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Experimental investigations of heat losses from a parabolic concentrator solar cooker

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ABSTRACT

The thermal performance of parabolic solar cooker, where an unglazed cooking pot is often used depends to a great extent on the prevailing wind conditions. Moreover, these types of cookers required tracking of the sun to keep the focus at the bottom of the cooking pot. This paper presents reports of the experimental investigations of heat losses from such a cooker under different prevailing weather conditions. The three components of the cooker considered for the analysis are: the absorber (cooking pot), cooking pot cover and air contained in the cooking pot. Convective heat losses are important determining factor in the performance of this type of solar cookers. Average values of convective heat losses determined are: absorber (cooking pot) to surrounding air ($Q_{conv,\ a\text{-}air}$) is 0.244 W, cooking pot cover to surrounding air ($Q_{conv,\ c\text{-}air}$) is 0.096 W, cooking pot cover to air gap ($Q_{conv,c\text{-}g}$) is -0.005 W. Radiative heat losses from cooking pot cover to absorber ($Q_{rad,c\text{-}a}$) and absorber to sky ($Q_{rad,a\text{-}sky}$) has an average of -0.029 and 0.379 W, respectively. It is concluded that convective heat transfer losses are high for this type of solar cooker.

Keywords: Heat, parabolic, solar, beam.

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INTRODUCTION

In solar thermal systems, heat loss can significantly reduce the efficiency and consequently the cost effectiveness of the system. It is therefore vital to fully understand the nature of these heat loss mechanisms. With paraboloidal dish, three types of heat losses were analyzed: conduction, convection and radiation. These heat losses from a paraboloid concentrator solar cooker primarily depend on the temperature of water contained in the cooking pot, wind speed, surface area of the cooking pot and orientation of the reflector.

The performance of any solar thermal energy conversion device is governed by the rates of heat transfer interactions between its components parts and its surroundings. Concentrating parabolic solar cookers were initially developed during the 1950s and 1960s. Since then, several models of such cookers have been fabricated and tested in many countries around the globe (Kumar et al., 1993). Amongst the designs developed so far, the parabolic concentrator solar cooker has received the most attention (Mishra et al., 1987). A test procedure for thermal performance evaluation of the concentrating solar energy cooker was proposed by Mullick et al. (1991). Experimental investigation on effect of reflector orientation of paraboloid concentrator solar cooker heat losses was carried out by Kumar et al. (1993). Several research work were conducted on the thermal testing and performance evaluation for concentrating solar cooker and combined concentrating/oven type solar cooker, and parameters that characterize the performance of the solar cooker (Nahar, 1990; Mullick et al., 1991; John et al., 1991; Nahar et al., 1993).

MATERIALS AND METHODS

Experimental set up

In order to carry out the experimental investigations, an

a b

Figure 1. a: Parabolic concentrator solar cooker; b: Pyranometer.

outdoor test was set up. It primarily consists of a parabolic reflector, absorber (cooking pot), pot cover and automatic tracking mechanism. During testing, temperature at different points was recorded, such as the absorber temperature, pot cover temperature, cooking fluid (water) temperature and ambient temperature using K-type thermocouples and Kane-May KM 330 Digital temperature output instrument. The thermocouples were the 2 mm diameter steel, grounded junction type. Their size was such that caused less obstruction to heat and their accuracy was ± 0.1°C, when employed with the digital temperature output meter Kane - May KM330.Instantaneous global components of solar radiation were measured using pyranometer (CM6B model, KIPP & ZONEN DELFT Holland) and other type CM11/121 fitted with shadow ring, measures the instantaneous diffuse component of solar radiation. Both were calibrated as $9.63 \times 10^{-6} V/WM^{-2}$. Wind speed was measured to see its effect on the performance of the cooker using cup counter anemometer; its accuracy was about ± 1%. This is shown in Figure 1a and b.

