Impact of Ambient Conditions and Top Heat loss on Useful Energy of Flat Plate Solar Collectors

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***Abstract*—Solar energy trapping device which uses water or air as working fluid called flat plate collector (FPC). The performance of solar flat plate collector highly depends on the value of top heat loss coefficient for different operating and climate condition. To obtain top heat loss coefficient, the value of effective black body sky temperature has to be inserted in the analytical equation. Effective black body sky temperature related equation described by different researcher mentioned in the literature. The present study shows maximum variations of estimated value of top heat loss coefficient 9.7%, radiative heat loss between the glass and ambient 13.45% and useful energy 11.3%. The range of variables:50-90% for relative humidity,10-25w/m^2 for wind heat transfer coefficient 288-308K for ambient temperature,323-423K for absorber plate temperature, 30mm for air gap between plate and glass ,0.9 for emittance of the plate and 0.85 emittance of glass cover.**

Keywords—top heat loss coefficient,radiative heat loss,effective black body sky temperature ,flat plate collector,useful energy.

I. INTRODUCTION

Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. The device that heat water by solar energy called solar water heater. A solar flat plate collector is one of key component of active solar-heating systems, gathers the energy from the sun, converts its radiation to heat, then transferring the heat to the fluid. A FPC is used extensively for domestic water heating applications usually employed for low temperature application varying from 40(^{o}c) to 100(^{o}c).It is simple in design and has no moving parts so requires little maintenance.

FPC consists of a water proof, metal or fiberglass insulated box containing a dark colored absorber plate, with one or more translucent glazing. Absorber plates are typically made out of metal due to its high thermal conductivity and painted with special selective surface coatings in order to absorb and transfer heat better than regular black paint. The glazing covers reduce the convection and radiation heat losses to the ambient. A heat-conducting fluid, usually water, glycol, or air, passes through pipes attached to the absorber plate.

II. ENERGY BALANCE EQUATION

$$Q_u = A_p I - Q_L \tag{1}$$

$$Q_L = A_p U_L (T_{pm} - T_a) \tag{2}$$

Where,

Q_u=useful heat gain in watt
A_P=area of the absorber plate in (m^2)
I=solar flux absorbed in the absorber plate in (w/m^2)
Q_u=rate of heat loss in watt
T_{mp}=average temperature of the absorber plate in kelvin
T_a=ambient temperature in kelvin
U_L=total heat loss coefficient in (w/m^{2}k)

Over all Heat loss Coefficients in solar collectors is the solar energy absorbed by the absorber plate is distributed to use full gain and to thermal losses through the top, bottom, and edges. For the purpose of calculating the total overall heat loss coefficient (U_L) of the solar collector the following equation is used

$$U_L = U_t + U_b + U_e , \tag{3}$$

Where,

U_b ,U_e ,U_t are loss coefficient from the edge, bottom and top of the solar collector to the ambient (W-m^{-2}-K). Majority of heat loss in flat plate collector is from top through glass cover so ignoring side and bottom loss insignificant change on over all heat loss. Evaluations of top heat loss coefficient of flat plate single glazed collector have been proposed [1]-[4]. Evaluations of top heat loss coefficient of flat plate collector based on ambient temperature as well effective black body sky temperature accurately proposed by [5].To obtain top heat loss coefficient, U_t, the value of effective black body sky temperature, T_s, has to be inserted in the analytical equation. Effective black body sky temperature related equation at same ambient condition described by different researcher mentioned in the literature.

‘‘Reference [6] Proposed relation between clear sky emissivity as a function dew point temperature, T_{dp} in (c^0).

$$\varepsilon_s = 0.711+0.56(\frac{T_{dp}}{100})+0.73\left(\frac{T_{dp}}{100}\right)^2 \quad (4)$$

‘‘Reference [7] revealed that emissivity of clear sky depend on the partial pressure of water vapor P_v, dew point temperature T_{dw} and the atmospheric temperature T_a given as

$$\varepsilon_s = 0.52+0.065P_v^{0.5} \quad (5)$$

‘‘Reference [8] derived correlation between sky emissivity versus surface dew point temperature.

$$\varepsilon_s = 0.741+0.0062T_{dp} \quad (6)$$

‘‘Reference [9] studied the behavior of effective black body sky temperature with different climatic condition and concluded that effective black body sky temperature changes with change in ambient temperature. The relation between effective black body sky temperature and ambient temperature (T_a)

$$T_s = 0.0552T_a^{1.5} \quad (7)$$

The effective black body sky temperature has been estimated for different climatic condition taken in Guwahati (India) for summer and winter seasons.

