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Performance Analysis of a Box Type Solar Oven Cooker

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Abstract

The global warming of the environment is now a universal concern. The use of firewood for cooking in rural areas causes carbon emission. Women waste huge amount of time to collect firewood that is hazardous for health. Fortunately our country is blessed with good solar energy for almost eight months of the year. We get sufficient sunlight to cook our food during these months using a solar cooker. A locally developed box type solar cooker was tested to analyze this concept and for cooking our traditional foods. The primary objective of research was to provide a simple, cheap but acceptable and effective cooking solution for rural women.

Keywords: Solar cooker

I. Introduction

The major energy supply for rural cooking comes from bio-mass. In Bangladesh[1] around 65% of it comes from biomass, agricultural residues, twigs and branches, fuel wood and cow dung. A serious fuel wood storage has lead to the use of all conceivable agricultural residues in village kitchens. Indiscriminate felling of trees produces a major effect on environment as well as climate. Use of Solar Oven Cooker can play an important role in such a situation.

In the country now-a-days bio-gas is also utilized as cooking fuel. About 80% of the population[2] lives in villages and they depend solely on biomass for cooking their food. The performance of bio-gas cooker depends on its maintenance and waste supply. Its initial investment is much high. On the other hand a solar cooker requires no traditional fuel. Its only fuel is sunshine.

From the sunshine data of the Meteorological Department of Bangladesh, it is seen[3] that sunny days are very common for two third of the year. Solar Oven Cooker offers a regular solution for cooking during this period. The effect of occasional clouds during cooking has not shown serious negative effect for the Box- type Solar Oven Cooker. So, we found[4] that solar cooking is possible on sunny days as well as on semi-cloudy days of the year by a box-type solar cooker.

A box type solar cooker is easy to construct and material cost is also low. It can be used as the regular source of cooking when sunny days are available in the country. In the rainy days cooking is done by burning fuel woods. Women in rural areas have to spend considerable time for collecting wood and cooking. But solar cooker does not demand continuous care during cooking. Thus time and effort is saved which can be utilized for other economic activities. Moreover this is a pollution -free way of cooking. So, more use of the modern technology will provide more contribution to clean environment.

II. Literature Review

The basic purpose of a solar box cooker is to heat things up-cook food, purifies water, and may be used to sterilize instruments. The first reported solar cooker user worldwide was by a Swiss, de Saussure[5] who built black insulated box cooker with several glass covers. Even without reflectors, he reported to have successfully cooked fruits at that time reaching a temperature of 88°C. Over the years, de Saussure and others focused their solar box cooker design work on variations of shape, size, sidings, glazing, insulations, reflectors, and the composition and reflectance of the internal surfaces. In Africa, an Englishman, John Fredrick Herschel[6], used solar cookers in 1837, at the Cape of Good Hope, South Africa. He used a black box made of hard wood with a double glass window without a reflector and buried it in sand for insulation. The temperature reached was 66°C. In Asia, experiments on solar cookers were carried out by an Englishman, William Adams, in Bombay[6], India in 1878. He used glass planar mirrors arranged in a shape of an inverted eight-sided pyramid that focused light through a cylindrical bell jar into the food container.

From early design considerations on the development of an urban solar cooker goes back for more than 30 years[7]. Fayadh M. Abed.[8] described a solar oven with compound conical reflectors.

The performance of a box solar cooker with outer-inner reflectors was evaluated by El-Sebaii[9]; the calculations indicated that good improvement in cooker performance was attainable.

The thermal analysis of a double reflector box solar cooker with transparent insulation material was investigated experimentally by Nahar[10].

Many works have been done on the reduction of the cooking time using modified cooking vessels as did Grupp et al[11]. They proposed an improved version of the box solar cooker with a fixed cooking vessel in good thermal contact with a conductive plate. Gaur et al.[12] analyzed the performance of the box solar cooker with modified utensils with a concave shaped lid.

Food containing a lot of moisture cannot get much hotter than 100°C (212°F) in any case, so it is not always

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necessary to cook at high temperatures indicated in standard cookbooks. Because the food does not reach too high temperature, it can be safely left in the cooker all day without burning[13].