Test procedure for the determination of heat losses

The cooking pot (absorber) of 0.522 kg and 1.0 kg of water was placed at the focus of the parabolic concentrator. Initial temperature of the absorber, pot cover, water (cooking fluid) and air contained in the cooking pot were measured at 15 min interval using the K-type thermocouples until a maximum temperature of the water in the cooking pot is reached. The corresponding wind speed and global solar radiation was recorded. It is convenient from the point of view of analysis to express the heat loss from the cooking pot in terms of an overall loss coefficient defined by the following equation:

$$q_l = U_l A_a (T_a - T_{air}) \quad (1)$$

Where,
U_l = Overall loss coefficient,
A_a = Area of the absorber,
T_a = Average temperature of the absorber,
T_{air} = Temperature of the surrounding air.

The heat loss from the absorber is sum of the heat lost from the top (pot cover) and the sides (cooking pot). Thus,

$$q_l = q_t + q_s \quad (2)$$

Where,
q_t = rate at which heat is lost from the pot cover,
q_s = rate at which heat is lost from the sides of the absorber.

Each of these losses is also expressed in terms of coefficients called the pot cover loss coefficient and the sides' loss coefficient as defined by Sukhatme (2005) in:

$$q_t = U_t A_a (T_a - T_{air}) \quad (3)$$

$$q_s = U_s A_a (T_a - T_{air}) \quad (4)$$

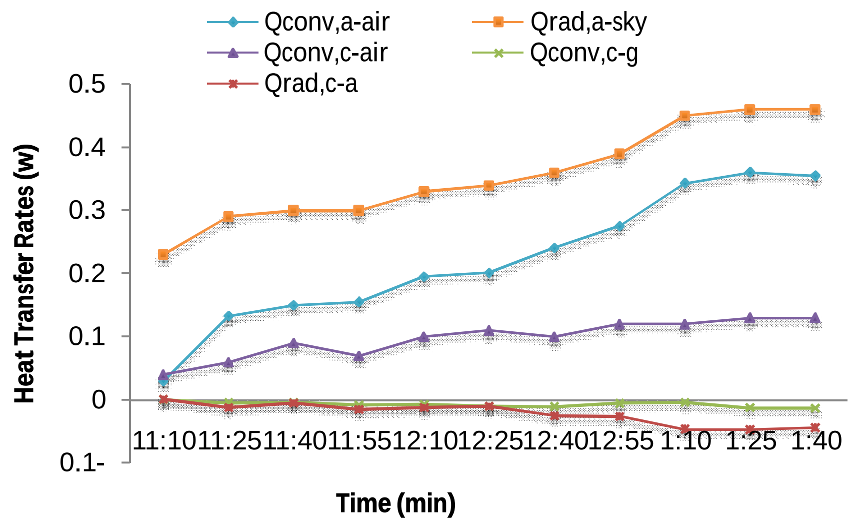

Figure 2. Variation of heat transfer rates with time.

Where,

$$U_l = U_t + U_s \tag{5}$$

And,

$$U = \frac{1}{\frac{L}{k} + \frac{1}{h}}$$

The rate of convective heat transferred from absorber to surrounding air was determined using the given relation:

$$Q_{conv,a-air} = (T_a - T_{air})(5.7 + 3.8V)[2\pi rh] \tag{6}$$

The radiative heat transferred from absorber to sky was determined using the given relation:

$$Q_{rad,a-sky} = 2\pi rh\sigma\epsilon[T_a^4 - 9.28 \times 10^{-6} T_{air}^6] \tag{7}$$

The conductive heat transferred from absorber to fluid was determined using the given relation:

$$Q_{cond,a-f} = \frac{\pi r^2 (T_a - T_f)}{\frac{L}{k} - \frac{1}{h}} \tag{8}$$

The convective heat transferred from top (cover) to surrounding air was determined from the given relation:

$$Q_{conv,c-air} = h\pi r_c^2 (T_c - T_{air})(5.7 + 3.8V) \tag{9}$$

The radiative heat transferred from pot cover to absorber was determined from the given relation:

$$Q_{rad,c-a} = \frac{\sigma A_{sides}(T_a^4 - T_c^4)}{\frac{1}{\varepsilon_a} + \frac{1}{\varepsilon_c} - 1} \tag{10}$$