In the present study, for the given range of absorber plate temperature, ambient temperature, humidity and wind transfer coefficient the variation of top heat loss coefficient has been studied .Mallik and samdrashi analytical equation has been used for calculating top heat loss coefficient by applying effective black body sky temperature obtained from correlation given by [6]-[9].

III. EVALUATION OF TOP HEAT LOSS COEFFICIENT

‘‘Reference [5] obtained accurate way of calculating top heat loss coefficient for single glazed flat plate collector.

The top Heat loss coefficient of single glazed flat plate collector given as

$$(U_t)^{-1} = (h_{rpg}+h_{cpg})^{-1}+(h_{rga}+h_w)^{-1}+\frac{L_g}{K_g} \quad (8)$$

Where, L_g and K_g are thickness and conductivity of the glass.

The above equation can be written as in the form of radiative heat transfer coefficient between plate and glass cover,(h_{rp-g}) radiative heat transfer coefficient between glass and ambient (h_{rg-a})and convective heat transfer coefficient between absorber plate and glass cover(h_{cp-g}) as follow

$$h_{rpg} = \frac{\sigma(T_p+T_g)(T_p^2+T_g^2)}{\frac{1}{\varepsilon_p}+\frac{1}{\varepsilon_g}-1} \quad (9)$$

$$h_{rga} = \frac{\sigma\varepsilon_g(T_g^4-T_s^4)}{(T_g-T_a)} \quad (10)$$

$$h_{cpg} = \frac{5.78(T_p-T_g)^{0.27}}{T_{mpg}^{0.31}L_{p-g}^{0.21}} \quad (11)$$

The glass temperature (T_g) determination based on the value of effective black body sky temperature and ambient temperature.

a) If ambient temperature equal to sky temperature, $T_s=T_a$

$$T_g = T_a + h_w^{-0.38}\left[0.567\varepsilon_p-0.403+\frac{T_p}{429}\right](T_p-T_a) \quad (12)$$

b) If ambient temperature is higher than sky temperature.

$$T_g = T_a + h_w^{-0.42}\left[\begin{array}{l}0.6336\varepsilon_p-0.6547+\\ \frac{T_p}{346}-1.16\exp^{\{-0.072(T_p-T_a)\}}\end{array}\right](T_p-T_a) \quad (13)$$

The mean temperature (T_{mpg}) between the plate and the glass given by

$$T_{mpg} = 0.5(T_p+T_g) \quad (14)$$

IV.RESULTS AND DISCUSSION

The value of top heat loss coefficient for single glazed flat plate solar collector obtained from the relation given by Mallik and samdrash using effective balack body sky temperature reported by [6]-[9].

The range of the variable considered for this analysis is for 50-90% relative humidity, 10-25w/m^2 for wind heat transfer coefficient, 288-308K for ambient temperature, 323-423K for absorber plate temperature, 30mm for air gap between plate and glass, 0.9 for emmitance of plate and 0.85 for emmitance of glass cover. The above various climatic conditions are common in summer and winter for different month of a year in Guwahati.

Top heat loss coefficient has been estimated using effective black body sky temperature from correlation proposed by [6]-[9] for the given particular value of absorber plate temperature, wind heat transfer coefficient, ambient temperature and relative humidity.

A comparison of value of U_t made in Figs.1, 2, 3, and 4. Figures 1 and 2 show variation of Top heat loss coefficient with plate temperature for ambient condition in summer and Fig.3, and 4 are for winter season in Guwahati. It can be seen from the Fig.1 and 2 U_t increases with absorber plate temperature. The highest value of U_t is obtained when T_s estimated from Eqs. (7) relation is used in analytical equation but least when Eqs. (8) relation is used. It can be seen from Fig.1 the maximum variation obtained in estimated value of U_t is 9.7% and 7.3% in Fig.2 when absorber plate temperature is 333K.

