Research Article

EXPERIMENTAL STUDY OF EFFECT OF WIND ENERGY ON HEAT TRANSFER COEFFICIENT IN TRAPEZOIDAL AND RECTANGULAR SHAPE OF ABSORBER PLATE IN BOX TYPE SOLAR COOKER

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ABSTRACT

The Box type Solar Cooker is the simplest device to convert solar energy into heat energy which is finally utilized to cook the food staff kept in the cooker. The box type solar cooker are constructed usually either with rectangular or trapezium absorber plate glass cover enclosure. In this paper simple thermal analysis carried out to evaluate the natural convective heat transfer coefficient h_{cplg} for a trapezoidal absorber plate- lower glass cover enclosure of a double glazed box type solar cooker. The experimental data has been correlated by an equation in the form; N_u=C Ra^n the values of constant C and n , obtained by simple linear regression analysis are used to calculate the convective heat transfer coefficient for reference wind speed 1.5 to 2.5 m/s. The heat transfer analysis predicts that h_{cplg} varies form 4.85 W/m^2 ^{0}C to 6.28 W/m^2 ^{0}C for the absorber plate temperature from 72.4 ^{0}C to 150 ^{0}C. These results of h_{cplg} are compared with those of rectangular enclosure for the same absorber-lower glass cover temperatures and gap spacing. It found that the values of convective heat transfer coefficient and top heat loss coefficients for rectangular enclosure are lower by 32.5 % and 12% respectively.

KEYWORDS Box-type solar cooker; Convective heat transfer coefficient; Trapezium enclosure; Top heat loss coefficient.

1. INTRODUCTION:

The box type solar cooker is the simplest device to convert solar energy into heat energy which is finally utilized to cook the food stuff kept in the cooker. The estimation of heat losses is of almost importance for performance evaluation of solar cooker, although the conduction losses through cooker may be estimated analytical, the estimation of Top heat losses is complex problem due to tray –shape absorber plate and the presence of combined convective and radiative mode of heat transfer. However the same correlation cannot be used for calculating top heat loss coefficient. [1]

1. In collectors, absorber is a flat plate while in cooker it is in the from of tray (Trapezium)
2. The spacing between glass cover and absorber plates is quite different in both the cases. (Approximate 15 to 40 mm in collectors and 70 to 100 mm in box cooker).
3. The presence of heat loss channels such as sealing edges and corner affects the heat losses more significantly in the case of box cooker as compared to the collector and hence heat loss coefficients will be different in both cases.

2. THERMAL PERFORMANCE FOR TOP HEAT LOSS COEFFICIENT:

It is convenient from the point of view of analysis to express the heat lost from the cooker in terms of an overall loss coefficient defined by the equation under steady state condition, the external energy supplied to the cooker equals the total heat loss from the cooker [1].

$$Q_{in} = Q_l = U_l A_c \left(T_{pm} - T_a\right) \quad \text{.........} \quad (2.1.)$$

$$U_l = \frac{Q_{in}}{A_c\left(T_{pm} - T_a\right)} \quad \text{...............} \quad (2.2.)$$

The total heat lost from the cooker is the summation of the heat losses from, Top, Bottom, Sidewalls, Edges, Corner and the Sealing of the corner. [1]

$$Q_l = Q_t + Q_b + Q_w + Q_e + Q_c + Q_s \quad \text{.........} \quad (2.3.)$$

2.1. Experimental Top Heat Loss Coefficient.

The absorber plate to the inner glass cover,

$$\frac{Q_{net}}{A_c} = U_{P\lg}\left(T_P - T_{\lg}\right) \quad \text{..................} \quad (2.4)$$

The Inner glass and Upper glass,

$$\frac{Q_{net}}{A_c} = U_{\lg ug}\left(T_{\lg} - T_{ug}\right) \quad \text{..............} \quad (2.5)$$

The Upper glass and ambient air,

$$\frac{Q_{net}}{A_c} = U_{Uga}\left(T_{ug} - T_a\right) \quad \text{.............} \quad (2.6)$$

Experimental the Top heat loss coefficient U_{tp} for the unloaded cooker can be computed by using the relation.

$$U_{tp} = \left[U_{p\lg}^{-1} + U_{\lg ug}^{-1} + U_{uga}^{-1}\right]^{-1} \quad \text{......} \quad (2.7)$$