RESULTS AND DISCUSSION

The parabolic concentrator solar cooker was tested for the period from June, 2010 to July, 2010 and the results presented here represent the average values of the data collected over this period. Heat losses determined from the experiment were the convective losses from absorber (cooking pot) to surrounding air ($Q_{conv,a-air}$), convective heat losses from top (cooking pot cover) to surrounding air ($Q_{conv,c-air}$), convective heat losses from cooking pot cover to air gap ($Q_{conv,c-g}$), radiative heat losses from cooking pot cover to absorber ($Q_{rad,c-a}$), radiative heat losses from absorber to sky ($Q_{rad,a-sky}$) and conductive heat from absorber to cooking fluid ($Q_{cond,a-f}$).

Figures 2 and 3 show the heat transfer rates variation with time for a given cooking fluid of 0.522 kg, at an average insolation of 436.1 and 507.7 W/m^2, wind speed of 0.6 and 0.9 m/s. It indicates that convective heat losses from cooking pot cover to air contained in the cooking pot and radiative heat losses from cooking pot cover to absorber are on the negative axis, this means absorber and air contained in the cooking pot are at higher temperature than the cooking pot cover throughout the period of the experiment. Tables 1a, 1b, 2a and 2b show the heat transfer rates between the components of the cooker and overall heat losses that took place from cooking pot cover to absorber sides for 436.1 and 507.7

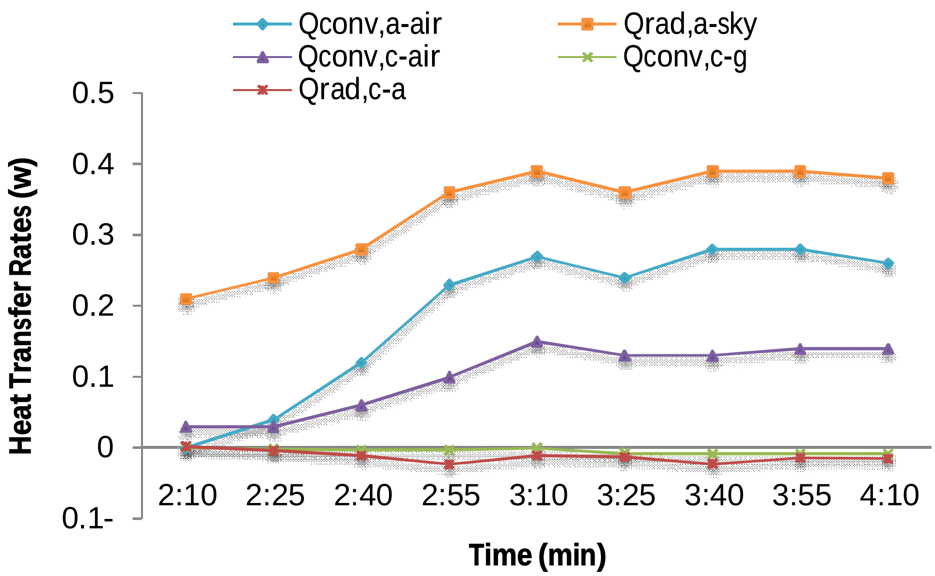

Figure 3. Variation of heat transfer rates with time.

Table 1a. Heat transfer rates for boiling. Test of water.

