of 0.02672108 to 0.02886952 Wm^{-2} °C^{-1}. Dynamic viscosity of water is predicted and is in the range of 1.8578x10^{-5} to 1.9871x10^{-5} Nsm^{-2}. The thermal conductivity and dynamic viscosity increase with respect to time and posses almost the same trend. The density of water is predicted for the still under these experiments and it is observed as 1.164163 to 1.06586248 kgm^{-3}. It concludes that the density decreases with respect to increase in water temperature and it starts to increase with the decrease in water temperature. Fig (2) shows the variation of insolation and distilled water collection with respect to time. Insolation increases linearly with time and reaches the maximum value from 12 p.m to 2 p.m and then decreases. Radiation received during this study is in the range of 386.46 W/m^2 to 1002.39 W/m^2. The maximum distilled water collection is in the range of 10 ml to 206 ml. The amount of daily distillate yield collected is in the range of 2.758 liters/day to 2.805 liters/day.

Fig (3) shows the variation of temperature for water, air, top cover and ambient with respect to time for still. The maximum rise in water temperature is observed as 70.5 °C.

Similarly the maximum air temperature of 75 °C is obtained. The variation of ambient temperature is in the range of 32 °C to 35.5 °C during the study. The impact of the ambient temperature over the still is more because the condensation at the top cover is mainly based on it. Similarly the variation of top cover temperature is in the range of 32 °C to 46 °C. normally, the rise in top cover temperature affects the condensation of water vapor over the top cover, because the top cover temperature rises to a maximum of 46°C. This rise in top cover temperature is higher than the ambient temperature. The difference between top cover temperature and ambient temperature is only 11.5 °C. Hence distillate yield obtained from the still is not slowed down. Fig (4) shows the variation of instantaneous efficiency and performance ratio of the still with respect to time performance study of step type glass top cover solar still. The instantaneous efficiency is increased according to the time. The variation of the efficiency observed during the study is in the range of 2.59 % to 30.76 %. Overall efficiency of the system for still performance is in the range of 16.16% to 18.22%. The performance ratio calculated is found increase with respect to time and reaches a steady state after. The performance ratio values observed during the study is in the range of 3 % to 29.98 % for still performance study. This shows that the value of performance ratio increases according to increase in distillate output. The warming up period causes a change in the performance ratio during rise in temperature. When it rises to maximum, the performance ratio maintains a steady state. This effect is due to the rise in temperature completely utilized for evaporation.

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Fig (2) Variation of solar radiation and water collection with respect to time

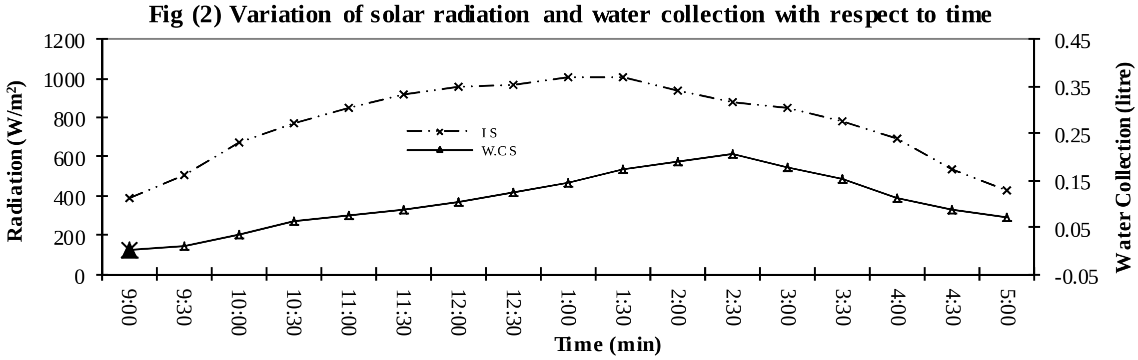

Fig (3) Variation of temperature with respect to time

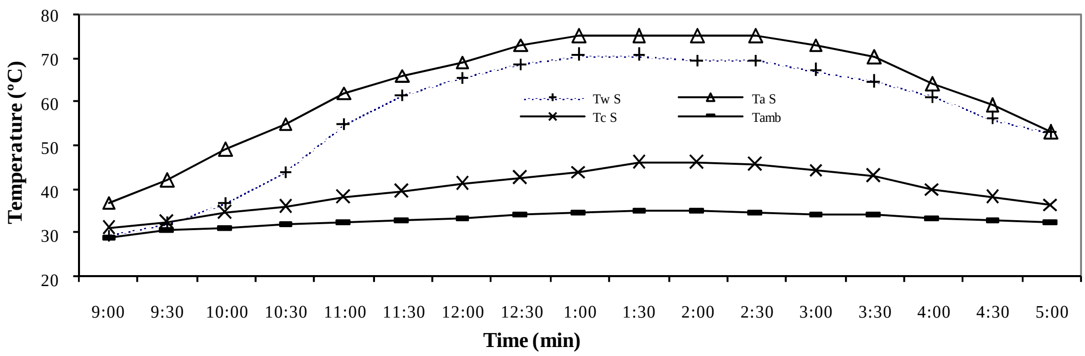

Fig (4) Varitaion of Instantaneous Effficiency and Performance Ratio with time