2.2. THEORETICAL TOP HEAT LOSS COEFFICIENT.

The heat loss factors of box type and concentrator type solar cooker have a strong influence on thermal performance; it is the function of the absorber plate temperature, wind heat transfer coefficient and ambient air temperature. Top heat loss coefficient for a box type solar cooker with double glazing is similar to that for a double glazed flat plate solar collector, it is a function of many variable such as plate temperature (T_p), Emittance, (ε_p), air gap spacing (L), and ambient air temperature (T_a). The top heat loss coefficient is evaluated by considering convection and re-radiation losses. For purpose of calculation it is assumed that the transparent covers and the absorber plate constitute a system of infinite parallel surfaces and that the flow of heat is one dimensional and steady, it is further assumed that the temperature drop across the thickness of the glass covers is negligible and that the interaction between the incoming solar radiation absorber by the covers and outgoing loss are neglected. [4]

2.2.1. The heat transfer by the convection and radiation between different components:

The absorber plate and lower glass cover

$$\frac{Q_{net}}{A_c} = h_{p\lg}\left(T_p - T_{\lg}\right) + \frac{\sigma\left(T_p^{\,4} - T_{\lg}^{\,4}\right)}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_g} - 1\right)} \qquad (2.8)$$

The lower glass cover and upper glass cover,

$$\frac{Q_{net}}{A_c} = h_{\lg ug}\left(T_{\lg} - T_{ug}\right) + \frac{\sigma\left(T_{\lg}^{\,4} - T_{ug}^{\,4}\right)}{\left(\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_g} - 1\right)} \qquad (2.9)$$

The upper glass cover and surrounding ambient air,

$$\frac{Q_{net}}{A_c} = h_w\left(T_{ug} - T_a\right) + \sigma\varepsilon_c\left(T_{ug}^{\,4} - T_a^{\,4}\right) \qquad (2.10)$$

Equation (2.8), (2.9), (2.10) is divided with respective temperature difference then we get,

Top heat loss coefficient of box type solar cooker as following, Subodh Kumar [4]

$$U_{tp}^{-1} = \left[h_{p\lg} + \frac{\sigma\left(T_p^{\,2} + T_{\lg}^{\,2}\right)\left(T_p + T_{\lg}\right)}{\left(\varepsilon_p^{-1} + \varepsilon_c^{-1} - 1\right)}\right]^{-1} + \left[h_{\lg ug} + \frac{\sigma\left(T_{\lg}^{\,2} + T_{ug}^{\,2}\right)\left(T_{\lg} + T_{ug}\right)}{\left(\varepsilon_c^{-1} + \varepsilon_c^{-1} - 1\right)}\right]^{-1} + \left[h_w + \sigma\varepsilon_c\left(T_{gu}^{\,2} + T_a^{\,2}\right)\left(T_{gu} + T_a\right)\right]^{-1} + \frac{\left(t_{\lg} + t_{ug}\right)}{k_g} \qquad (2.11)$$

2.3. NATURAL CONVECTIVE HEAT TRANSFER IN TRAPEZOIDAL ENCLOSURE OF BOX TYPE SOLAR COOKER.

The natural convective heat transfer coefficient, h_{cplg} for the absorber plate-lower glass enclosure can be computed using the expression for the Nusselt number as [5].

$$N_u = \frac{h_{cp\lg} L_{p\lg}}{K} = C\left(G_r P_r\right)^n \qquad (2.12)$$

$$h_{cp\lg} = \frac{K \times C\left(G_r P_r\right)^n}{L_{p\lg}} \qquad (2.13)$$

Where,

$L_{p\lg}$ = Characteristic length, the distance between the absorber plate and inner glass.

K = Thermal conductivity of the air at the mean temperature of the plate-glass.

Under steady state condition, the net input electrical energy (Q_{net}) is equal to the rate of heat loss from the plate to the inner glass cover. The upward heat loss from the cooker absorber plate at an average temperature T_p to the inner glass cover at an average temperature T_{lg} is given by.

$$Q_{net} = A_c\left(h_{cp\lg} + h_{rp\lg}\right)\left(T_p - T_{\lg}\right) \qquad (2.14)$$

Where A_c the aperture area of solar cooker and h_{cplg} and h_{rplg} are the natural convective and radiative heat transfer coefficients respectively between plate and inner glass cover.