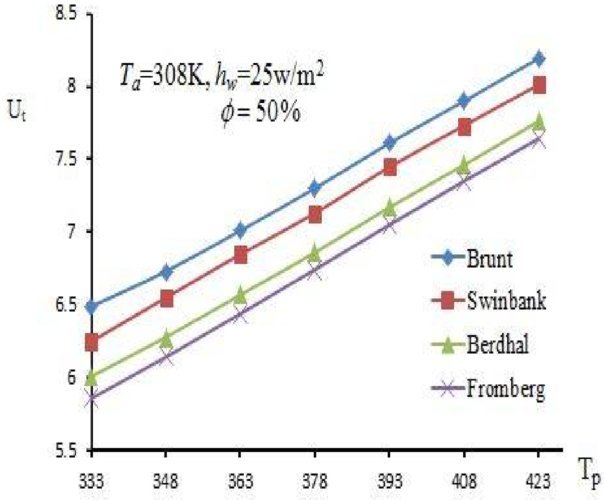

Figure 1: variation of U_t with T_p for summer season

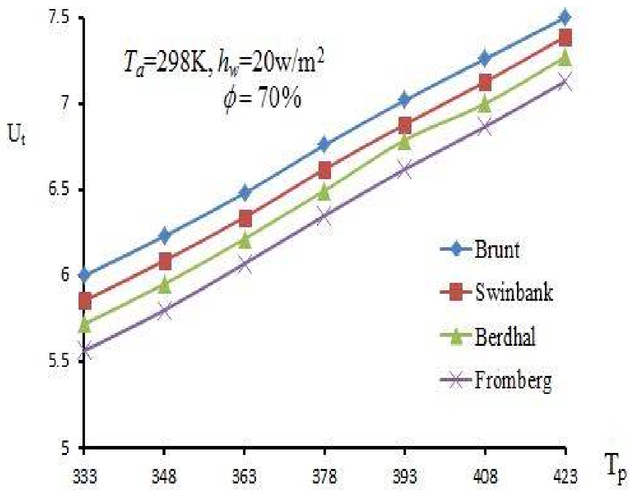

Figure 2: variation of U_t with T_p for summer season

It can be seen from Fig.3 and 4 U_t increases with absorber plate temperature and the maximum U_t variation for winter season for the given absorber plate temperature is 3.24% and 1.9%.

