Front Window Heat Loss From Different Material of Flat Plate Collector

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Abstract

The present paper includes a theoretical study concerning front window heat loss of a single glazing flat plate collector, for different emissivity (e) of material (black chrome , black paint copper and black paint aluminum) and ambient temperature (T_a). A computer program is devised to find a relationship between heat loss through the glass cover and collection plate temperature. Computed data are fitted to 4^{th} order polynomial equation include a constant coefficients shown in table (1) for application convenience.

Keywords :

- Flat plate solar collector
- Glass cover temperature

1. Introduction

Solar heating panels generate heat when solar radiation is absorbed by a blackened absorber plate. In steady-state operation this heat must be equal to the thermal energy leaving the panel. The energy leaves either as useful heat extracted by a transfer fluid or alternatively by thermal leakage to the surroundings. An efficient panel is one that enhances heat transfer to the fluid while minimizing that transfer to the cooler surroundings[1]. A measure of a flat plate collector performance is the collector efficiency defined as the ratio of the useful energy gain (Q) to the incident Solar energy ($AI_N(t)$) over a particular time period. The useful energy gain, in turn, depends strongly on the energy losses from the top surface of the collector both due to convective and radiative heat transfer processes[2] [3].

An accurate calculation of the top loss coefficient becomes desirable by using network thermal analysis. An approximation to this iterative analysis[4], were the first to propose an empirical equation. Klein[5] has suggested several modified equations. Agarwal and Larson[6] used equation similar to that proposed by Klein[5], only different in parameter's value. Channiwala and Doshi [7], have suggested a correlation for estimating the heat loss coefficient. Sasaki[8], studied a transient heating technique, improving the constant - rate - heating technique for the measurements of thermal diffusivities of metals, is proposed. Geuder[9], have calculated the heat transition coefficient for several glazing with two low - emissivity coated window.

In the present paper the computation of the front window heat loss of a single glazing (n=1) flat plate collector based on a detailed heat transfer balance: blackened absorbing panel-glass cover-atmospheric surroundings. The calculations are repeated for different emissivity (e) of absorbing material.

II. Heat Losses

From second law of thermodynamics, heat always flows from hotter to colder regions. There are three modes by which this transfer can occur, namely conduction, convection and radiation[1].

The heat losses by both convection and radiation, and to a lesser extent, by conduction, are reduced by fitting one or more transparent cover sheets. Each transparent cover reduces the outward heat losses from the front window of the collector, but also reduces the total amount of incoming solar radiation which can reach the absorbing surface. Radiation losses can be reduced by treating the absorbing surface to make it selective absorber[10].

III. The Front Window Heat Loss

Although the glass cover is transparent to visible radiation, it is opaque, due to strong absorption bend, to the emission infrared radiation.

We assume that the emittance (e) (=the absorptance (a)) of the glass plate to the concerned infrared radiation is unity, i.e., the glass plate is considered ideally black with respect to the emission radiation from the underlying absorbing black surface.

The glass cover of a single glazing flat plate collector therefore plays two main rules:

(1) It partially reflect back the emitted infrared radiation from the underlying absorbing black surfaces the emitted radiation is totally absorbed by the glass cover. The resulting heat is then partially dissipated by re-radiation from the two sides of the glass cover. The downwards re-radiation amounts to an effective reflective of the emitted radiation from the blackened absorbing surface.

(2) The glass cover shield, be the hot absorbing surface from the turbulent cold atmospheric air, thus reducing the effective heat transfer coefficient.

On the other hand, as long as single glazing is utilized, the glass cover by itself is considered if negligible resistance to heat transfer across its two surfaces. The thickness of the glass cover is normally small, where as the glass conductivity is appreciable compared with the air conductivity.

With reference to Fig. (1) a plate absorber (P), of emissivity (e) in the infrared region, is covered at distance (X_a) by a single sheet of glass (G). To suppress convective heat transfer from the plate (P) and to the glass cover and maintain maximum conductive resistance, the distance (X_a) is taken to be 2.5 cm. Let the plate temperature (T_p), glass temperature (T_g), and the atmospheric air temperature (T_a). According to the above prescription, the heat transfer from (P) to (G) is mainly conductive and radiative whereas the heat transfers, from the glass cover and the atmosphere air is mainly convective and radiative.

