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Letter to Editor

UPWARD HEAT FLOW ANALYSIS IN BASIN TYPE SOLAR STILL

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Abstract

The present work aims at estimating radiative, convective and evaporative heat transfer co-efficient for upward heat flow in a conventional basin type solar still for different water temperatures, ambient temperatures and wind speeds. The glass temperature for given water temperature and ambient condition is obtained from heat balance equation on the glass by trail and error. The convective heat transfer coefficient between glass cover and ambient air is estimated from the empirical relation suggested by McAdams. The sky temperature is obtained from the ambient temperature through the relation suggested by ' SwinBank'. The radiative, convective and evaporative heat transfer coefficients between water and glass cover are estimated through the expressions given by Dunkel`, 'Krieth and Krieder' and ' Duffe and Beckman' respectively. The range of variables covered in the present analysis is 350 to 800C in water temperature, 1 to 10 m/sec in wind speed and 30 to 350C in ambient temperature. The ratio of the area of glass cover to the area of water surface is taken as 1.2. A temperature difference between water and ambient of atleast 50C is assumed. Various heat transfer coefficients vs water temperatures for different wind speeds are plotted.

Keywords: The radiative; Convective and evaporative heat transfer; Heat flow; Glass cover; Wind speed

1. Introduction

The basin type solar still can be erected horizontally on the ground with its bottom

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insulated as shown in figure 1.

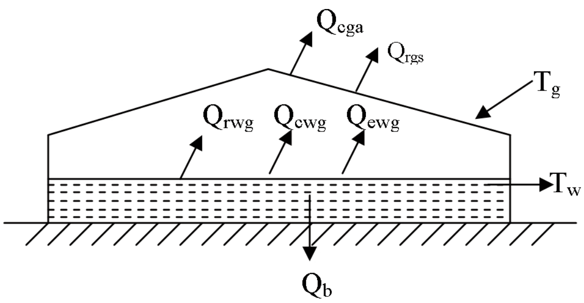

Fig. 1 Conventional solar still

From the available literature it can be concluded that the productivity of the still can be improved considerably by increasing the water temperature. The water in the basin absorbs the solar radiation penetrated through the glass cover. But due to the heat losses the energy entering the still is not fully utilized to produce vapours and hence the quantity of distillate depends on the heat losses from the basin. The heat loss from the still is mainly through the base of the still on the down ward direction and across the top cover in the upward direction. Thermal circuit of a solar still is shown in the figure 2.

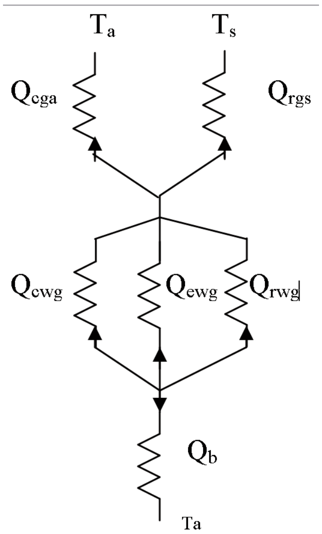

Fig. 2 Thermal circuit of a solar still

For a still well insulated the bottom losses can be neglected, the upward heat losses in a still is due to radiative, convective and evaporative heat exchange between water surface and glass cover and convective and radiative heat exchange between glass and surroundings.

The present work aims at studying the effect of wind speed on convective, radiative and evaporative heat transfer coefficients between water and glass cover for given water temperature and ambient temperature. For a given condition the heat balance equation on the glass cover is solved for the glass temperature by trial and error. The glass temperature thus obtained is used to estimate the above heat transfer coefficients.

2. Property relations

Some of the property relations used in this work are presented below The relation to estimate the partial pressure of water at any temperature T given by 'Keenan and Keys'[1] is

$$P = 165960.72 \times 10^{-\frac{\left[x\left(a+bx+cx^3\right)\right]}{\left[T(1+dx)\right]}} \quad ..1$$

Where, x = 647.27 – T, a = 3.24378, b = 5.8683 10^{-3}, c = 1.170238 10^{-8}, and d = 2.18785 10^{-3}, T is in degrees K.

The latent heat of vaporization given by [2] is

$$h_{fg} = 2325.89\left[1359.2 - 0.575\left(T_w \times 1.8\right)\right] \quad ..2$$

Generally in a solar still the heat exchange between glass and surroundings is estimated with reference to the sink temperature. Usually sky temperature is used as sink temperature.

