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Comparison of Outer Glass Cover Temperatures of a Double Glazed Flat Plate Solar Collector/Box Type Solar Cooker

Abstract

To characterize thermal performance of a flat plate solar collector/box type solar cooker, it is necessary to know its top heat loss coefficient (U_t). In order to compute U_t from analytical equations available in literature, outer glass cover temperature (T_2) of a double glazed flat plate solar collector is to be used in such equations, as a variable. An attempt is made to compare three different values of T_2 obtained from iterative/numerical solution of heat balance equations, empirical relations proposed by Smadarshi and Mullick and from experiments. Values of outer glass cover temperature obtained from three different methods were plotted for different days of experiment. Studies show that values of T_2 obtained from the three different procedures are almost same, for different days of experiment. Error in estimated T_2 and experimental T_2 was also studied, as difference in values of T_2, obtained from numerical solution of heat balance equations as base value. It reveals that experimental values of T_2, differ more as compared to those obtained from empirical relations proposed by Smadarshi and Mullick. Increase in the values of T_2 obtained from experiments may be due absorption of solar radiation in glass cover. It can be concluded that it is not necessary to measure the values of outer glass cover temperature from experiments, for its use in performance characterization of the double glazed flat plate solar collector. One can preferably use the existing expressions for T_2 available in literature e.g. proposed by Smadarshi and Mullick.

Keywords: *Flat plate solar collector, Box type solar cooker; Estimation of outer glass cover temperature.*

1. INTRODUCTION

A flat-plate solar collector is a large, shallow box, typically mounted on a roof that is used for heating applications using energy emitted from the Sun. Some of the heating applications involve domestic water heating, space heating, industrial purpose heating and solar cooking etc. Use of flat plate solar collector for cooking has great potential in developing countries. Two broad categories of solar collectors/cookers used for cooking are (i) Concentrating type (ii) Flat plate/Box type. Out of these two types of solar cookers, flat plate/box type solar cookers/collectors are most widely used around the world due to its ease in handling and simple design.

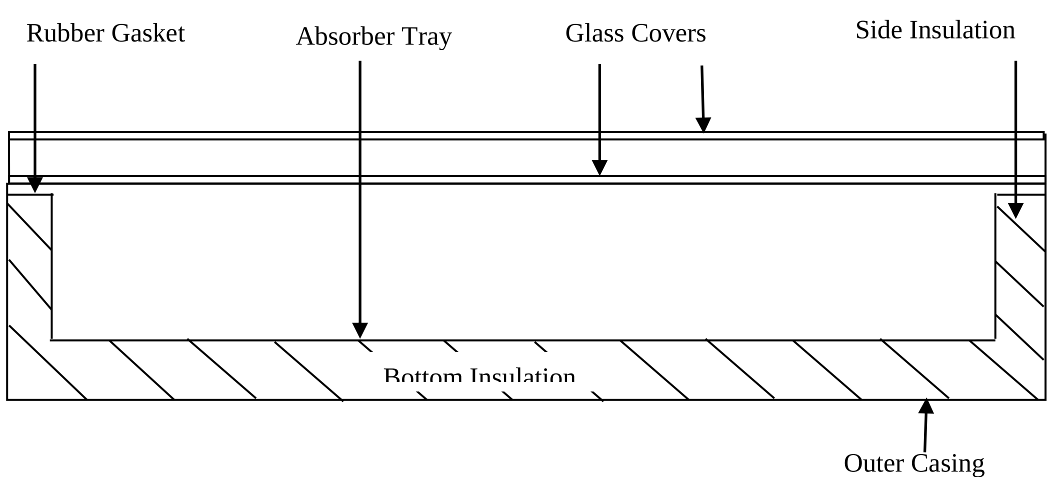

Fig. 1: Schematic diagram of the Flat Plate Solar Collector/box solar cooker used in experiments

A flat plate solar collector consists of a black painted absorber tray, usually made of aluminum or copper sheet. An insulating material is used below the absorber tray and also on its sides. A double glazed lid is placed on the top of the absorber tray. Absorber tray, insulating material and glazing are supported by an outer casing (Fig. 1)

Different designs of solar collectors/box solar cookers have been developed and field tested [1-11]. One of the important requirements for the development of flat plate solar collector is the availability of suitable performance characterization methods. Calculation of heat loss from the collector is required for design or simulation of the performance of solar collectors. Overall heat loss coefficient U_L is the sum of top heat loss coefficient, U_t, and bottom and side heat loss coefficient, U_{b+s}. Top heat loss coefficient U_t is the main component for estimation of overall heat loss coefficient U_L.