The radiative heat transfer coefficient h_{rplg} is computed using the following standard relation.

$$h_{rp\lg} = \frac{\sigma\left(T_p^{\,2} + T_{\lg}^{\,2}\right)\left(T_p + T_{\lg}\right)}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1\right)} \qquad (2.15)$$

Substituting value $h_{cp\lg}$ in equation (2.12) it's becomes,

$$\left[\left(\frac{Q_{net}}{A_c\left(T_p - T_{\lg}\right)} - h_{rp\lg}\right)\left(\frac{L_{p\lg}}{K}\right)\right] = C\left(G_r P_r\right)^n = Z \qquad (2.16)$$

Therefore Equation (2.16) becomes

$$Z = C\left(G_r P_r\right)^n$$

Taking the logarithm of both sides of the above equation, one can write

$$LnZ = LnC + nLn(G_r P_r) \quad (2.17)$$

Equation (2.17) is represented an equation of a straight line in the following form,

$$Y = pX + q \quad (2.18)$$

Where, $Y = LnZ$, $p = n$, $X = \ln\left[G_r P_r\right]$ and $q = \ln C$.

The values of X and Y are calculated from the experimental data of the absorber plate and inner glass temperatures and upward heat flow values for different wind speeds. The different physical properties of air used for the computation of the Grashof number (G_r) and Prandtl number (P_r) have been evaluated at mean fluid temperature. The value of the constants p and q are obtained by using the simple linear regression analysis method. Following proposed correlation are calculated for Nusselt Number for different wind speed The constant C and n in Equation (4.19) are obtained by simple linear regression analysis with r.m.s. 85-90 %.

- $N_u = 0.056 \times \left(G_r P_r\right)^{0.415}$

  For wind speed = 1.5 m/s
- $N_u = 0.071822 \times \left(G_r P_r\right)^{0.398}$

  For wind speed= 2.0 m/s
- $N_u = 0.090157 \times \left(G_r P_r\right)^{0.381}$

  For wind speed = 2.5 m/s

Subodh kumar has evaluated the natural convective heat transfer coefficient for a trapezoidal absorber plate inner glass cover enclosure of double glazed box type solar cooker. They have proposed one correlation for the convective heat transfer coefficient of box type solar cooker with trapezoidal shape of absorber plate.[4].

$$h_{cal} = \frac{15.4 \times \left[\left(T_p - T_L\right)\right]^{0.285}}{T_{mal}^{\ 0.34}} \quad (2.4).$$

Samdarshi and Mullick have suggested an approximate equation for the convective heat transfer coefficient for horizontal rectangular enclosure in doubled-glazed flat plate solar collector.[5].

$$h_{cal} = \frac{5.78 \times \left[\left(T_p - T_L\right)\right]^{0.27}}{T_{mal}^{\ 0.31} L_{PL}^{\ 0.21}} \quad (2.5).$$

2.4. Empirical Equation for Top loss Coefficient for rectangular enclosure:

Top heat loss coefficient of Flat plate collector with rectangular absorber plate by Klein [6].

$$U_{tp} = \left[\frac{M}{\left(\frac{C}{T_{pm}}\right)\left(\frac{T_{pm} - T_a}{M + f}\right)^{0.33}} + \frac{1}{h_w} \right]^{-1} +$$

$$\left[\frac{\sigma\left(T_{pm}^{\ 2} + T_a^{\ 2}\right)\left(T_{pm} + T_a\right)}{\frac{1}{\varepsilon_p + 0.05M\left(1 - \varepsilon_p\right)} + \frac{\left(2M + f - 1\right)}{\varepsilon_g} - M} \right]$$

