AN EXPERIMENTAL STUDY ON BOX-TYPE SOLAR COOKER

Sonali Kesarwani¹, Ajeet Kumar Rai², Vivek Sachann³

ABSTRACT

In this paper, box type solar cookers with plain and finned absorber plates are experimentally investigated in Allahabad climate conditions. The Figure of merits ($F_1$ and $F_2$) are calculated for both the systems. Performance is evaluated on the basis of exergy analysis. It is found that solar cooker with finned base is of A grade. The exergy efficiency of finned base box-type solar cooker is higher than the unfinned base box type solar cooker.

INTRODUCTION

Solar cooker is a convenient and accepted thermal device which is available throughout the world. Its low-cost makes it very attractive commercially, especially among the rural population in the developing countries. Mullick et al.[1] performed no load and full load test on box type solar cooker and suggested two figures of merits ($F_1$ and $F_2$) as a measure of its thermal performance. These parameters were also accepted by Bureau of Indian Standard as benchmark indicator of its thermal performance. Funk and Larsor[2] and Funk [3] proposed new parameters for performance estimation of solar cooker.

PERFORMANCE EVALUATION OF THE COOKER

Determination of $F_1$

The value of $F_1$ is determined by a stagnation test carried out under no-load condition and is mathematically expressed as

$$F_1 = \frac{\eta}{U_{LS}} = \frac{T_b - T_a}{g_s} \tag{1}$$

Where $\eta$ is the optical efficiency, defined as the fraction of the incident solar radiation, which reaches the absorber and gets absorbed and $U_{LS}$ the heat loss factor at stagnation. The stagnation temperature of the absorbing plate($T_b$), ambient temperature ($T_a$) and solar insolation ($G_s$) are measured when a steady state is reached.
Determination of $F_2$

The $F_2$ is obtained by heating the containers placed on the absorbing plate, i.e. under a full-load condition and is mathematically expressed as:

$$F_2 = \frac{F_1(mC_p)_{w}}{A(t_2-t_1)} \ln \left[ \frac{1 - (T_{w1} - T_a)/F_2G_s}{1 - (T_{w2} - T_a)/F_2G_s} \right]$$

(2)

Where $t_1$ is the time when water temperature reached $T_{w1}$ in ($^\circ$C), $t_2$ the time when water temperature reached $T_{w2}$ ($^\circ$C), $(t_2 - t_1)$ the time taken for heating water from $T_{w1}$ to $T_{w2}$ in seconds. $T_a$ ($^\circ$C) the average ambient temperature from the time period $t_1$ to $t_2$, $G_s$ (W/m$^2$) the average solar radiation from the time period $t_1$ to $t_2$ and $(mC_p)_{w}$ the product of the mass of water and specific heat (J/$^\circ$C).

ENERGY AND EXERGY ANALYSIS

Energy analysis

For the steady-state flow process during finite time interval ($\Delta t$), the overall energy balance equation for Solar box cooker can be written as

$$[\text{Energy gained by water in the vessel}] = [\text{Energy supplied to water in the vessel}] - [\text{Energy lost from water in the vessel}]$$

(3)

The energy gained by water in the vessel kept inside the cooker can be considered as the output energy ($E_o$) of the system (in KJ) and is given as

$$E_o = mC_p(T_{w2} - T_{w1})$$

(4)

Where, $m$ and $C_p$ are the mass (kg) and specific heat capacity of the water (J/kgK) respectively. $T_{w2}$ and $T_{w1}$ are the instantaneous final and initial temperatures (K) of the water during the full load test. In the expression above, the output energy depends only on the difference in final and initial values of temperatures ($T_{w2} - T_{w1}$) but in actual practice, ambient temperature as well as the initial and the final temperature values also play the role in deciding the efficiency of the system, and this type of qualitative effect cannot be accommodated in the energy based approach.

The energy supplied to water in the vessel kept inside the cooker can be considered as the input energy ($E_i$) of the system (in KJ) and is written as

$$E_i = G_s A \Delta t$$

(5)

Where, $G_s$ is instantaneous solar isolation (W/m$^2$) recorded over a time interval $\Delta t$, during the test period; $A$ is the gross area (m$^2$) of the glazing surface.