III. Experimental

Materials used

The solar oven cooker box is made of milled steel sheet, glass wool, plane glass, rubber seal and mirror. The inside and outside of the box is made black color to absorb radiation.

Design

The measurements of a typical solar box cooker are 20″×20″×10″ externally and 16″×16″×6″ internally respectively. The covered box is kept in the solar box which is provided with a thermometer. The maximum temperature measured inside the oven is 110^0C. The temperature rises gradually from morning till 13.30. At that time temperature reaches to the maximum.

Operation Principles

The principle of greenhouse effect is the basic of a solar oven box cooker. According to this principle, when an energetic short wave radiation falls on a glass cover, surface of the glass is heated up. The incident solar radiation will then be divided into three parts. One is reflected, one is absorbed and one is transmitted by the glass cover to the desirable materials like cooking pot and its contents placed on the absorber plate for cooking a required food item or heating water in accordance with the relation[14].

$$I = r_\lambda + a_\lambda + t_\lambda$$

Where, I = Incident solar radiation

r_λ= reflectivity at a particular wavelength

a_λ= absorptivity at a particular wavelength and t_λ = transmissivity at a particular wavelength.

Rice, vegetables and meat are mixed after cleaning and sufficient water is added for boiling and put in a box. After about 3 hours rice and vegetables will be boiled but the meat will take half an hour more.

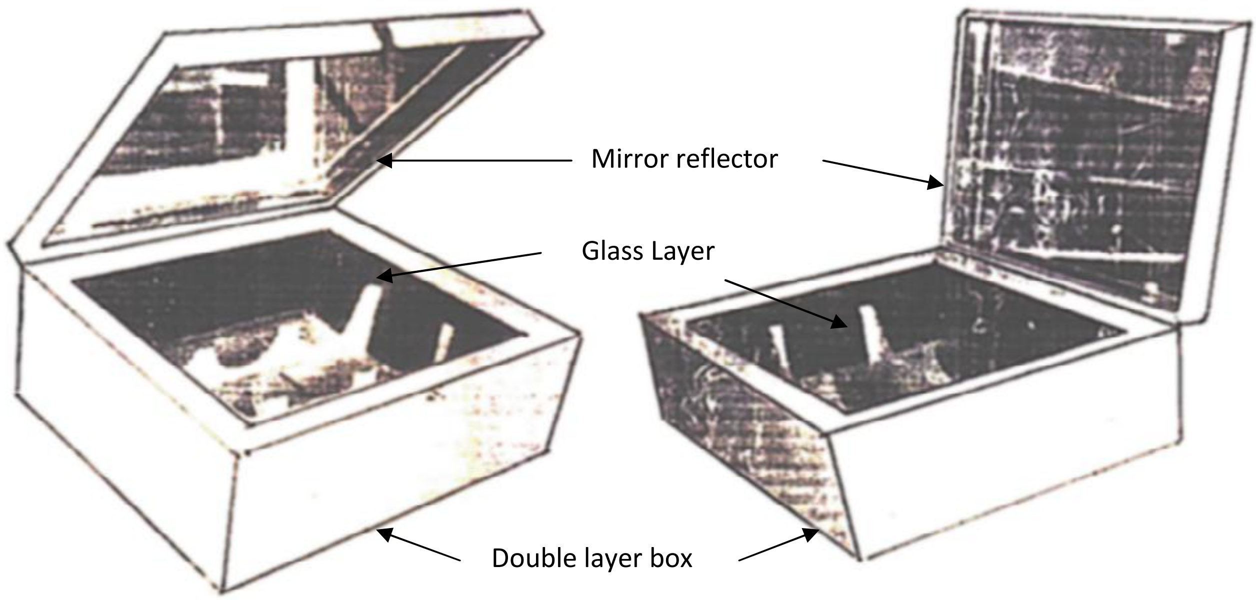

Fig. Solar Cooker

Performance criteria of Solar Oven Cooker

The efficiency of the Solar Oven Cooker was estimated by using the relation[15].

$$\eta_c = \frac{(m_p c_p + m_w c_w)(\bar{T}_w - \bar{T}_a)}{A_c Q_c t} \qquad (A)$$

Where, m_p and m_w represent mass of pot(1kg) and mass of water(0.3kg) respectively and c_p and c_w represent specific heat capacity of aluminum pot (920J/Kg ^{o}C) and water (4200J/ Kg ^{o}C) respectively. $\bar{T}_w$ and $\bar{T}_a$ stands for average water and ambient absolute temperatures respectively. A_c represents the area of the solar collector(0.17m^2) and Q_c stands for the average global radiation intensity and t for the daily time period of investigation(3600s).