$f = (1 - 0.04h_w + 0.000h_w^{\ 2})(1 + 0.091M)$,

$C = 365.9(1 - 0.00883\beta + 0.0001298\beta^2)$

M = Number of glass cover

3. EXPERIMENTAL DETAIL AND SETUP

An experimental double glazed box type solar cooker of ply wood body has been used for the indoor experiment. The matt black painted aluminum trapezoidal shape tray with an aperture of 0.25 m^2 is fitted inside the cooker, and rock wool insulation is used on the bottom and sides of the cooker to minimize the thermal losses through conduction. The absorber tray (400mm*400 mm in size at the bottom) is heated by electrical coil (1000W). These are fixed under the bottom portion of tray and to provide uniform heating through a servo stabilized electric power supply as shown in Fig.3.1.The plate and sides are heated to different temperature by adjusting the power input supply through separate variac 150-1P max load 15 Amps, 240V. The power input heater coil is measured by a single Phase wattmeter (AC/DC) Dynamometer Type, Current rang 5/10 A, Scale range (0-1250W). All the temperature is measured by calibrated Cr-Al thermocouples with help of a digital thermometer .All thermocouple is located at different locations in absorber plate, as well in the centre of the inner glass and outer glass cover. The plate temperature and side temperature of the cooker is determined as the average of the thermocouple temperature. The ambient air temperature is measured with separate thermocouple. The forced air flow over the outer cover of the cooker is produced through the electrical fan and different wind speeds are produced by adjusting the speed of fan and distance from the cooker and it measured with help of 3 cup anemometer. The experimental work in this project is carried out for three different wind speeds, 1.5 m/s, 2 m/s, 2.5 m/s with two glazing.

Detail of Experimental Box type solar cooker

S.No.	Detail	Material	Dimension	Remark
1	Outer casing of the cooker	Plywood (12mm)	600*600*165 mm	
2	Absorber plate	Aluminum	Top=500*500mm Bottom=400*400mm Depth=95mm Thickness=1mm	emissivity of the absorber plate 0.90
3	Glazing	Plain glass	Thickness =4mm Spacing =20mm	emissivity of the glass cover=0.88
4	Insulation	Rook wool	Thickness=50mm Slab, 65 density	
5	Electrical coil		1000W	
6	Thermocouple	Cr-Al		
7	Coating absorber	Matt black		

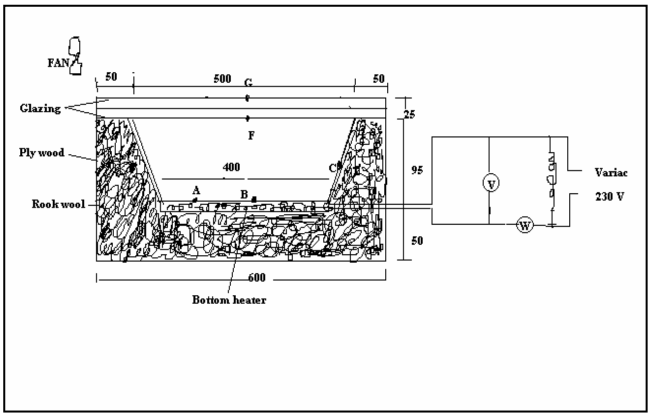


Fig.3.1. Schematic diagram of Box type solar cooker

Fig.3.2.. Indoor experimental set p (unloaded) in indoor condition.