The relation for the sky temperature given by [3] is

$$T_s = 0.0552 \times T_a^{1.5} \quad ...3$$

3. Individual heat transfer coefficient relations

The radiative, convective and evaporative heat transfer coefficients between water and glass cover of a basin type solar still are respectively given by [4,5]

$$h_{rwg} = 0.9\sigma\left(T_w^2 + T_g^2\right)\times\left(T_w + T_g\right) \quad ...4$$

$$h_{cwg} = 0.884\left\{\left(T_w - T_g\right) + \left[\left(P_w - P_g\right)\Big/\left(2016 - P_w\right)\right]T_w\right\}^{1/3} \quad ..5$$

$$h_{ewg} = \frac{9.15\times10^{-7}\times h_{cwg}\left(P_w - P_g\right)h_{fg}}{\left(T_w - T_g\right)} \quad ...6$$

The radiative heat transfer coefficient between glass cover and sky is giv en by

$$h_{rgs} = \varepsilon_g\sigma\left(T_g^2 + T_s^2\right)\left(T_g + T_s\right) \quad ...7$$

The convective heat transfer coefficient between the top of the glass cover and the surroundings suggested by 'McAdams' [6] is

$$h_w = 5.7 + 3.8V \quad ...8$$

Heat balance on the glass cover

Neglecting the heat capacity and thermal resistance of the glass cover and the solar radiation absorbed by it, the heat balance on the glass cover (assuming steady state heat transfer) can be written as

$$Q_{cga} + Q_{rgs} = Q_{rwg} + Q_{cwg} + Q_{ewg} \quad ...9$$

or,

$$A_g h_w\left(T_g - T_a\right) + A_g h_{rgs}\left(T_g - T_s\right) =$$

$$= A_w\left[h_{rwg} + h_{cwg} + h_{ewg}\right]\left(T_w - T_g\right) \quad ...10$$

Where $A_r = \dfrac{A_g}{A_w}$

$$A_r h_w\left(T_g - T_a\right) + A_r h_{rgs}\left(T_g - T_s\right) =$$

$$= \left[h_{rwg} + h_{cwg} + h_{ewg}\right]\left(T_w - T_g\right) \quad ...11$$

Substituting heat transfer coefficients from equations (4) to (7) in equation (11) can be written as

$$0.9\sigma\left(T_w^4 - T_g^4\right) + 0.884\bullet$$

$$\bullet\left\{\left(T_w - T_g\right) + \left[\left(P_w - P_g\right)\Big/\left(2016 - P_w\right)\right]T_w\right\}^{1/3}\bullet$$

$$\bullet\left[\left(T_w - T_g\right) + 9.15\times10^{-7}\times\left(P_w - P_g\right)h_{fg}\right] =$$

$$= \varepsilon_g\sigma A_r\left(T_g^4 - T_s^4\right) + A_r h_w\left(T_g - T_a\right) \quad .12$$

The value of hw is obtained from equation (8) by substituting wind velocity in it. The glass cover temperature is obtained from equation (12) by trail and error. The glass temperature thus obtained is substituted in equations (4), (5) and (6) to estimate the respective heat transfer coefficients. The range of variables covered in the analysis are water temperature from 35°C to 80°C, Wind speed from 1m/s to 10 m/s. The ambient temperatures considered are 30°C and 35°C. Ar, the ratio of the area of glass to area of water surface, is assumed as 1.2.