$Q_{conv,\ a\text{-}air}$	$Q_{rad,\ a\text{-}sky}$	$Q_{conv,\ c\text{-}air}$	$Q_{conv,\ c\text{-}g}$	$Q_{rad,\ c\text{-}a}$
0.0299	0.23	0.04	0.0004	0.001
0.1325	0.29	0.06	-0.0045	-0.012
0.1496	0.30	0.09	-0.0041	-0.005
0.1553	0.30	0.07	-0.0078	-0.015
0.1952	0.33	0.10	-0.0070	-0.012
0.2009	0.34	0.11	-0.0103	-0.010
0.2408	0.36	0.10	-0.0107	-0.025
0.275	0.39	0.12	-0.0053	-0.026
0.3434	0.45	0.12	-0.0041	-0.046
0.3605	0.46	0.13	-0.0119	-0.047
0.3548	0.46	0.13	-0.0131	-0.044

Weather condition: Partially clear, Rain in the morning, Setting Time: 11:10 a.m.

Table 1b. Overall heat losses.

q_{top}	q_{sides}	q_{total}	U_L
-0.16	0.26	0.10	0.00
-0.14	0.42	0.29	-0.21
-0.11	0.45	0.34	-0.37
-0.13	0.46	0.33	-0.38
-0.10	0.53	0.43	-0.22
-0.09	0.54	0.45	-0.30
-0.10	0.60	0.50	-0.58
-0.08	0.67	0.58	-1.79
-0.08	0.79	0.71	1.18
-0.07	0.82	0.75	10.06
-0.07	0.81	0.74	-2.13

Average wind speed: 0.9 m/s, Average insolation: 436.1 W/m^2, Date: 09/06/2010, Mass of water: 522 g.

Table 2a. Heat transfer rates for boiling test of water.

$Q_{conv,\ a\text{-}air}$	$Q_{rad,\ a\text{-}sky}$	$Q_{conv,\ c\text{-}air}$	$Q_{conv,\ c\text{-}g}$	$Q_{rad,\ c\text{-}a}$
0.00	0.21	0.03	0.001	0.002
0.04	0.24	0.03	-0.001	-0.004
0.12	0.28	0.06	-0.003	-0.011
0.23	0.36	0.10	-0.003	-0.023
0.27	0.39	0.15	0.000	-0.011
0.24	0.36	0.13	-0.007	-0.013
0.28	0.39	0.13	-0.008	-0.022
0.28	0.39	0.14	-0.008	-0.014
0.26	0.38	0.14	-0.008	-0.015

W/m^2 beam radiation, respectively. Convective heat transfer rate from absorber to ambient air, from pot cover to ambient air and radiative heat transfer from absorber to sky increases with increase in temperature as heating continued.

Figures 4, 5 and 6 represent the variation of heat transfer rates for cooking fluid of 1 kg, at average solar insolation of 484.6, 540 and 623 W/m^2, respectively. Tables 3a, 4a, and 5a are the heat transfer rates for boiling test of 1 kg of water at the stated beam radiations. Convective heat transfer from absorber to ambient air and that from cooking pot cover to ambient air increases

Table 2b. Overall heat losses.

q_{top}	q_{sides}	q_{total}	U_L
-0.17	0.21	0.04	0.00
-0.17	0.28	0.11	-0.26
-0.14	0.40	0.27	-0.53
-0.10	0.59	0.48	1.89
-0.05	0.66	0.60	3.42
-0.07	0.60	0.53	-0.61
-0.07	0.68	0.60	-0.69
-0.06	0.67	0.61	-0.61
-0.06	0.64	0.58	-0.43

Weather condition: Clear; Setting time: 2:10 p.m.; Average wind speed: 0.6 m/s, Average insolation: 507.7 W/m^2; Date: 11/06/2010; Mass of water: 522 g.

