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Performance Evaluation of Double Glaze Flat Plate Solar Thermal Collector

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Abstract: One of the most popular thermal system is Flat Plate Solar Collector (FPSC) which can transform solar energy into useful thermal energy of the fluids. The applications of FPSC are water heating, solar cooling, heat process and room heating etc. FPSCs are very simple in design and can be fabricated locally. The major drawback of FPSC is its low performance. Further, performance of FPSCs is low due high emissivity of absorber plate particular at high temperature. Additionally, absorption of solar radiation in glass cover increase its temperature and leading to high values of conductive and radiative heat transfer coefficient which causes to high heat loss. To overcome these high heat loss, double glazing can utilized as heat barrier and serves as opaque for insolation. This paper present the evaluation of the performance of double glazed solar collector and the results have been compared with the results of single glazed collector.

Keywords: Solar Thermal Collector, Double Glazing, Thermal Resistance, Efficiency.

1. Introduction

Conventionally energy is extracted from exhaustible sources of energy which included coal, crude oil and natural gas, etc. These conventional sources of energy are confined in nature and will be eventually consumed in a little span of time [1]. Therefore, renewable energy are getting importance which are green energy and inexhaustible in nature. Among all renewable energies, solar energy is placed in top position due to its abundant quantity, omnipresent, clean and pollution free nature. Solar energy can be utilized in number of ways, however, the most common are water heating for domestic and industrial applications. One of the most common thermal system is Flat Plate Solar Thermal Collector (FPSC) which can produce hot water by harnessing solar energy. FPSCs are simple in design and inexpensive [2]. However, the performance of FPSCs are low due to dilute nature of insolation and high heat losses to environment. Heat losses are very high due to high temperature of absorber which have three component i.e. back heat loss, side heat loss and top heat loss [3]. First two components are very small and can be controlled [4]. Major heat losses are experienced from top cover as absorber plate is totally exposed to environment [5]. Top heat losses can be minimized by placing glass covers which act as convection barrier and help to reduce the overall heat transfer coefficient [6]. In this paper, an analytical method has been presented for determining thermal efficiency and overall heat loss coefficient for two glass covers and results of FPSC having two and single glass covers have also been compared.

2. Methodology

A MATLAB program have been made and calculations are carried out for efficiency and heat loss coefficient of FPSC of 1 mt×1mt collector area. The flow chart of the calculations has been presented in Fig. 1.

Thermal analysis of double glaze FPSC has been carried out using thermal network as shown in Fig. 2. Some typical location of absorber and glass cover have been presented. Solar energy I is absorbed which is distributed into useful heat gain to fluid, top heat loss, bottom heat loss and side edge heat loss. The energy loss through the top cover by convection and radiation. It is assumed that the absorber temperature and ambient temperature are Tp and Ta respectively.

Heat Exchange between absorber and first cover

$$q_{loss,p-c1} = h_{c,c-p1}\left(T_p - T_{c1}\right) + \frac{\sigma\left(T_p^4 - T_{c1}^4\right)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1}$$

$$= \left(h_{c,p-c1} + h_{r,p-c1}\right)\left(T_p - T_{c1}\right) \quad (1)$$

where,

$$h_{r,p-c1} = \frac{\sigma\left(T_p^2 + T_{c1}^2\right)\left(T_p + T\right)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1} \quad (2)$$

Thermal Resistance

$$R_1 = \frac{1}{\left(h_{c,c-p1} + h_{r,c-p1}\right)} \quad (3)$$

Convective heat transfer between absorber and first cover is calculated as give below;

$$h_{c,p-c1} = \frac{Nu.k}{L} \quad (4)$$

where, Nu is Nusselt number in between plate which is given below [7]

$$Nu = 1 + 1.44\left[1 - 1708/RaCos\beta\right]^{+}\left\{1 - 1708(\sin 1.8.\beta)^{1.6}/Racos\beta\right\} + \left[(RaCos\beta/5830)^{0.33} - 1\right]$$

$$R_a = \frac{g.\beta'.(T_p - T_c).L^3}{\nu.\alpha}$$

Where, k is conductivity

L is distance between plates

β is slope

Air physical properties are taken as kinematic viscosity (υ), thermal diffusivity (α) and thermal expansion (β') at mean plate's temperature