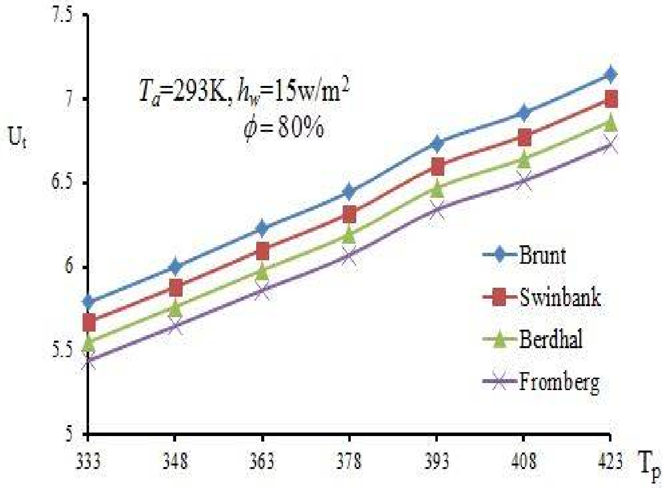

Figure 3: variation of U_t with T_p for winter season

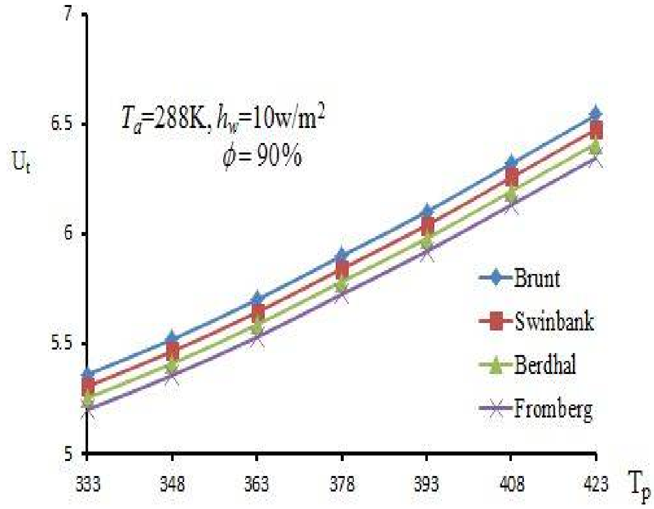

Figure 4: variation of U_t with T_p for winter season

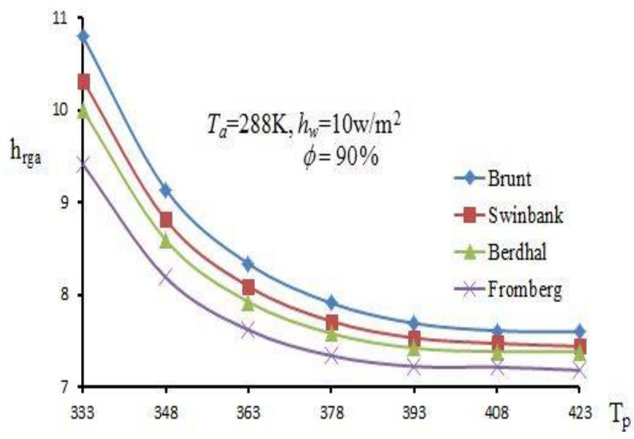

Figure 5: Variation of h_{rga} with T_p for winter season

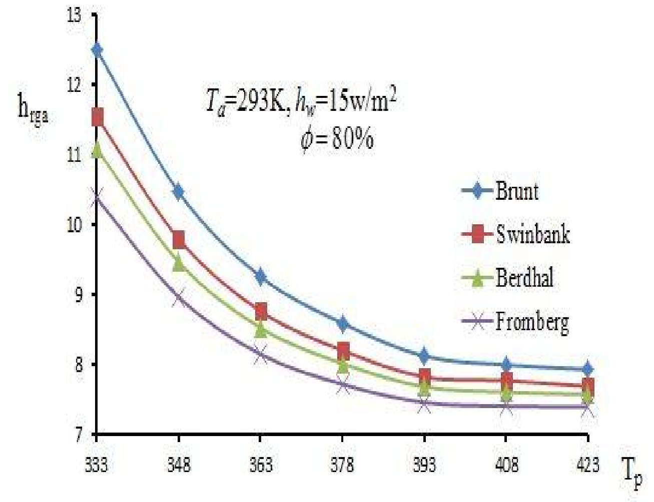

Figure 6: Variation of h_{rga} with T_p for winter season

Variation in radiative heat loss coefficient between glass cover and ambient with absorber plate temperature for different ambient conditions shown in Fig.5 and 6. It can be seen from Fig.5 and 6 radiative heat loss coefficient decreases with increase absorber plate temperature. It also observed that use of Eqs. (7) relation for sky temperature gives highest values of h_{rga} and Eqs. (8) results in lowest value of h_{rga}. Maximum variation obtained in estimated value of h_{rga} is 11.1% and 13.45%.

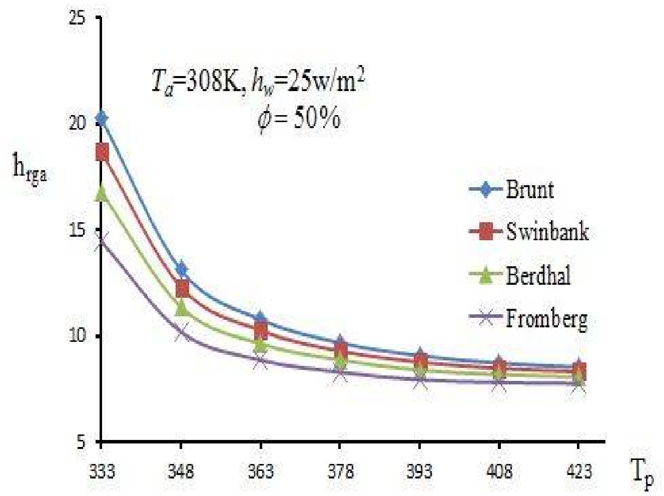

Figure 7: Variation of h_{rga} with T_p for summer season

Radiative heat loss coefficient between the glass cover and ambient for winter season can be seen in Fig.7 and 8. It can be seen that the value of Radiative heat loss coefficient decreases as the absorber plate temperatures increases. The maximum variation in radiative heat loss for summer season using Eqs. (7) and Eqs. (9) less than 5% but for the first and last is variation near to 20%.