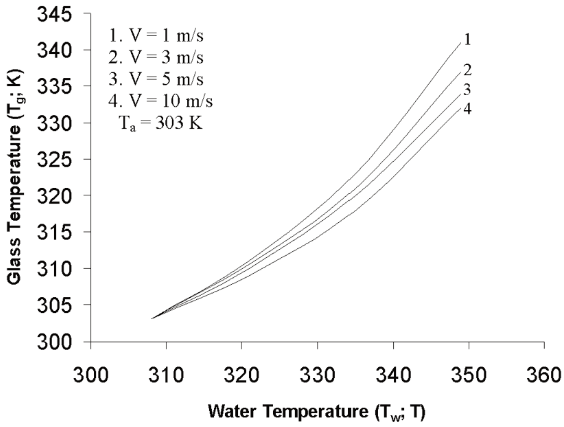

Fig.3. Water temperature vs glass cover temperature

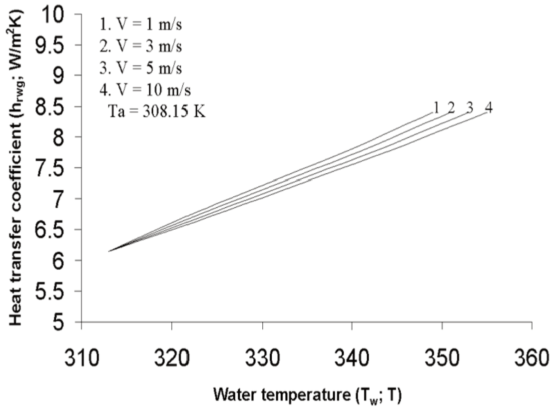

Fig.6. Water temperature vs heat transfer coefficient

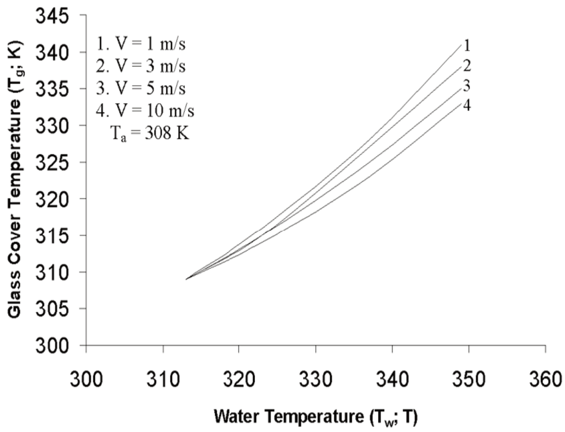

Fig.4. Water temperature vs glass cover temperature

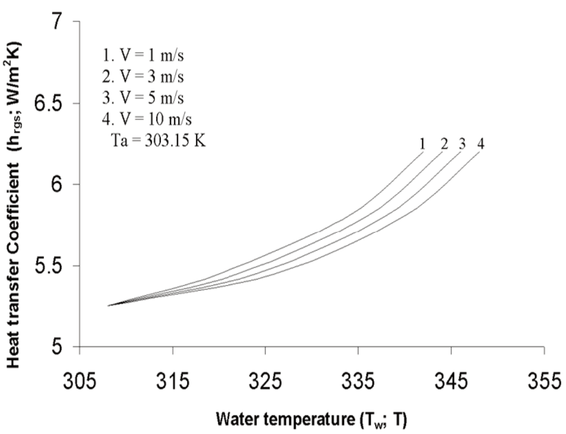

Fig.7. Water temperature vs heat transfer coefficient

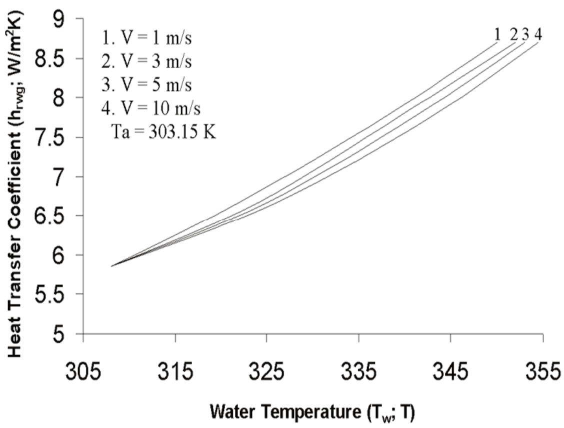

Fig.5. Water temperature vs heat transfer coefficient

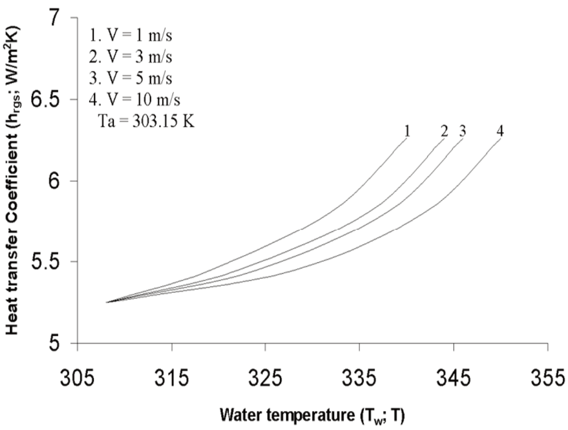

Fig.8. Water temperature vs heat transfer coefficient

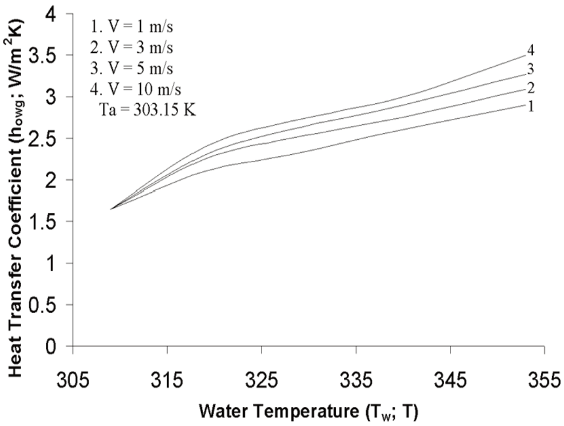

Fig.9. Water temperature vs heat transfer coefficient

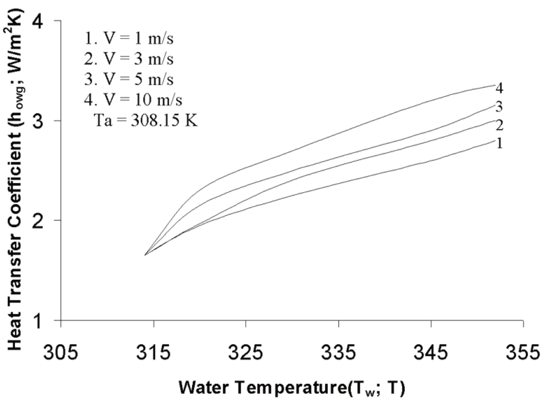

Fig.10. Water temperature vs heat transfer coefficient

4. Conclusion

In this work an attempt is made to study the influence of wind speed on various heat transfer coefficients involved in the upward heat flow process in a conventional basin type solar still. For this, the glass cover temperature is obtained by trial and error to a reasonably good accuracy. Results indicate that for a given water temperature and wind speed the glass temperature is increasing with the increase in ambient temperature. But at elevated water temperatures this increase is marginal. With the increase in wind speed the glass temperature is decreasing, but this variation is considerable at elevated water temperatures. This is due to the increasing convection losses from the glass cover at higher wind speeds. For given water and ambient temperatures the radiative heat transfer coefficient between water and glass (h_{rwg}) is decreasing