Similarly, heat exchange between first and second cover

$$q_{loss,c1-c2} = h_{c,c1-c2}\left(T_{c1} - T_{c2}\right) + \frac{\sigma\left(T_{c1}^4 - T_{c2}^4\right)}{\frac{1}{\varepsilon_{c1}} + \frac{1}{\varepsilon_{c2}} - 1}$$

$$= \left(h_{c,c1-c2} + h_{r,c1-c2}\right)\left(T_{c1} - T_{c2}\right) \quad (5)$$

where,

$$h_{r,c1-c2} = \frac{\sigma\left(T_{c1}^2 + T_{c2}^2\right)\left(T_{c1} + T_{c2}\right)}{\frac{1}{\varepsilon_{c1}} + \frac{1}{\varepsilon_{c2}} - 1} \quad (6)$$

(6)

Thermal Resistance between glass cover,

$$R_2 = \frac{1}{\left(h_{c,c1-c2} + h_{r,c1-c2}\right)} \quad (7)$$

Same procedure is adopted to calculate the convective heat transfer coefficient between first cover (c1) and second cover (c2) and air properties is taken at mean plate's temperature.

Heat loss to top cover to ambient can be calculated as

$$q_{loss,c1-c2} = \left(h_{r,c2-ca} + h_w\right)\left(T_{c1} - T_{c2}\right) \quad (8)$$

The radiation resistance from top cover for account for radiation exchange with the sky at Ts, So that radiation heat transfer coefficient can be written as

$$h_{r,c2-a} = \frac{\sigma\varepsilon_{c2}\left(T_{c2} + T_s\right)\left(T_{c2}^2 + T_s^2\right)\left(T_{c2} - T_s\right)}{\left(T_{c2} - T_a\right)} \quad (9)$$

The resistance to surrounding,

$$R_3 = \frac{1}{\left(h_{r,c2-a} + h_w\right)} \quad (10)$$

For two cover glass, the top loss coefficient from collector to ambient is calculated as

$$U_t = \frac{1}{\left(R_1 + R_2 + R_3\right)} \quad (11)$$

Heat loss from absorber to ambient through double glass cover can be calculated as

$$q_{loss} = U_t\left(T_p - T_a\right) \quad (12)$$

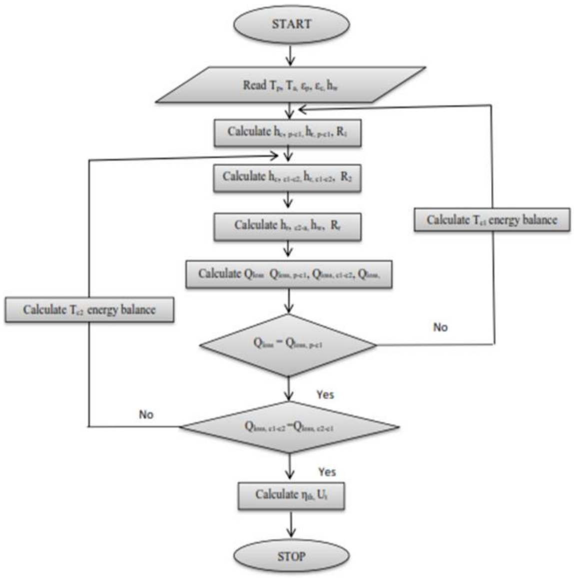

Figure 1. Flow Chart

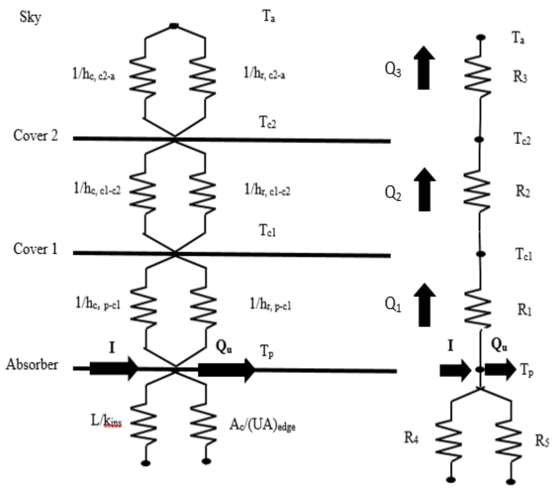

Fig. 2: Thermal network of double glaze FPSC

Since the energy exchange between plates must be equal to overall heat loss.

$$q_{loss} = q_{loss,p-c1} = q_{loss,c1-c2} = q_{loss,c2-a} \quad (13)$$

In the first step, plate and ambient temperature are assumed. Using equation 1-13, a new temperature is calculated for first cover. This new first cover temperature is used to calculate the next cover temperature, and so on. For any two adjacent cover or plate, the new temperature is calculated using following equation.

$$T_{new} = T_{old} - \frac{U_t.(Tp - Ta)}{h_{c,i-j} + h_{r,i-j}} \quad (14)$$

This process is repeated until the heat exchange between cover and plate becomes equal to overall heat loss to ambient. This method fives the covers temperature and top heat loss coefficient.

