

Solar Flat Plate Collector Performance By Variation of Different Parameters

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ABSTRACT

The flat plate collector is one of the most widely used device for harnessing the solar energy. The measurement of the flat plate collector performance is the collector efficiency. The collector efficiency is the ratio of the useful energy gain to the incident solar energy over a particular period of time. The useful energy gain in turn depends on the energy loss from the top surface of the collector both due to convective & radiative heat transfer processes. The losses from the bottom and from the edges of the collector do exist but their contribution is not as significant as the losses from the top. Hence investigations are carried out to study the losses by changing the collector tilt to determine the top loss coefficient.

Keywords -Collector, Useful Heat Gain, Losses, Top loss coefficient, Efficiency.

I. INTRODUCTION

The technology of harnessing the solar energy has reached to the state of commercialization on mass scale. The greatest advantage of using solar energy is that it is an inexhaustible and pollution free source of energy. The Lord Sun gives approximately 1.8×10^{11} MW powers, which is many thousand times higher than the present consumption rate on earth. This makes it one of the most promising of the Unconventional sources of energy.

II. NOMENCLATURE

A_p Area of absorber plate, m^2
 Q_s Losses of heat from sides, W
 Q_b Losses of heat from bottom, W
 Q_t Losses of heat from top, W
 E_{in} Energy input, W
 β Collector tilt angle, degrees
 N No. of covers
 σ Stefan Boltzmann constant $5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$
 ϵ_p Emissivity of plate
 ϵ_c Emissivity of cover
 T_b Temperature of bottom cover of collector, K
 T_{c1} Mean temperature of 1st cover, K
 T_{c2} Mean temperature of 2nd cover
 T_c Thickness of cover, m
 U_t Top heat loss co-efficient, $\text{W/m}^2\text{K}$
 U_L Over all heat loss co-efficient of collector, $\text{W/m}^2\text{K}$
 T_h Temperature of heater plate, K
 T_p Temperature of absorber plate, K
 h_w wind induced convective heat transfer co-efficient, $\text{W/m}^2\text{K}$
 h_{C1-2} Convective heat transfer co-efficient between 1st and 2nd cover, $\text{W/m}^2\text{K}$
 K_c Thermal conductivity of cover, $\text{W/m}^2\text{K}$

h_{p-c} Convective heat transfer co-efficient between absorber plate & cover, $\text{W/m}^2\text{K}$

h_{c-a} Convective heat transfer co-efficient between cover & atmosphere, $\text{W/m}^2\text{K}$

F_{p-c} Radiation shape factor between plate & cover

ϵ_g Emissivity of glass cover

Q_u Useful energy gain, W

S Flux absorbed by collector, W/m^2

III. FLAT PLATE COLLECTOR

The flat plate collector shown in Fig. 1 is one of the most widely used device for harnessing solar energy. In any solar collection device, the principle usually followed is to expose a dark surface to solar radiation so that the radiation is absorbed. A part of the absorbed radiation is then transferred to a fluid like air or water. When no optical concentration is done; the device in which the collection is achieved is called the flat plate collector. The flat plate collector is the most important type of solar collector because it is simple in design, has no moving parts and requires little maintenance. It can be used for a variety of applications in which temperature ranging from 40°C to 100°C is required.

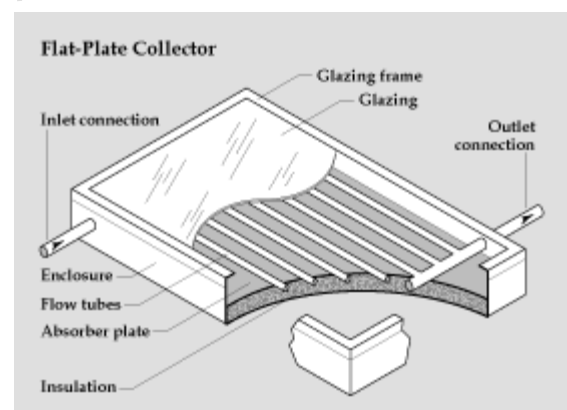


Fig. 1 Solar flat plate collector

IV. PERFORMANCE ANALYSIS OF FLAT PLATE COLLECTOR

An energy balance on the absorber plate yields the following equation for steady state:

$$q_u = A_p S - q_1 \quad (1)$$

where, q_u = useful heat gain, i.e., the rate of heat transfer to the working fluid; S = incident solar flux absorbed in the absorber plate; A_p = area of the absorber plate and q_1 = rate of heat loss. by the absorber. In order to determine the flux 'S' absorbed by the absorber a term called the transmittivity absorptivity product (τ_a) which is defined as the

ratio of the flux absorbed in the absorber plate to the flux incident on the cover system, is evaluated and is given by 'S'.

$$S = I_b r_b (\tau \alpha) + I_d r_d + (I_b + I_d) r_r \quad (2)$$

Where

τ = transmittivity of glass cover system.

