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Study of Instantaneous Thermal Efficiency of Solar Flat Plate Collector with varying Solar Irradiation under Cold Climatic Zone of India

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Abstract: The Flat-plate solar collector is the heart of any solar energy collection system designed for operation in the low temperature range (ambient 60^0C) or in medium temperature range (ambient 100^0C). It is used to absorb the solar energy, convert it into heat and then transfer the heat into the stream of liquid or gas. It absorbs both the beam and diffused radiation, and is usually planted on the top of the building or other structures. It does not require tracking of sun and requires little maintenance. Thermal efficiency is the, ratio of useful gain to the incident energy over the same period of time. It is the basic parameter on which generally the effectiveness of a flat plat collector lies or is calculated. India is basically divided into six major climatic zones as follows: Hot & Dry, Warm & Humid, Temperate, Cold & Sunny, Could & Cloudy and Composite. The present study is carried out into cold & cloudy zone which covers major parts of northern India (Jammu & Kashmir, Parts of Himachal and Parts of Uttarakhand). It is noted that the coldest month of year in these parts is *January* with the lowest values of solar irradiation, so the climatic parameters of *January* are taken for the study.

Keywords: Thermal efficiency; Flat Plate Collector; Solar Irradiation

1. Introduction

The most important part of the solar collector is the absorber plate along with the pipe or duct to pass liquid or air in thermal contact with the plate to transfer heat from it. The function of collector plate is to absorb maximum possible solar radiation incident on it through the glazing, to emit minimum heat to the atmosphere and downwards, through the back of casing, and to transfer the retained heat to the fluid. Material generally used for collector plates, in decreasing order of cost and conductance are copper, aluminum and steel. The surface coating of the plate should be such that it has high absorptivity and poor emissivity for the required temperature range. The product of transmissivity and absorptivity of the glazing surface in the present study is taken as 0.8.

Charter et. al. (1) proposed for collector testing is to operate the collector on the test stand, under conditions in which operation is nearly steady. In order to achieve the above conditions, water at constant temperature is supplied to the collector at a constant flow rate from the fixed head tank as the collector is rotated to face the sun to reduce the angle of incidence. The efficiency is then calculated from the carefully measured incident radiation, inlet and outlet temperatures of the fluid, the ambient temperature and the flow rate of fluid through the collector.

The useful energy of the collector is given by

$$\dot{Q}_u = \dot{m} C_f \left(T_{f_0} - T_{f_i}\right) \qquad (1)$$

Where $\dot{m}$ the flow rate of fluid through the collector, C_f is the specific heat of the fluid, T_{fo}, T_{fi} are outlet and inlet fluid temperature.

Tiwari et. al. (2) studied the deposition of the dust on the transparent cover reduces the transmittance of the cover. It is very difficult to generalize its effects due to dependence on type of glazing, angle of incidence, wind speed, rain fall and place. The plastic covers attract more dust due to its electrostatic nature than the window glass cover. It has been reported that transmittance of glass cover is reduced by average 8-10 percent at angle 45^0 in the regions of north India. The transmittance of glass cover will be less affected for horizontal surface and clear sky condition of cold regions.

India is sub divided into six major climatic zones as follows: Hot & Dry, Warm & Humid, Temperate, Cold & Sunny, Could & Cloudy and Composite. The present study comes into cold & cloudy zone which covers major parts of northern India (Jammu & Kashmir, Parts of Himachal and Parts of Uttarakhand). It is noted that the coldest month of year in these parts is *January* with the lowest values of solar irradiation, so the climatic parameters of *January* are taken for the study.

Climatic Parameters

The climatic data for *January* of *Srinagar* are given below:

Time	I (W/m^2)	T_a (^{0}C)
7-8	270	-1.5
8-9	363	-0.8
9-10	486	0.1
10-11	566	1.2
11-12	593	2.4
12-13	566	3.2
13-14	486	4.0
14-15	363	4.3
15-16	207	4.3
16-17	100	3.9

2. Formulation

In steady state condition, the rate of energy absorbed by the plate per unit area should be equal to sum of rate of useful energy ($\dot{Q}_u$) transferred to the fluid and the rate of energy lost ($\dot{q}_L$) per unit area by the plate of surrounding.