with the increase in wind speed. This is mainly due to the lower glass temperature at higher wind speeds. But this heat transfer coefficient is following a reverse trend with ambient temperature for a fixed wind speed and water temperature. The convective heat transfer coefficient between water and glass (h_{cwg}) is varying directly with wind speed under similar conditions. The wind speed has very marginal influence on the evaporative heat transfer coefficient between water and glass (h_{ewg}), as this coefficient mainly depends on the water temperature and its partial pressure, and hence water temperature vs h_{ewg} could not be plotted. Finally, the radiative heat transfer coefficient between glass and sky (h_{rgs}) with increase in wind speed decreases. This is due to the decreased glass temperature at higher wind speeds.

Nomenclature

A_g = area of glass cover (m^2)

A_W = surface area of water (m^2)

h_c = convective heat transfer coefficient (W/m^2K)

h_e = evaporative heat transfer coefficient (W/m^2K)

h_{fg} = latent heat of vaporization (J/Kg)

h_r = radiative heat transfer coefficient (W/m K)

h_w = wind heat transfer coefficient (W/m K)

P = partial pressure of water vapor (mm of Hg)

Q = heat transfer rate (W)

Q_c = convective heat transfer rate (W)

Q_e= evaporative heat transfer rate (W)

Q_r = radiative heat transfer rate (W)

T = temperature (K)

V = Wind speed (m/sec)

σ = Stefan-Boltzmann constant $(W/m^2/k^4)$

ε = emissivity

Subscripts

a = ambient

g = glass cover

gs = glass to sky

s = sky

w = water in the basin

wg = water to glass

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