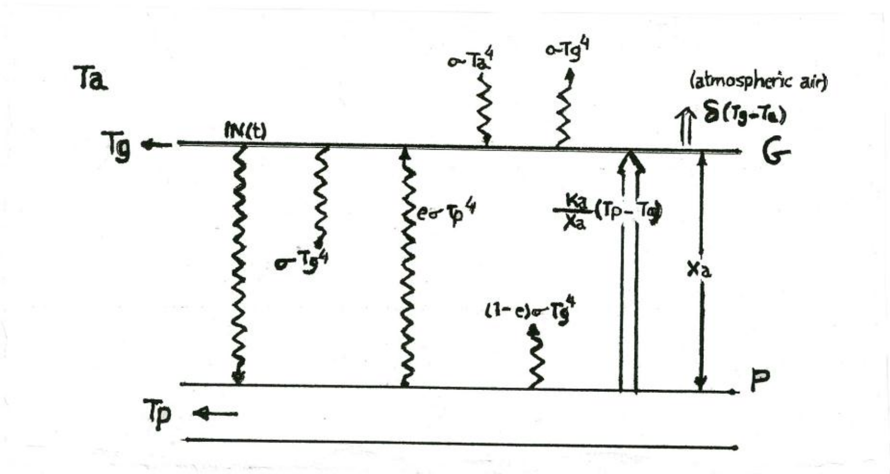

Fig. (1) Heat Balance of Glass Cover

The net front window heat loss is then given by:
FHL= $\sigma (T_g^4 - T_a^4) + \delta (T_g - T_a)$ …(1)
Where, σ is the Stefan's constant, δ is the convection heat loss coefficient, which is given by $C\Delta T^{1/4}$,where C, is a constant equal[1] :

$$C = \frac{(C^{hor} + C^{ver})}{2} = 0.51 \times 10^{-4}\ \text{Cal/cm}^2 .\ \text{C}^{o5/4}.\text{Sec}$$

On the other hand, the net heat transfer from the plate to the glazing is:

$$J = e\sigma (T_p^4 - T_g^4) + \frac{K_a}{X_a}\ (T_p - T_g) \qquad …(2)$$

Where, K_a is the coefficient of conductivity of air.
For steady state the total transfer from the plate to the glazing must be equal to the transfer from the glazing to the surroundings. This means:

$$\delta(T_g - T_a) + \sigma(T_g^4 - T_a^4) = e\sigma(T_p^4 - T_g^4) + \frac{K_a}{X_a}(T_p - T_g)$$

after rearrangement we get:

$$e\sigma T_p^4 + \frac{K_a}{X_a}T_p = (e+1)\sigma T_g^4 + \delta(T_g - T_a) - \sigma T_a^4 + \frac{K_a}{X_a}T_g \quad …(3)$$

Therefore solution of Eq. (3) is refers to that (T_g) is a function of (T_p). After obtaining this solution, Eq.(l) may be applied again to determine the sought front window heat loss (FHL) as a function of plate temperature T_p .

IV. Calculation and Results

Eq. (3) is a highly nonlinear relation between T_p and T_g . However, a solution of this equation is affected numerically by graphical method. (We have $\sigma = 1.3499 \times 10^{-12}$ Cal/sec cm^2 K^4 , $K_a = 5.7 \times 10^{-5}$ Cal / sec. Cm. C^o , X_a = 2.5 cm.)
The collection panel is placed tilted at 45^0 with the horizontal. This paper considers collectors which differ according to absorber coating material: (black chrome, black paint copper and black paint aluminum with emissivities e = 0.08, 0.3 and 0.97 respectively)[11].
Thus, for each value of the emissivity (e), and different values of ambient temperature (T_a = 0°C, 10°C, 20°C) the result of equation (3) is repeated to obtain the corresponding values of T_p and T_g. The result of the above method are shown in figure (2).