Top heat loss coefficient of a flat plate solar collector/box type solar cooker can be calculated by a simple analytical equation suggested by Suresh Kumar et al. [12]. The simplified equation suggested by [12] for U_t of Box type solar cooker is mentioned below:

$$U_t = \left[\frac{1}{0.017(T_p + T_2) - 6.452} + \frac{1}{h_w + 0.059\,(Tp - Ta)}\right]^{-1} \qquad (1)$$

In equation (1) linear functions of variables i.e. T_p, T_2 and T_a have been used. The wind heat transfer coefficient (h_w) has been used as an independent variable. 'h_w' can be estimated from velocity based correlation [13] by using measured value of the wind speed. In outdoor testing of box-type solar cookers, the tray temperature (T_p) and ambient temperature (T_a) can be measured experimentally.

Temperature of outer glass cover (T_2) to be used in the Eqn. (1), can be obtained by different methods such as, numerical solution of heat balance equations, computed analytically by an empirical equation suggested by Samdarshi and Mullick [14] and can also be measured experimentally. An attempt is made in this study to compare the three different values of T_2 to be used in Eqn. (1).

2. METHODOLOGY

As mentioned above, the objective of this study is to make a comparison of the three values of T_2 obtained by different methods such as,(i) Numerical solution of heat balance equations (ii) Analytical computation by an empirical equation suggested by Samdarshi and Mullick [14] and (iii) Measured experimentally .The approach used for the study is briefly described in the following paragraphs:

Outdoor experiments were conducted on a flat plate solar collector (Fig. 2) having a geometry similar to that of a box type solar cooker (air gap spacing between absorber plate and inner glass cover of 95 mm). Experimental setup consists of a stevenson screen to measure ambient temperature and an anemometer for measurement of wind speed. K-type thermocouples were fixed at the center of outer glazing and at the center of collector tray to measure respective temperatures. Data logger was used to record the temperatures of the absorber tray, glazing, ambient temperature, intensity of solar radiation and wind speed.

Fig. 2: Experimental test set-up

2.1 Determination of T_2 from Numerical Solution

Under steady state conditions, the thermal energy loss from plate at an average temperature T_p to the inner glass-cover at an average temperature T_1, equals to that from inner glass-cover to outer glass-cover at an average temperature T_2 and equals to that from outer glass-cover to ambient air at T_a. Top heat loss flux from plate to inner glass-cover is given by

$$\dot{Q}_t'' = \left(h_{cp1} + h_{rp1}\right)\left(T_p - T_1\right) \quad (2)$$

From inner glass-cover to outer glass-cover by

$$\dot{Q}_t'' = \left(h_{c12} + h_{r12}\right)\left(T_1 - T_2\right) \quad (3)$$

And from outer glass-cover to the atmosphere by

$$\dot{Q}_t'' = \left(h_w + h_{r2a}\right)\left(T_2 - T_a\right) \quad (4)$$

The effective black body temperature of surroundings is taken equal to ambient temperature. Solar radiation absorbed in glass covers have been neglected for the reasons mentioned in [15]. Equations (2) to (4) are solved simultaneously to find values of outer glass cover temperature T_2.

2.2 Determination of T_2 from Empirical Equation by Samdarshi and Mullick

For estimating the temperature of the second (outer) glass cover (T_2), following empirical relation was employed:

$$T_2 = T_a + h_w^{-0.4}[0.0012\, T_p + 0.37\, \varepsilon_p - 0.146](T_p - T_a) \quad (5)$$

Values of absorber plate temperature (T_p) and ambient temperature (T_a) were recorded experimentally. Emissivity of the coating of absorber plate, used in experiment is, 0.90. Wind speed (V_w) is used for estimation of wind heat transfer coefficient (h_w), hence it was also recorded while conducting the experiments. h_w was calculated by velocity based correlation suggested in [13]:

$$h_w = 7.15 + 3.19\ V_w \tag{6}$$

T_2 was computed by substituting values of T_p, T_a, ε_p and h_w in empirical equation (5).

2.3 Determination of T_2 from Experiments

K-type thermocouples were fixed at the center of outer glazing and with the help of data logger, T_2 was recorded experimentally.

3. RESULTS AND DISCUSSION

Values of outer glass cover temperature (T_2) obtained from numerical solution of heat balance equations, estimated by empirical equation by Samdarshi and Mullick and those measured experimentally, are plotted in Fig 3, for each day of experiment.