α = absorptivity of absorber plate.

$(\tau \alpha)_b$ = transmittivity absorptivity product for the beam radiation falling on the collector.

$(\tau \alpha)_d$ = transmittivity absorptivity product for the diffuse radiation falling on the collector.

Now, rate of the heat loss is given by,

$$q_l = U_l A_p (T_{pm} - T_a) \quad (3)$$

Where,

U_l = overall loss coefficient

A_p = area of absorber plate.

T_{pm} = average temperature of the absorber plate, and

T_a = temperature of surrounding air.

The heat loss from the collector is the sum of the heat loss from the top, the bottom and the sides.

$$q_l = q_t + q_b + q_s$$

Where,

$$q_t = U_t A_p (T_{pm} - T_a)$$

$$q_s = U_s A_p (T_{pm} - T_a)$$

$$q_b = U_b A_p (T_{pm} - T_a)$$

$$U_l = U_t + U_b + U_s$$

Here, U_t , U_b and U_s are the top, the bottom and the side loss co-efficient respectively.

V. TOP LOSS COEFFICIENT

The top loss co-efficient U_t is evaluated by considering the convection and the radiation loss from the absorber plate in the upward direction. For the purpose of calculation, it is assumed that

- 1) The transparent covers and the absorber plate constitute a system of infinite parallel surface and flow of the heat is one dimensional and steady.
- 2) Temperature across the thickness of the cover is negligible and that the interaction between the incoming solar radiation absorbed by the covers and the outgoing loss may be neglected

A schematic diagram of two-cover system is shown in the Fig. 2.

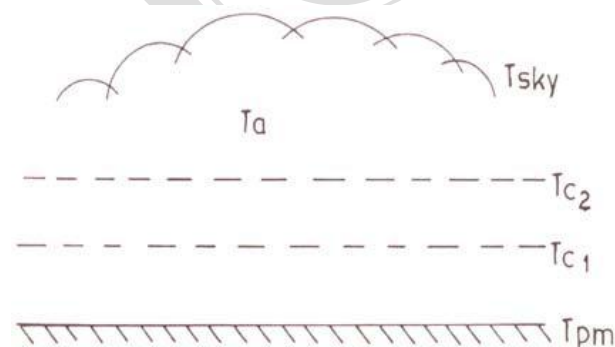


Fig. 2 schematic diagram of two-cover system

In steady state the heat is transferred by convection and radiation between the following:

- 1) The absorber plate and the first cover.
- 2) The first cover and the second cover and
- 3) The second cover and the surrounding must be equal.

$$\frac{q_t}{A_p} = h_{pc} - c_1 (T_{pm} - T_{c1}) + \frac{\sigma (T_{pm}^4 - T_{c1}^4)}{\left(\frac{1}{\epsilon_p} + \frac{1}{\epsilon_c} - 1\right)}$$

$$\frac{q_t}{A_p} = h_p - c_2 (T_{c1} - T_{c2}) + \frac{\sigma (T_{c1}^4 - T_{c2}^4)}{\left(\frac{1}{\epsilon_p} + \frac{1}{\epsilon_c} - 1\right)}$$

$$\frac{q_t}{A_p} = hw (T_{c2} - T_a) + \sigma \epsilon_c (T_{c2}^4 - T_{sky}^4)$$

Equations 9 to 11 constitute a set of three nonlinear equations, which can be solved iteratively by assuming T_{c1} and T_{c2} for which q_t/A_p is same by all these equations. There exists few correlations for calculating h_{p-c} , hw , and U_t which have been derived based on different experiments and techniques which may not be representative of real life collector. The present work is an attempt to present the comparative assessment of these correlations, based on systematic experiments, on an experimental research collector which is a representative of real life collector and to study the effect of collector tilt angle on top losses and top loss co-efficient.

VI. EXPERIMENTAL DETERMINATION OF VARIOUS PARAMETERS

Once the steady state is achieved the top loss, the overall loss and the convective heat transfer coefficients are evaluated from the energy balance equation as follows:

$$Q_u = Q_t + Q_b + Q_s + Q_c + Q_e + Q_{sl} \quad (12)$$

Q_u is the total energy supplied to the heaters which is same as the heat losses from collector under steady state. The bottom losses, Q_b , side losses, Q_s , edge losses, Q_e , corner losses, Q_c . Sealing losses are assumed as 1% and hence top losses are calculated by subtracting all these losses from input energy Q_u . Once Q_t is obtained U_l , U_t , h_{p-c} and hw may be evaluated as follows:

$$U_t = \frac{Q_{in}}{A_p} (T_p - T_a)$$

$$U_t = \frac{Q_t}{A_p} (T_p - T_a)$$

$$\frac{q_t}{A_p} = h_{pc} - c_1 (T_{pm} - T_{c1}) + \frac{\sigma (T_{pm}^4 - T_{c1}^4)}{\left(\frac{1}{\epsilon_p} + \frac{1}{\epsilon_c} - 1\right)}$$

$$h_{pc} - c_1 = \frac{q_t}{A_p(T_{pm} - T_{c1})} - \frac{\sigma(T_{pm}^4 - T_{c1}^4)}{(\frac{1}{\epsilon_p} + \frac{1}{\epsilon_c} - 1)(T_{pm} - T_{c1})}$$

$$hw = \frac{q_t}{A_p(T_{c2} - T_a)} - \frac{\sigma\epsilon_c(T_{c2}^4 - T_{sky}^4)}{T_{c2} - T_a}$$

I. RESULT AND DISCUSSION

Fig.2(a) it is seen that the values of the useful heat gain and efficiency increase sharply from 0900 to 1100 hour touch a peak around noon and then drop sharply after 1500 hour .the variation obtained is typical for flat plate collector and indicates the strong dependence of these factors on the radiation incident on the collector.Fig.2(b) It is also seen that the value of the top loss coefficient vary with useful heat gain during the day hours ,as noon increase the U_t , Q_u also increases. Fig.2(c) it is observed that effect of absorber plate temperature on top loss coefficients for days hours and peak around noon U_t and T_{pm} also maximum. Efficiency over the whole period ,during which useful energy is collected efficiency and solar radiation are valid of an hour, the efficiency average over 10 hours from 0830 to 1630h works out to be 39.6 percent.

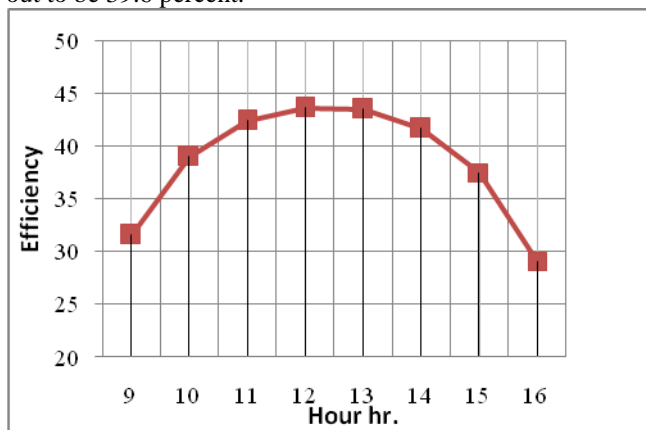


Fig.2 (a) variation of efficiency of a collector with day hours.

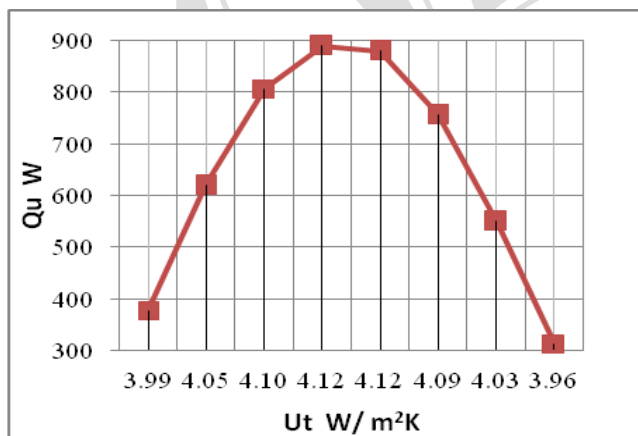


Fig.2(b) top loss coefficients versus heat gain during the day hours.

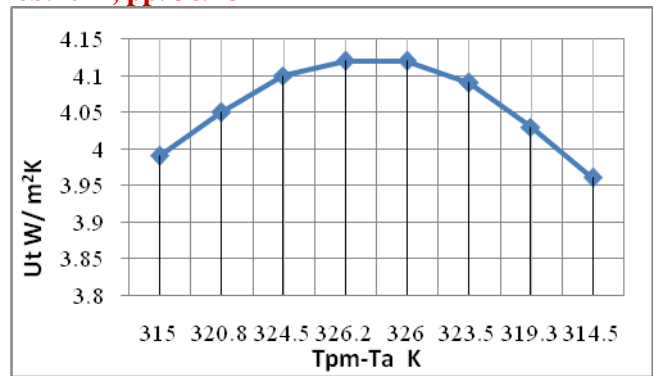


Fig.2(c) effect of absorber plate temperature on top loss coefficients

II. CONCLUSION

Efficiency over the whole period, during which useful energy is collected the efficiency average over 10 hours from 0830 to 1630h works out to be 39.6 percent. The increase in efficiency Q_u U_t and T_{pm} , at peak hour of noon and then drop sharply after 1500 hour.

III. REFERENCES

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