Thus, the instantaneous energy efficiency ($\eta_E$) of the system can be defined as the ratio of the energy gained by water to the ratio of the energy supplied to water and is expressed below as

$$\eta_E = \frac{E_o}{E_i} = \frac{mC_p(T_{w2} - T_{w1})}{G_s A \Delta t}$$

(6)

Exergy analysis

For the steady-state flow process during a finite time interval, the overall exergy balance equation for solar box cooker can be written as
In an experimental study on box-type solar cookers, Sonali Kesarwani, Ajeet Kumar Rai and Vivek Sachann, the exergy of solar radiation as the exergy input $E_{xi}$ to the solar cooker can be calculated using the available solar energy flux ($G_s A \Delta t$) and is expressible through equation given below which has the widest acceptability [6,7].

$$E_{xi} = G_s \left[1 + \frac{1}{3} \left(\frac{T_a}{T_s}\right)^4 - \frac{4T_a}{3T_s}\right] A\Delta t$$  \hspace{1cm} (8)

Where, $T_s$ is surface temperature of sun. The sun’s black body temperature of 5762 K results in a solar spectrum concentrated primarily in the 0.3 – 3.0 µm wavelength band [8]. Although the surface temperature of the sun ($T_s$) varies due to the spectral distribution of sunlight on the earth’s surface, the value of 5800 K has been considered for performing calculations.

The exergy gained by water in the vessel kept inside the cooker due to rise in temperature can be considered as the output exergy ($E_{xo}$) of the system and expressed as [9]

$$E_{xo} = E_o - m C_p T_a \ln \frac{t_{w2}}{t_{w1}}$$  \hspace{1cm} (9)

The instantaneous exergy efficiency ($\eta_X$) of the system can be defined as the ratio of the exergy gained by water to the ratio of the exergy supplied to water and is depicted as

$$\eta_X = \frac{E_o - m C_p T_a \ln \frac{t_{w2}}{t_{w1}}}{G_s \left[1 + \frac{1}{3} \left(\frac{T_a}{T_s}\right)^4 - \frac{4T_a}{3T_s}\right] A\Delta t}$$  \hspace{1cm} (10)

**Experimental setup**

Two similar box type solar cookers have been fabricated to operate in the Saharan Environment; they differ only by absorber plate shape. Figure 1 shows the photographic view of box type solar cooker used in experiments. Box type solar cookers were constructed using GI sheet and insulated by a layer of styro-foam (Thermal conductivity = 0.033 W/m-K). For the first box solar cooker, the absorber plate consists of GI sheet painted black of a surface area (0.5625 m$^2$, i.e. 0.75m x 0.75 m) and 0.0010058 m thickness. For the second one, the absorber plate is similar to that of the first one but its upper surface is provided with fins made of GI painted black. Fins are of rectangular cross section (0.75 m by 0.01 m) and have a length of 0.020 m.

![Figure 1](Photo of box-type solar cooker)
RESULT AND DISCUSSIONS

Comparative study on two different type solar cookers, one with conventional and another with fins integrated on the absorbing plate has been carried out based on the exergy analysis. Figure 2, 3 and 4 shows observations taken on a particular day during the experimentation. Figure 2 shows the solar intensity with respect to the time of the day, figure 3 shows the wind velocity with respect to the time of the day and figure 4 shows the variation of the temperature of different component of the cookers with respect to the time of the day for one liter water in the cooker.

From the figure 4 it is found that the absorber plate temperature with fin is higher than the absorber plate temperature without fins. According to Mullick et al., 1987 the first figure of merit $F_1$ varies between 0.12 and 0.16. A high value of $F_1$ indicates good optical efficiency and low heat loss factor. Their prototype will then be classified as Grade A. For the experimental stagnation test, for finned and without finned the figure of merit $F_1$ is calculated as 0.10617; 0.145679 respectively by using above equation with values of ambient temperature 41°C; solar intensity 720 W/m$^2$ and absorber plate temperature for finned and without finned solar cooker is 100°C and 84°C respectively. Factor $F_1$ and $F_2$ are calculated by the equation 1 and 2 respectively.

Exergy input for finned and without finned base box type solar cooker is same which is 1249821.248 and exergy out is 17014.35265 and 16533.3958 for finned and without finned base box type solar cooker respectively.

![Solar Intensity](image.png)

**Figure 2.** Variation of solar intensity with time
CONCLUSION

On the basis of a comparative experimental study of two box-type solar cooker, which have been tested under same conditions of Allahabad, the following conclusion have been drawn:

The first figures of merit ($F_1$) is found as 0.145 for finned absorber plate box-type solar cooker and 0.106 for without finned absorber plate box-type solar cooker. According to BIS, finned absorber plate solar cooker falls in A Grade category.

The second figures of merit ($F_2$) of finned solar cooker was 35.5% more than without finned solar cooker.

The stagnation temperature for box-type solar cooker integrated with finned absorber plate was about 19% higher than without fin absorber plate box-type solar cooker.
REFERENCES