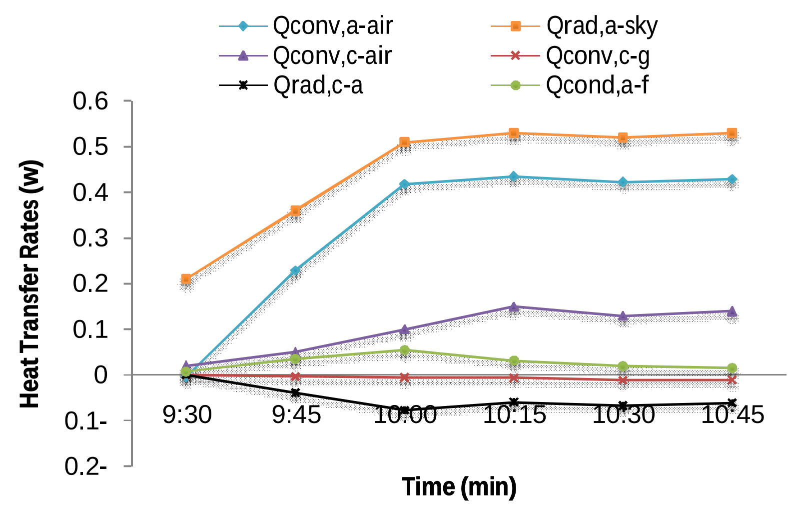

Figure 4. Variation of heat transfer rates with time.

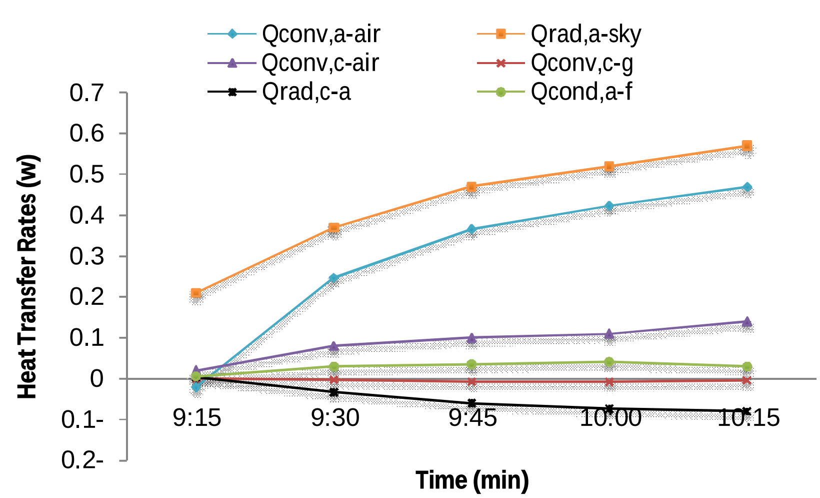

Figure 5. Variation of heat transfer rates with time.

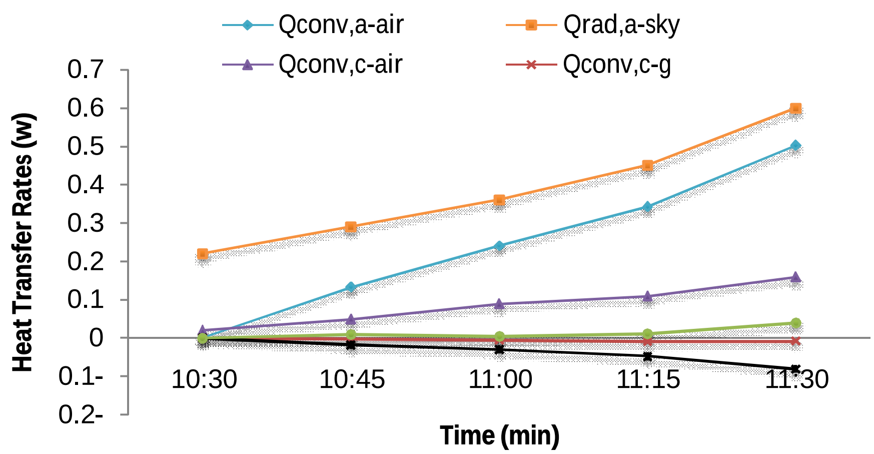

Figure 6. Variation of heat transfer rates with time.