Back heat loss coefficient and edge loss coefficient are calculate as

$$U_b = \frac{1}{(R_4)} = \frac{k_{ins}}{L'}$$

and

$$U_e = \frac{1}{(R_5)} = \frac{(UA)_{edge}}{A_c} \quad (15)$$

Overall heat loss coefficient [9],

$$U_o = U_t + U_b + U_e \quad (16)$$

The useful heat gain to fluid [10],

$$Q_u = \left[I(\iota\alpha) - U_o(T_p - T_a)\right]A_c \quad (17)$$

where, (ατ) is transmittance-absorptance product of absorber

Efficiency of the collector,

$$\eta_{th} = \frac{Q_u}{A_c.I} = \left[(\iota\alpha) - \frac{U_o(T_p - T_a)}{I}\right] \quad (18)$$

3. Results and Discussion

The cover temperatures and the heat flux by convection and radiation are shown in thermal network of double glaze collector (Fig. 2.). The efficiency and overall heat loss coefficient of double glaze as well as single glaze collectors have been calculated. Plots of efficiency and heat loss as a function of temperature rise parameters have been presented in Fig. 3. It has been clearly seen from the plots, the efficiency of both the collectors decrease with increase in temperature rise parameter, however, overall heat loss coefficient of both collectors increase with increase in temperature rise parameter. This is happened due to increase in absorber plate temperature which indent to lost their heat to environment. On the other hand, higher emissivity of absorber plate at higher temperature is partially responsible to high heat loss to environment. .

Comparison of efficiency and heat loss coefficient of double and single glaze collectors have also been presented in Fig. 3. and data of efficiency and overall heat loss coefficient have been listed in Table 1. It can be seen clearly from the plots, the average efficiency of double glaze collector is 24% higher than the efficiency of single glaze collector when temperature rise parameter varies from 50º to 100º C. The higher efficiency and low heat loss coefficient of double glaze flat plat collector has been found. Double glaze offers comparatively higher thermal resistance to heat flow as convection between the glasses are very less which leads to low temperature of outer glass and low heat loss to environment.

Temperature of first glass cover (TC1), second glass cover (TC2) and ambient temperature have been plotted as a function of temperature rise parameter for double glaze collector at 1000 W/m2 insolation as shown in Fig. 4. Significant difference in temperature of first glass cover and second glass cover can be seen clearly. These difference in temperature is low at lower temperature rise parameter which increases with the increase in temperature rise parameter. Low temperature of top glass cover indicate that loss to the environment is low and leads to high thermal efficiency.

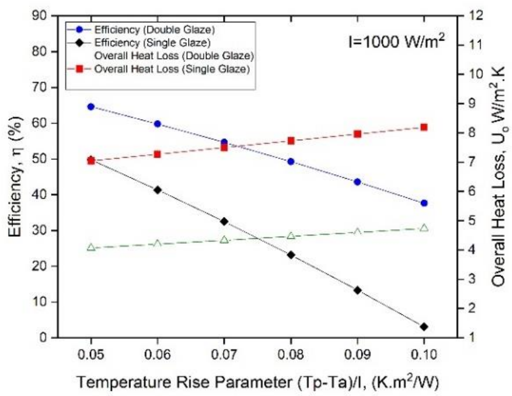

Fig. 3: Plots of efficiency and overall heat loss coefficient v/s absorber temperature

The efficiency of double glaze collector have been also been calculated on different insolation and have been plotted as a function of absorber temperate as shown in Fig 5. It can be seen from the Fig. 5. efficiency of collector has been found maximum for 1000 W/m2 insolation and minimum efficiency has been found for 600 W/m2.

In order to show the effect of glass spacing, efficiency of collector at different glass spacing has been plotted as function of temperature rise parameter as shown in Fig. 6. It can be seen from the Fig. 6 that higher efficiency has been found on small gap i.e. 10 mm and lower efficiency has been found on large gap i.e. 40 mm. For small spacing, convection is suppressed and the heat transfer mechanism through the gap is by conduction and radiation. Therefore, small gap i.e 10 mm decrease top loss coefficient. When the gap increase to 40 mm, fluid motion begins to contribute convection and leads to heat transfer process. Addition to this, too small gap contribute to strong heat conduction in the air and have responsible to higher top heat loss and consequently low efficiency.