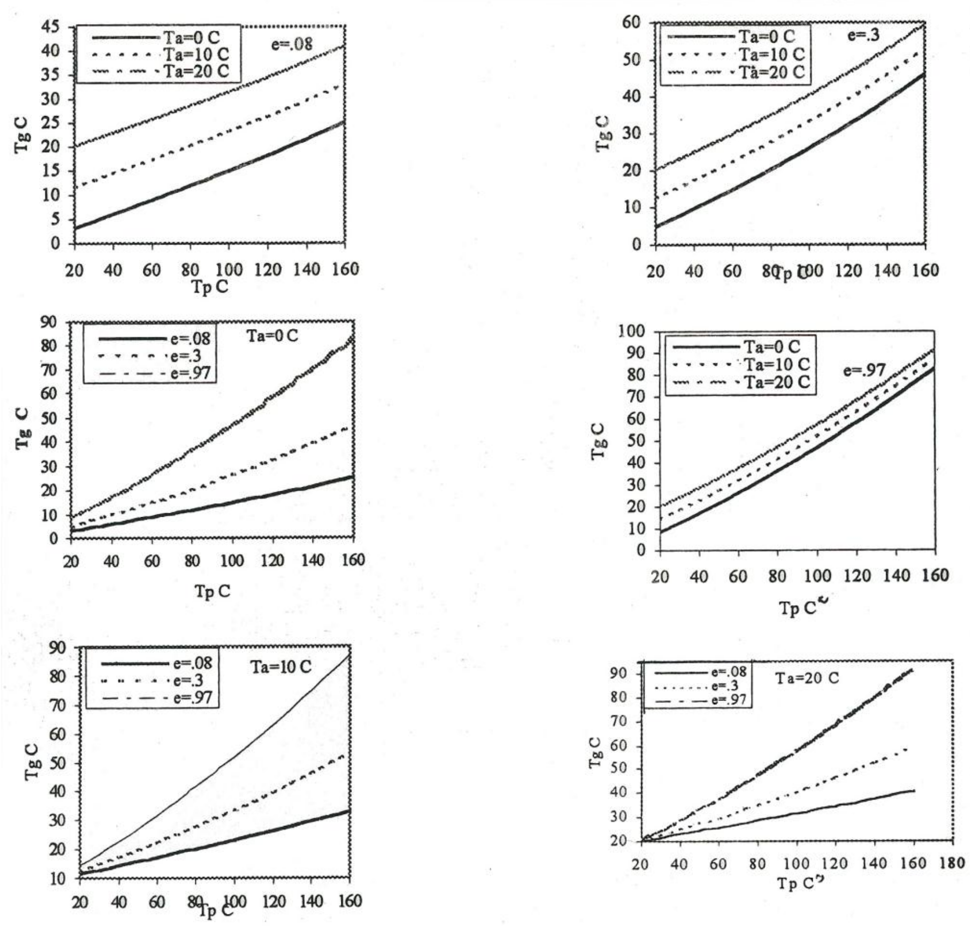

Fig. (2) Variation of Glass Temperature (T_g) with Plate Temperature (T_p) for Different Values of Ambient Temperature (T_a) and Emissivities (e).

Front window heat loss (FHL) and glass temperature (T_g) can be computed from equation (1) for different values of ambient temperatures (T_a). Thus FHL as a function of plate temperature (T_p) are obtained for a given set of values of T_p and T_g computed by the above method (Eq. 3). This relation between FHL and T_p for different values of ambient temperatures (T_a) and emissivities (e) are shown in figure (3). To obtain an analytic relation for practical convenience, the given data is fitted to a 4th order polynomial equations of the form:

$$FHL = a_\circ + a_1 T_p + a_2 T_p^{\,2} + a_3 T_p^{\,3} + a_4 T_p^{\,4} ..... (4)$$

where a_o ... a_4 are constant coefficients depending upon different values of (e) and (T_a), the results are tabulated in Table (1).