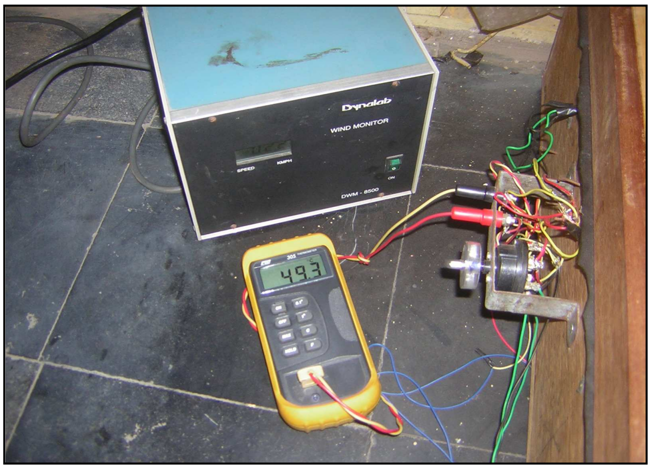


Fig.3.3. Temperature Pick up point

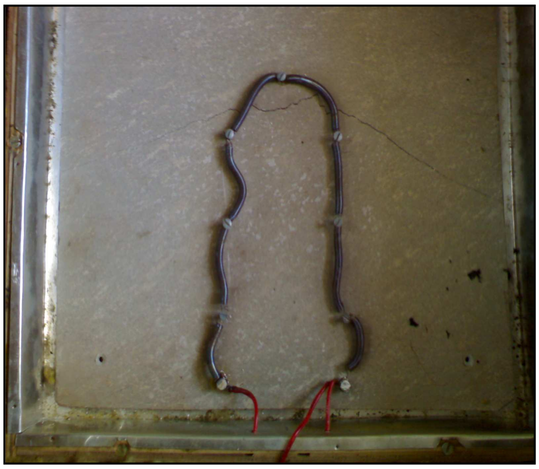


Fig.3.4. Electrical heater coil

4. RESULTS AND DISCUSSION:

Fig.4.1 to 4.3 is presents the comparison results it found that the values h_{cplg}, experimental correlation is higher 0.6 to 3.4 % higher with wind speed varies form 1.5 to 2.5 m/s for two glazing cover Fig.4.1 to 4.3 shows that the values of, h_{cplg} for rectangular enclosure are lower as compare to trapezium enclosure. Form the results it found the h_{cplg} of rectangular enclosure are 30.5 to 32.5 % lower than those computed for the trapezium enclosure with two glazing. Therefore greater care is required while using the relations for a rectangular enclosure in computing the convective heat transfer coefficient within the trapezium enclosure. Because the large gap spacing between absorber plate and lower glass in box type solar cooker so that nature air circulation higher in trapezium enclosure as compare to rectangular enclosure.

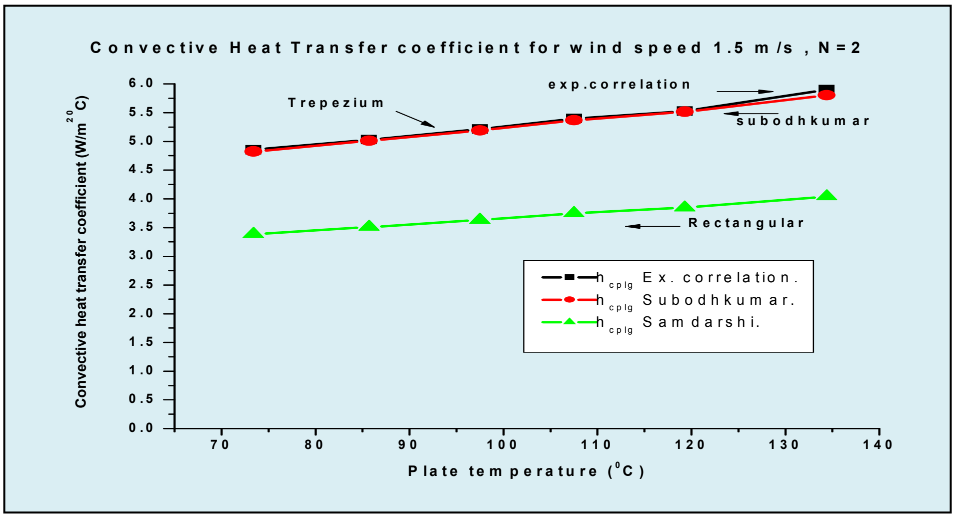


Fig.4.1. Variation of h_{cplg} for trapezium and rectangular enclosures for wind speed of 2.0 m/s, N=2