IV. Results and Discussion

The following tables show the recorded temperature at different time and average efficiency of solar box cooker during experiment in three different days. Global radiation values for the days of experiment are collected from Renewable Energy Research Center (RERC), University of Dhaka.

Table 1. Average efficiency on 16/4/2009

Date	Time	Sky Condition	Temperature (Day) Or Ambient Temperature (T_a) as $\bar{T}_a$ °c	Temperature of water (inside the box cooker) (T_w), °c	Average Temperature of Water ($\bar{T}_w$) °c	Global Radiation (Q_C) (w/m²)	Average Global Radiation ($\bar{Q}_C$) (w/m²)	Efficiency of solar boxcooker (η_c)	Average Efficiency of solar box cooker ($\bar{\eta}_c$)
16/4/2009	11:45	Clear	36	110	102.50	900	769.50	30.78%	30.78%
	12:45			110		820			
	13:45			100		758			
	14:45			90		600			

Table 2. Average efficiency on 23/4/2009

Date	Time	Sky Condition	Temperature (Day) Or Ambient Temperature (T_a) as $\bar{T}_a$ °c	Temperature of water (inside the box cooker) (T_w), °c	Average Temperature of Water ($\bar{T}_w$) °c	Global Radiation (Q_C) (w/m²)	Average Global Radiation ($\bar{Q}_C$) (w/m²)	Efficiency of solar boxcooker (η_c)	Average Efficiency of solar box cooker ($\bar{\eta}_c$)
23/4/2009	11:30	Clear	36	110	104.00	920	760.60	31.85%	31.85%
	12:30			110		903			
	13:30			110		811			
	14:30			100		649			
	15:30			90		520			

Table 3. Average efficiency on 25/4/2009

Date	Time	Sky Condition	Temperature (Day) Or Ambient Temperature (T_a) as $\bar{T}_a$ °c	Temperature of water (inside the box cooker) (T_w), °c	Average Temperature of Water ($\bar{T}_w$) °c	Global Radiation (Q_C) (w/m²)	Average Global Radiation ($\bar{Q}_C$) (w/m²)	Efficiency of solar boxcooker (η_c)	Average Efficiency of solar box cooker ($\bar{\eta}_c$)
25/4/2009	12:00	Clear	38	110	108.00	915	630.00	33.92%	33.92%
	13:00			110		802			
	14:00			110		646			
	15:00			110		437			
	16:00			100		350			

The measured values are shown graphically in following figure for a clear day (16/4/2009) with day temperature at 36^{0}C.

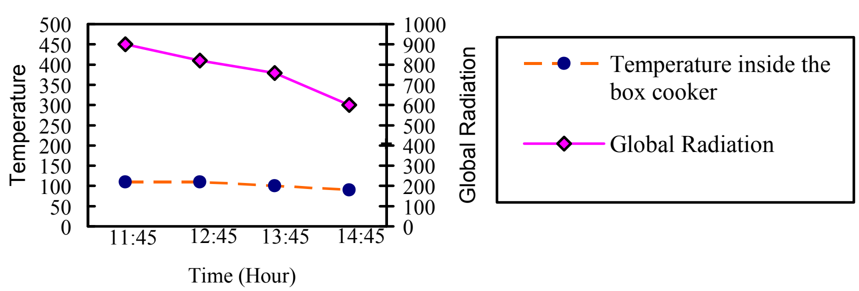

Fig. 1. Time versus temperature and Global radiation Chart on 16/04/2009

The graph drawn below shows the temperature inside box and radiation decrease over time for a clear day (23/4/2009) with day temperature at 36^0C.