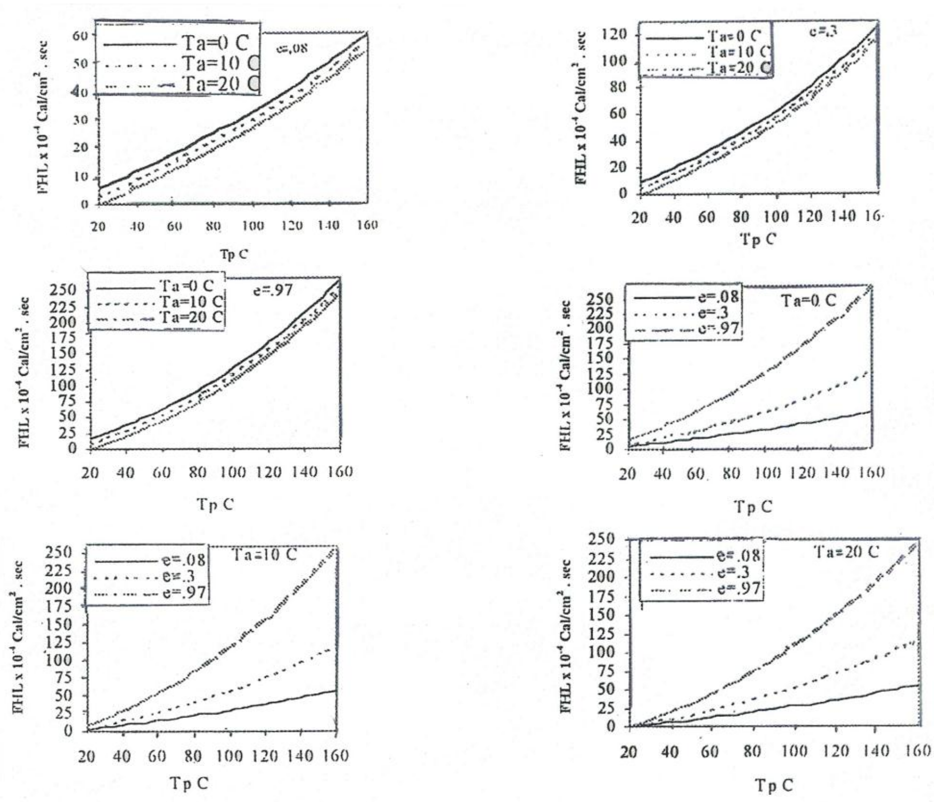

Fig. (3) Variation of Front Window Heat Loss (FHL) with Plate Temperature (T_p) for Different Values of Ambient Temperature (T_a) and Emissivities (e).

Table -1- The Variation of the Coefficient (a_o ... a_4) with Different Emissivity (e) and Ambient Temperature (T_a)

T_a/C^0	e	0.08	0.3	0.97
0	a_0	1.265143 X 10^{-4}	-4.56255 x 10^{-4}	3.338256 x 10^{-3}
	a_1	1 .724697 x 10^{-5}	7.432906 x 10^{-5}	-1.232186 x 10^{-4}
	a_2	2.762566 x 10^{-7}	-4.531142 x 10^{-7}	3.733023 x 10^{-6}
	a_3	-1.978448 x $l0^{-9}$	4.99657x $l0^{-9}$	-2.017671 x 10^{-8}
	a_4	6.516407 x 10^{-12}	-l.l74225x 10^{-11}	4.610137 x 10^{-11}
10	a_0	-2.745707 x 10^{-4}	-4.329885 x 10^{-4}	-8.206873 x10^{-04}
	a_1	2.65888 x 10^{-5}	4. 121615 X 10^{-5}	7.436379 xl 0^{-5}
	a_2	5 . 678211 x 10^{-8}	1 .879032 x 10^{-7}	4.613169 x 10^{-7}
	a_3	3.072195 x 10^{-11}	1.586866 X 10^{-10}	4.951941 X 10^{-10}
	a_4	2.842404 x 10^{-13}	7.601044 X 10^{-13}	1.167866 x 10^{-12}
20	a_0	-5.491849 x 10^{-4}	-8.857307x 10^{-4}	-1.568197 x10^{-13}
	a_1	2.616644 x 10^{-5}	4.01516 X 10^{-5}	6.703513 X 10^{-5}
	a_2	6.211718 x 10^{-8}	1.979317 x 10^{-7}	5.449143 X 10^{-7}
	a_3	3.351553 x 10^{-12}	8.706687 X 10^{-11}	-7.257887 X10^{-11}
	a_4	3.345004 x 10^{-13}	9.464665 x 10^{-13}	2.553256 X 10^{-12}