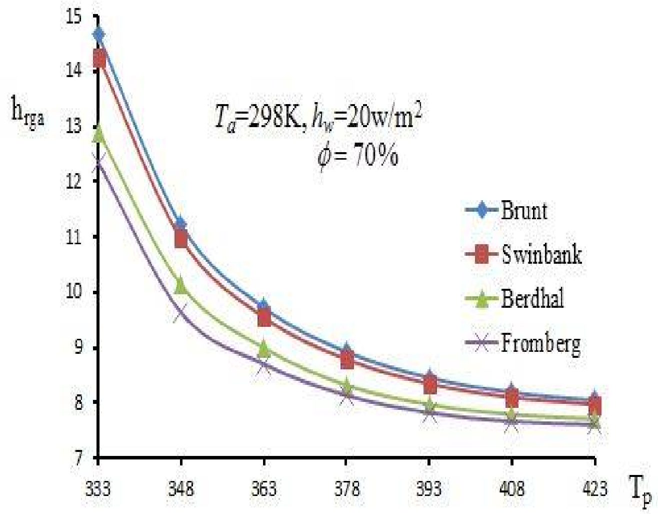

Figure 8: Variation of h_{rga} with T_p for summer season

The useful energy of the collector is the actual amount of energy that is available from the collector, after meeting the heat loss. For estimating of useful energy the size of the solar collector is 1.5m x 1.1m, the thickness of the glass is 5mm, 30mm for air gap between the glass and the absorber plate and intensity of solar radiation is 350W/m^2.

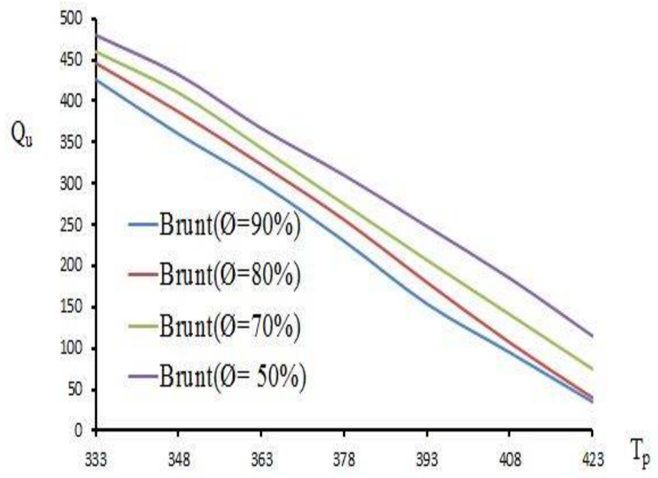

Figure 9: Variation of useful energy with T_p

It can be seen from the Fig.9 the value of useful energy is decreasing as the plate temperature increases, this is due to the increase of top heat loss coefficient as the absorber plate temperature increase. The maximum percentage of variation in useful energy is 11.3%.

V.CONCLUSION

1. Top heat loss coefficient U_t decreases with increase of in absorber plate temperature whereas value of radiative heat loss (h_{rga}) coefficient increase in absorber plate temperature.
2. The useful energy of single glazed collector decrease as the plate temperature increases; this is due to the increase of top heat loss coefficient.
3. Using Eqs. (7) relation for estimation of effective black body sky temperature results highest and Eqs. (8) results lowest value of top heat loss coefficient and radiative heat loss coefficient for the whole range of variable covered in this study.
4. The maximum variation in useful energy for single glazed collector found to be 11.3%.
5. The maximum variation in top heat loss coefficient found to be 9.7% for summer season at absorber plate temperature is 333K.

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NOMENCLATURE

T_a-ambient temperature (K)
T_s-effective black body sky temperature (K)
T_g-average temperatures of glass cover (K)
T_p-absorber plate temperature (K)
T_{dp}- dew point temperature (^oc)
U_t-top heat loss coefficient (W m^{-2} K^{-1})
I-intensity of solar radiation (Wm^{-2})
Q_u-useful energy (W)
ε_s -emmitance of clear sky
ε_p -emmitance of coating absorber plate
ε_g -emmitance of glass cover
P_v-partial pressure of water vapour in mb
L-air gap spacing (m)
L_g-thickness of the glass (m)
K_g-conductivity of the glass (W m^{-2} K^{-1})
h_w-wind heat transfer coefficient (W m^{-2} K^{-1})
h_{cpg}-convective heat transfer coefficient between plate and glass (W m^{-2} K^{-1})
h_{rga}-radiative heat transfer between glass and ambient (W m^{-2} K^{-1})
h_{rpg}-radiative heat loss between glass and absorber plate (W m^{-2} K^{-1})

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