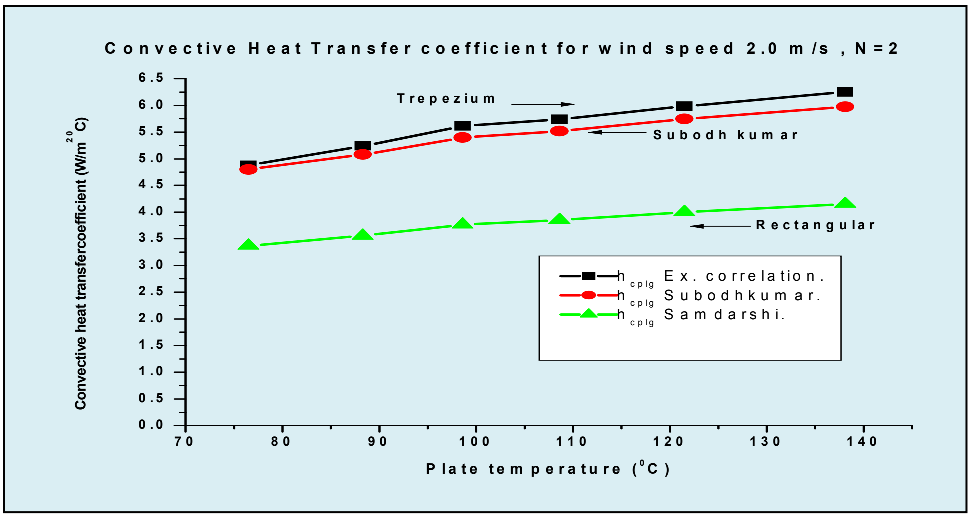


Fig.4.2. Variation of h_{cplg} for trapezium and rectangular enclosures for wind speed of 1.5 m/s, N=2

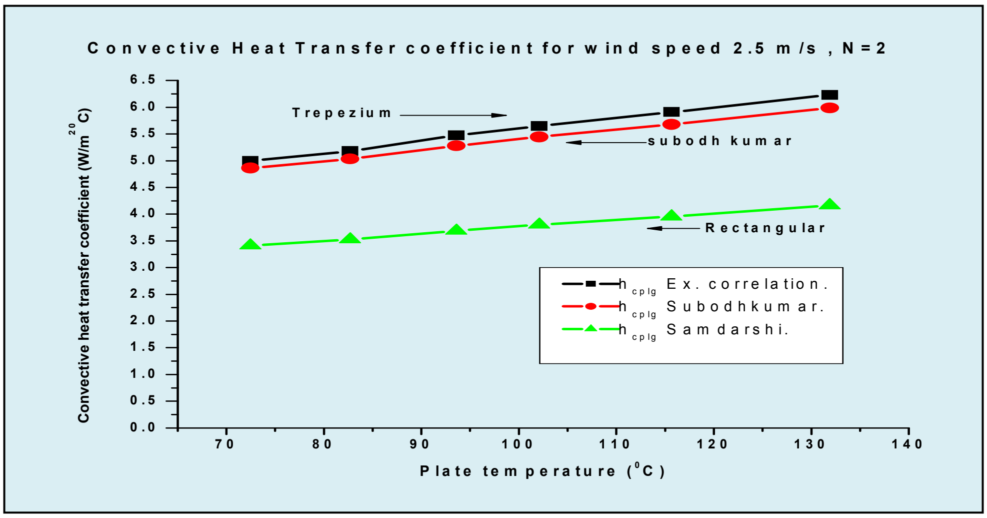
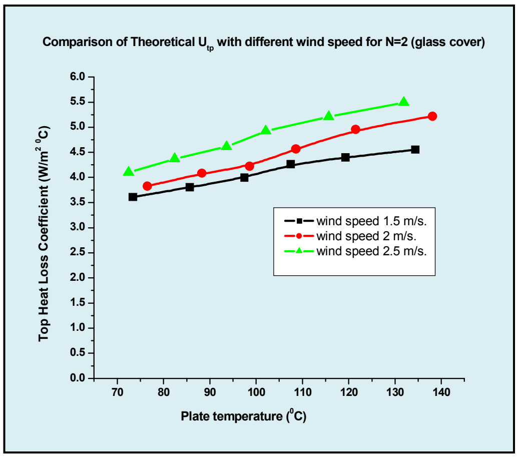


Fig.4.3.. Variation of h_{cplg} for trapezium and rectangular enclosures for wind speed of 2.5 m/s, N=2