$$\dot{q}_{ab} = \dot{q}_L + \dot{Q}_u \quad (3)$$

$$\dot{q}_{ab} = (\alpha\tau)I \quad (4)$$

$$\dot{q}_L = U_L(T_p - T_a) \quad (5)$$

where U_L is overall heat loss coefficient

The overall heat loss coefficient U_L is the sum of the top, bottom and edge loss coefficient, i.e.,

$$U_L = U_t + U_b + U_e \quad (6)$$

Edge loss coefficient (U_e)

Tabor *et* al (3) the energy lost from the side of collector casing is exactly the same as that from the back if the thickness of edge insulation is the same as that of back insulation.

$$U_e = U_b\left(\frac{A_e}{A_c}\right) \quad (7)$$

Where A_e is the edge area

Back loss coefficient (U_b)

Heat is lost from plate to the ambient by conduction through the insulation and then subsequently by convection and radiation from the bottom surface casing. The bottom loss coefficient is given by

$$U_b = \left[\left(\frac{L_{in}}{K_{in}}\right) + \left(\frac{1}{h_b}\right)\right]^{-1} \quad (8)$$

Where h_b is the heat loss coefficient from the bottom, and is the sum of convective heat loss coefficient h_{bc} and radiative heat loss coefficient h_{br}. The values of h_{bc}, h_{br} can be calculated as in case of top cover.
The suffix 'in' indicates insulation.

Top loss coefficient (U_t)

$$U_t = \left[\left(\frac{1}{h_1}\right) + \left(\frac{1}{h_2}\right)\right]^{-1} \quad (9)$$

Thermal Efficiency

The instantaneous thermal efficiency of the collector is given by

$$\eta_i = \frac{\dot{Q}_u}{A_c\, I} \quad (10)$$

where A_c is collector area and I is radiation incident on the collector (W/m^2)

Design Parameters

The following design parameters are taken to study the variation of instantaneous thermal efficiency of the flat plate collector with time and varying solar irradiation.
Transmissivity and absorptivity product $(\alpha\tau)$ = 0.8
Mass flow rate of air through the collector $(\dot{m})$ = 0.035 kg/sec

Collector efficiency factor $\dot{F}$ = 0.8
Overall heat loss coefficient (U_L) = 6W/m^2 ^{0}C
Collector heat removal factor (F_R) = 0.787
Plate temperature, (T_p) = 40 ^{0}C
Collector Area (Ac) = 1 m^2

3. Result and Discussion

Figure 1 shows the variation of solar irradiation with time in a particular day length. As the sun rises the intensity of the radiation from the sun is week due to which the value of solar irradiation (i.e., total amount of radiation incident on the surface) is low as the day progresses the value of the solar radiation also increases and reaches to the maximum value by the noon and the again there is a decrease in the value of solar irradiation. Figure 2 shows the variation efficiency of the collector with time. It is seen from Figure 1 that as the day progresses (time increases) there is an increases in solar irradiation due to which the instantaneous efficiency of the collector also increases, due to the fact with increase in time the efficiency of collector also increases shown in Figure 2. The flat plate collector shows its highest efficiency (41%) during the period of 11-12 AM which is due the maximum value of solar irradiation at this period (593W/m^2). After this with passage of time the solar irradiation decreases and hence the collector efficiency in turn also decreases. Figure 3 clearly give the relation between solar irradiation and collector efficiency i.e. with the increase in solar irradiation there is an increase in the collector efficiency and during evening as the solar irradiation decreases the efficiency of the collector drops down to minimum. Instantaneous efficiency of flat plate collector with time is shown in Table – 1. It is observed from the table that the efficiency is maximum between the times 11-12 AM when the intensity is maximum.