Figure (4) shows the comparison between the present work and the results obtained from equation (4) concerning the relation between front window heat loss (FHL) and plate temperature (Tp) for different emissivities.

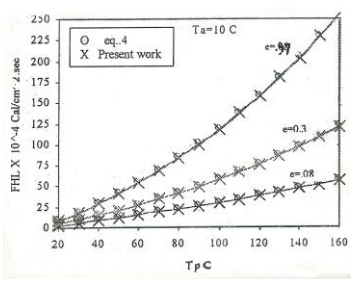

Fig .. (4) Comparison Between the Present Work and the Result Obtained from Equation 4.

V. Discussion

Calculation carried out for a typical collector with one glass cover and for three values of absorber emissivity. Figure (2) shows the directly proportion between plate and glass temperatures for different ambient temperatures and emissivities. This proportion increases when increasing the emissivity and ambient temperature (T_a) .

Figure (3) indicates that the front window heat loss (FHL) increases when increasing the plate temperature (T_p) . Also this figure shows that there are no heat loss from the collectors when the values of the plate temperature and the ambient temperature are equals whatever the value of the emissivity is.

As shown previously in Fig(3) for the same ambient temperature (FHL) decreases when decreasing the emissivity , and the best material can be used is the black chrome (e = 0.08) . However, it is not so important to use the less emissivity materials because the difference in (FHL) will be small. Therefore , the black paint copper material (e = 0.3) can be chosen which gives approximately the same results and low cost .Also , this figure shows for the same emissivity, (FHL) increases as (T_a) increases.

The constance given in table -1- can be used in equation (4) for calculating front heat loss FHL as a function of plate temperature (T_p) for different emissivity and ambient temperature (T_a) .Figure (4) shows a good agreement between the present work and the results obtained from equation (4). In other words using this simple equation will be much easier for us than using several equations to calculate the FHL as a function of (T_p).

Vi. Conclusion

Front window heat loss of a single glazing flat-plate collector (FHL) has been calculated directly as a function of plate temperature (T_p) for different absorber coating material (black chrome, black paint copper and black paint aluminum). This calculation is based on a relationship of 4th order polynomial equation between (FHL) and (T_p), this equation consists of constant coefficients (a_o ... a_4) changed with changing (T_a) and e (Table 1).

The advantage of the present work, in future studies, is to help the researchers in saving time and efforts by using equation (4) in calculating (FHL) as a function of (T_p).

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الفقدان الحراري من الجهة الأمامية لصفائح مختلفة للسخان الشمسي

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الملخص

يتضمن البحث دراسة نظرية حول الفقدان الحراري لصفيحة السخان الشمسي مغطاة بطبقة زجاجية واحدة ولمواد مختلفة الإنبعاثية (المواد المطلية بالصبغة السوداء وهي الكروم،النحاس والألمنيوم) ودرجة حرارة المحيط. صمم برنامج على الآلة الحاسبة لإيجاد العلاقة بين الفقدان الحراري من خلال الغطاء الزجاجي ودرجة حرارة الصفيحة الجامعة. أدخلت القيم المستحصلة في معادلة متعددة الحدود من الدرجة الرابعة تتضمن ثوابت موضحة في جدول رقم (1) لاستخدامها في تطبيقات مناسبة.