Fig.4.4. Comparison of Exp U_{tp} with diff .wind speed



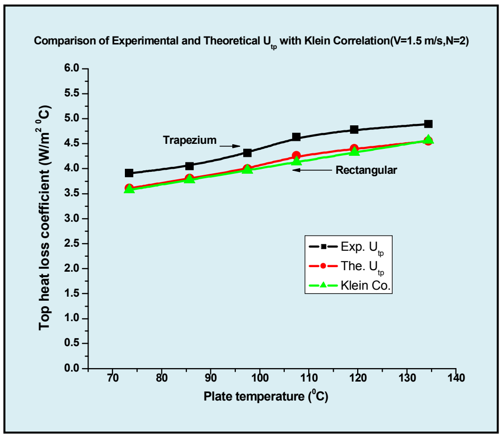
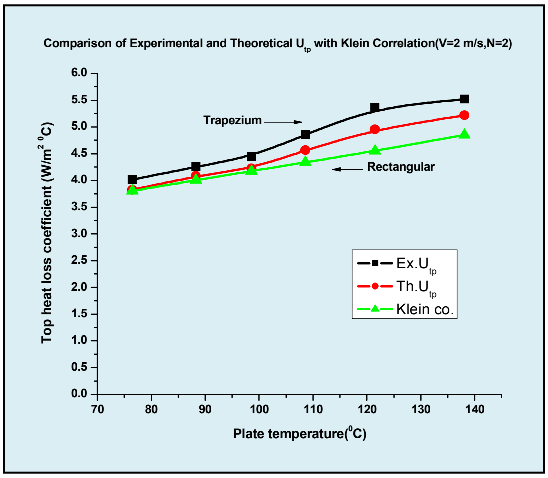


Fig.4.5 Comparison of Utp with diff. (V)

Fig. 4.6 Comparison of Utp diff. Enclosure (V = 1.5)



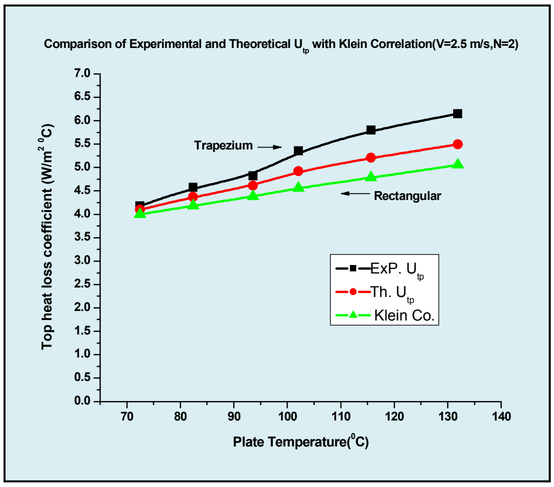


Fig.4.7. Comparison U_{tp} in diff. Enclouser (v=2m/s)

Fig.4.8. Comparison U_{tp} in diff. Enclouser (v=2.5m/s)

The top heat loss coefficient in case of flat plate collector and box type solar cooker are different due to following reasons. In collectors, absorber is a flat plate rectangular shape while in cooker it is a trapezium, the gap spacing between absorber plate and lower glass are quite different in both cases so that heat loss coefficients will different in both cases. Here, For the purpose of comparison the top heat loss coefficient has also been computed for rectangular enclosure using empirical correlation given by the Klein for the same absorber plate and lower glass cover temperatures and gap spacing, form result top heat loss coefficient in case of rectangular enclosure is lower as compare the box type solar cooker. Fig.4.5. shows wind speed 1.5 m/s and glass cover two, its experimental U_{tp} of trapezium enclosure is higher 8.41% than rectangular enclosure in both correlations. Fig.4.6 shows for wind speed 2.0 m/s and glass cover two, its experimental than rectangular enclosure using Klein of trapezium enclosure is higher 9.1 % than rectangular enclosure using Klein Fig.4.7 presents wind speed 2.5 m/s and glass cover two its experimental U_{tp} of trapezium enclosure is higher 11.9 % than rectangular enclosure using Klein. Fig.4.4.shows that the increases the wind speed the top heat loss coefficient is increases at rising in the plate temperature.

CONCLUSIONS:

Different wind speeds will not effect more in interior part's of cooker, convective heat transfer coefficient is depend on the absorber plate, lower glass temperature and air spacing between these two components. The convective heat transfer coefficient of rectangular enclosure is 30.5 to 32.5 % lower than those computed for the trapezium enclosure with two glazing

The top heat loss coefficient U_{tp} in case of box type solar cooker is 12 % higher than the flat plate collector. The major advantage of using a trapezoidal shaped tray in a box type solar cooker is the absorption of higher fraction of incident solar radiation falling on the aperture at larger incidences angles, due to more exposed surface area. In addition, less absorber material is required, thus resulting in lower fabrication cost.

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