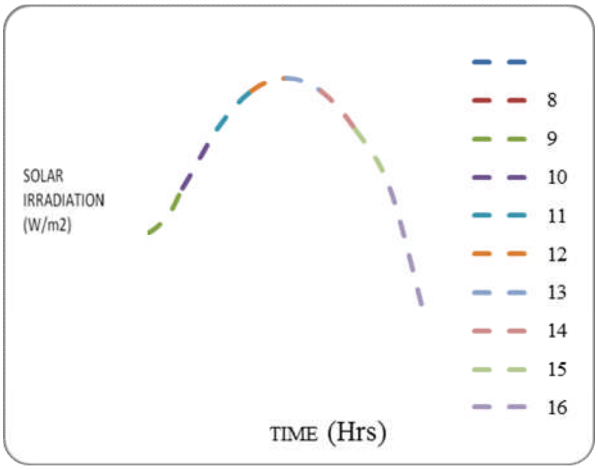

Figure 1: Variation of solar irradiation with time as day passes

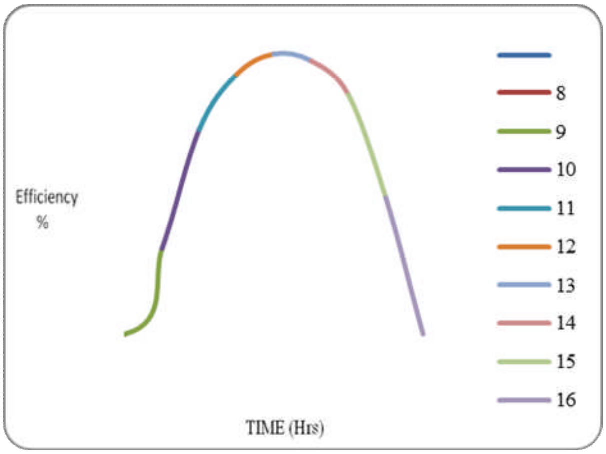

Figure 2: Variation of instantaneous efficiency of flat plate collector with time as day passes

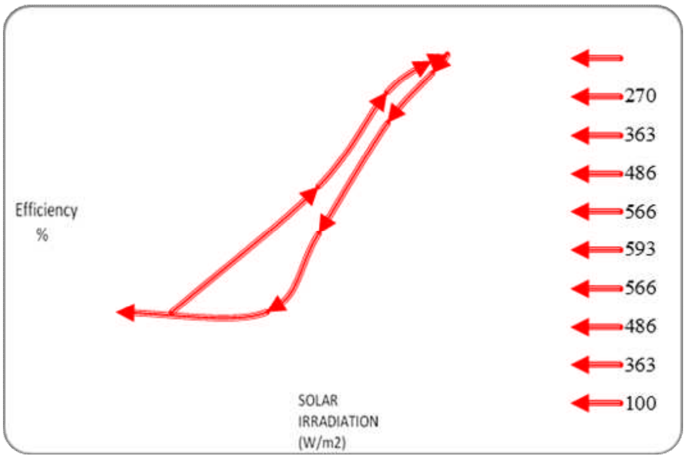

Figure 3: Variation in efficiency of collector with solar irradiation as the day passes

4. Conclusion

The hourly study of solar collector gives the following conclusions:

(i) In the northern parts of India having cold climatic zone the use solar flat collectors for various applications is very beneficial and clean. Since in these parts the sky is normally clear during the winters the solar irradiation of high order is achieved and efficient solar collector can be designed considering various design parameters.

(ii) During the morning and evening the efficiency of the solar collector is minimum due to the lower value of solar irradiation.

(iii) However the ambient temperature is much lower during morning and evening in morning it can be less than 0^0C and the plate temperature is maintained at much higher value increases the heat loss to the atmosphere and should not be operated during these periods.

Table 1: Instantaneous Efficiency of Flat Plate Collector

Time	I (t) (W/m^2)	$\dot{q}_{ab}$ (W/m^2)	T_a (^{0}C)	$\dot{q}_L$ (W/m^2)	$\dot{q}_a$ (W/m^2)	η_i (%)
7-8	270	216	-1.5	249	0	0
8-9	363	290.4	-0.8	244.8	45.6	12.5
9-10	486	388.8	0.1	239.4	149.4	30
10-11	566	452.8	1.2	232.8	220	38
11-12	593	474.4	2.4	225.6	248.8	41
12-13	566	452.8	3.2	220.8	232	40
13-14	486	388.8	4.0	216	172.8	35
14-15	363	290.4	4.3	214.2	76.2	20
15-16	207	165.6	4.3	214.2	0	0
16-17	100	80	3.9	216.6	0	0

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