Table 1: Efficiency and overall heat loss coefficient of single and double glaze collectors

Temp Rise Parameter (K.m2/I)	Double Glaze		Single Glaze	
	Efficiency (%)	Overall heat loss, (W/m2.K)	Efficiency (%)	Overall heat loss, (W/m2.K)
0.05	64.63	4.07	49.77	7.04
0.06	59.77	4.20	41.37	7.27
0.07	54.61	4.34	32.49	7.50
0.08	49.26	4.47	23.16	7.73
0.09	43.59	4.60	13.37	7.96
0.10	37.62	4.74	3.08	8.19

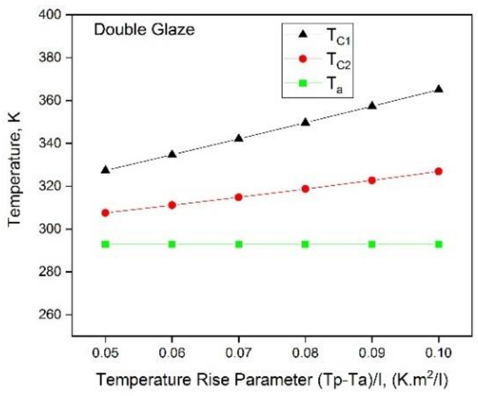

Fig. 4: Temperature of first and second glass cover with ambient temperature.

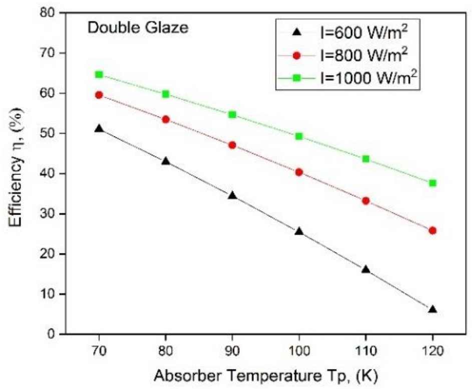

Fig. 5: Efficiency v/s Absorber temperature at different insolation

The enhancement in thermal efficiency of double glaze collector has been expressed in terms of enhancement factor (EF) [10], which is defined as the ratio of the thermal efficiency of double glaze collector to that with thermal efficiency of single glaze collector of same dimensions and operating under similar conditions.

$$EF = \frac{\eta_{DG}}{\eta_{SG}} \tag{19}$$

The enhancement factor (EF) of double glaze collector have been listed (Table 2) at different temperature rise parameters. Enhancement factor (EF) increases with increase in the temperature rise parameter. Maximum EF of double glaze collector has been observed at maximum temperature rise parameter which is come 12.22.

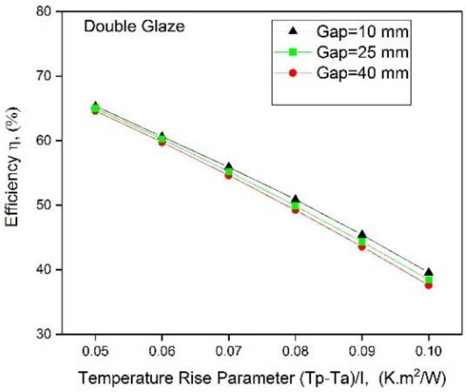

Fig. 6: Efficiency v/s temperature rise parameter at different gap

Table 2: Enhancement factor in efficiency and heat loss at different temperature rise parameter at 1000 W/m2

Temperature Rise parameter	Enhancement Factor in Efficiency (EF)
0.050	1.30
0.060	1.45
0.070	1.68
0.080	2.13
0.090	3.26
0.100	12.22

4. Conclusion

In order to measure the thermal performance of double glaze collector, an analytical model of thermal performance has proposed. The performance of collector in term of thermal efficiency and overall heat loss coefficient has been estimated. Results of double glaze collector have also been compared with single glaze collector. On the basis of results analysis, the following conclusions have been drawn.

1. Efficiency of double glaze collector has been found 24% average higher than the efficiency of single glaze collector when the temperature rise parameter varies from 0.050-0.100 K.m2/W. This difference in the efficiency of both collector is due to the different in overall heat loss coefficient as double glazing offers higher thermal resistance to heat flow.
2. Effect of insolation on the efficiency of double glaze collector has been predicted. The maximum and minimum efficiency has been found at insolation of 1000 W/m2 and 600 W/m2, respectively.
3. Effect of spacing between glass cover has been studied. Higher efficiency has been found for small gap. Small spacing between the glass cover surpasses the convention and heat transfer mechanism through the gap is only by conduction and radiation.
4. Enhancement factor in efficiencies have been evaluated and found to be more than unity which implies that double glazing is beneficial for efficiency point of view.

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