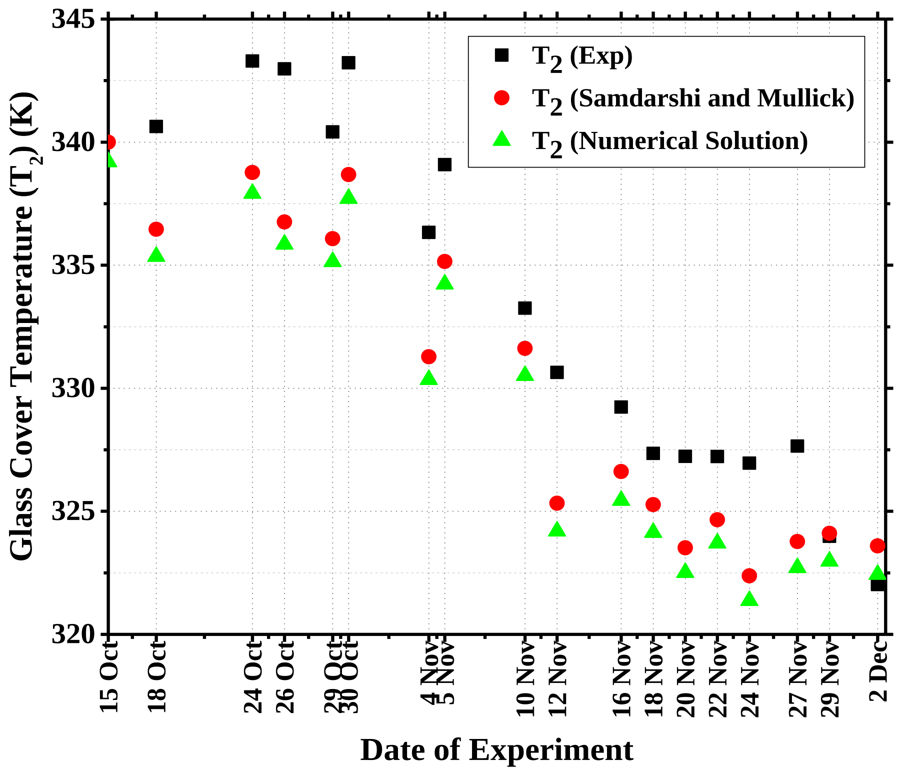

Fig 3: Comparison of T_2 for different days of experiment

As shown in Fig. 3, the values of T_2 obtained from three different methods are almost same. It is observed that experimental values of T_2 are slightly higher than those obtained from numerical solution or from empirical equations by Samdarshi and Mullick [14]. Possible reason for increased values of T_2 from experiments may be absorption of solar radiation in glass covers.

Table 1 presents the difference in values of T_2 obtained from experimental values to those obtained from numerical solution (Difference, Exp T_2). It also shows the difference in values of T_2 obtained from empirical equation by Samdarshi and Mullick[14] and to those obtained from numerical solution of heat balance equations (Difference, Samdarshi and Mullick T_2). It is evident from the table that the difference is higher in case of experimental values of T_2. The difference in values of T_2 in case of empirical equation is about 1 degree. Obtaining T_2 by experiments may involve uncertainties, primarily due to absorption of solar radiation in the glass cover.

Table 1: Difference in values of T_2 from Experiments and that from equation by Samdarshi and Mullick taking T_2 obtained from numerical solution as base value

Date	T_p (K)	Difference, Exp T_2 (K)	Difference, Samdarshi & Mullick T_2 (K)
15-Oct	405.40	6.01	0.80
18-Oct	392.18	5.28	1.10
24-Oct	401.89	5.38	0.86
26-Oct	398.75	7.12	0.90
29-Oct	396.87	5.27	0.93
30-Oct	401.10	5.51	0.97
04-Nov	389.33	5.98	0.93
05-Nov	394.68	4.85	0.92
10-Nov	383.12	2.74	1.10
12-Nov	373.36	6.45	1.13
16-Nov	373.83	3.79	1.17
18-Nov	371.15	3.21	1.13
20-Nov	376.18	4.72	1.01
22-Nov	380.62	3.52	0.94
24-Nov	374.51	5.58	1.01
27-Nov	373.56	4.94	1.06
29-Nov	371.63	1.01	1.13
02-Dec	367.81	0.41	1.16

4. Concluding remarks

From the results presented in the study, it may be concluded that for performance characterization of a flat plate solar collector/box type solar cooker there is no need to measure the outer glass cover temperature (T_2). Instead, existing correlations developed by researchers e.g. Samdarshi and Mullick [14] can be used to estimate its value. Such an estimation of T_2 can be used in equation (1) for estimating U_t of a flat plate/box type solar cooker.

Nomenclature

ε_p	emittance of coating on the absorber tray of the solar collector
h_c	convective heat transfer coefficient ($Wm^{-2} K^{-1}$)
h_r	radiative heat transfer coefficient ($Wm^{-2} K^{-1}$)
h_w	wind heat transfer coefficient ($Wm^{-2} K^{-1}$)
I	solar radiation (Wm^{-2}) incident on the aperture of solar collector
$\dot{Q}''_t$	top heat loss flux (Wm^{-2})
T_1	temperature of first glass cover (K)
T_2	temperature of second glass cover (K)
T_a	ambient temperature (K)
T_p	average temperature of the absorber tray of solar collector (K)

U_{b+s}	combined bottom and side heat loss coefficient (W $m^{-2}K^{-1}$)
U_L	overall heat loss coefficient (W $m^{-2}K^{-1}$)
U_t	top heat loss coefficient (W $m^{-2}K^{-1}$)
V_w	wind speed (ms^{-1})

Subscripts

$p1$	plate to first glass-cover
12	first glass cover to second glass cover
2a	second glass-cover to ambient

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