Table 3a. Heat transfer rates for boiling test of water.

$Q_{conv,a-air}$	$Q_{rad,a-sky}$	$Q_{conv,c-air}$	$Q_{conv,c-g}$	$Q_{rad,c-a}$
-0.004	0.21	0.02	0.0004	0.001
0.229	0.36	0.05	-0.0033	-0.039
0.418	0.51	0.10	-0.0053	-0.077
0.435	0.53	0.15	-0.0062	-0.059
0.423	0.52	0.13	-0.0111	-0.067
0.429	0.53	0.14	-0.0107	-0.061

Table 4a. Heat transfer rates for boiling test of water.

$Q_{conv,a-air}$	$Q_{rad,a-sky}$	$Q_{conv,c-air}$	$Q_{conv,c-g}$	$Q_{rad,c-a}$
-0.021	0.21	0.02	0.0000	0.003
0.247	0.37	0.08	-0.0025	-0.033
0.366	0.47	0.10	-0.0070	-0.060
0.423	0.52	0.11	-0.0078	-0.073
0.469	0.57	0.14	-0.0045	-0.080

Table 5a. Heat transfer rates for boiling test of water.

$Q_{conv,a-air}$	$Q_{rad,a-sky}$	$Q_{conv,c-air}$	$Q_{conv,c-g}$	$Q_{rad,c-a}$
0.001	0.22	0.02	0.0000	0.000
0.133	0.29	0.05	-0.0016	-0.018
0.241	0.36	0.09	-0.0049	-0.030
0.343	0.45	0.11	-0.0090	-0.048
0.503	0.60	0.16	-0.0070	-0.081

due to absorber and cover were at higher temperature than the ambient air. Tables 3b, 4b and 5b show overall heat losses for the mentioned beam radiations, it was

Table 3b. Overall heat losses.

q_{top}	q_{sides}	q_{total}	U_L
-0.18	0.21	0.03	0.00
-0.15	0.59	0.44	0.02
-0.10	0.93	0.83	0.22
-0.05	0.97	0.92	0.70
-0.07	0.94	0.87	1.31
-0.06	0.95	0.90	1.55

Weather condition: Clear; Setting time: 9:30 a.m.; Average wind speed: 0.7 m/s. Average insolation: 484.6 W/m^2; Date: 13/06/2010; Mass of water: 1 kg.

Table 4b. Overall heat losses.

q_{top}	q_{sides}	q_{total}	U_L
-0.18	0.18	0.00	0.00
-0.12	0.61	0.50	0.00
-0.10	0.83	0.73	0.37
-0.09	0.94	0.86	0.48
-0.06	1.03	0.97	0.76

Weather condition: Clear; Setting time: 9:15 a.m.; Average wind speed: 0.98 m/s. Average Insolation: 540 W/m^2; Date: 20/06/2010; Mass of Water: 1 kg.

observed that the heat losses were high, this exposes this type of solar cooker that has cooking pot placed at the focus unglazed and there is a rapid continues increase in temperature that bring about high heat losses.

Conclusion

It was observed that the convective heat losses were

Table 5b. Overall heat losses.

q_{top}	q_{sides}	q_{total}	U_L
-0.18	0.22	0.04	0.00
-0.15	0.42	0.27	0.12
-0.11	0.60	0.49	1.93
-0.09	0.79	0.70	1.16
-0.04	1.10	1.06	0.48

Weather condition: Clear; Setting time: 10:30 a.m.; Average wind speed: 0.36 m/s. Average insolation: 623 W/m^2; Date: 09/07/2010; Mass of water: 1 kg

higher, this exposes this type of solar cooker that has cooking pot placed at the focus unglazed and there is a rapid continuous increase in temperature that brings about high heat losses. Nevertheless, the results obtained from full analysis of heat transfer processes governing the performance of parabolic solar cooker have led to recognition that this type of cooker can adequately be used for cooking in tropical areas.

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