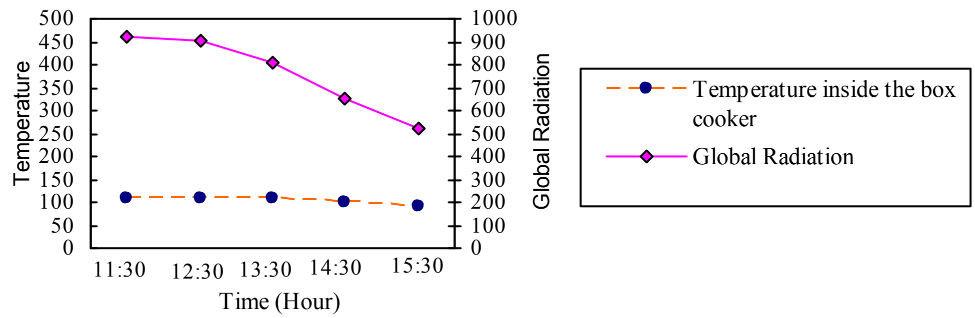

Fig. 2. Time versus temperature and Global radiation on 23/04/2009

The graph drawn below shows the temperature inside box and radiation decrease over time for a clear day (25/4/2009) with day temperature at 38^0C.

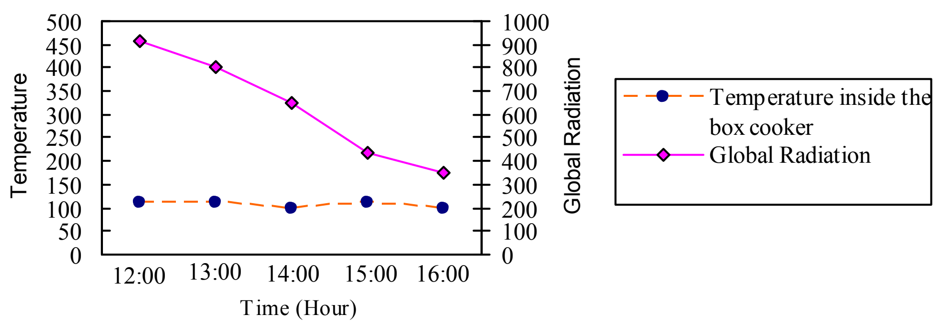

Fig. 3. Time versus temperature and Global radiation Chart on 25/04/2009

The graph drawn below shows the average efficiency of solar cooker versus day time.

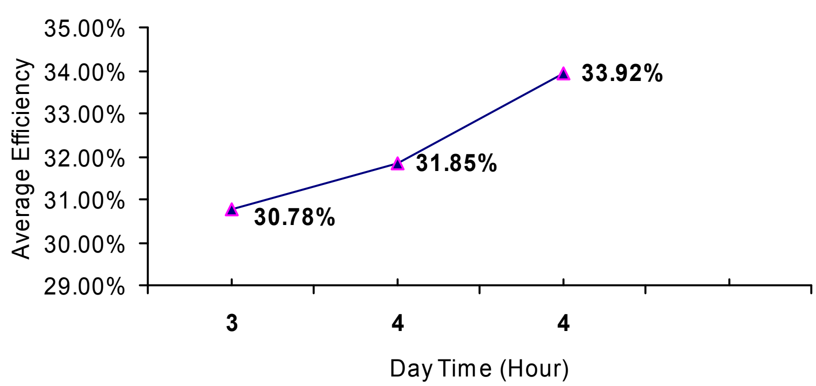

Fig. 4. Average efficiency versus day time.

The result of the study observed on three different clear days 16/4/2009, 23/4/2009/, and 25/4/2009 with relatively bright sunlight and hourly variations of temperature which are presented in Tables:1, 2 and 3. The temperature was 2^0C more in the case of one of the observed day (25/4/2009).Table 1,2 and 3 show the variations of the water temperature inside the box cooker (T_w), average working fluid (water) temperature ($\bar{T}_w$), average ambient temperature ($\bar{T}_a$) and average global radiation ($\bar{Q}_C$) observed on three different favorable days of performance test. As shown in figure 1, the maximum temperature of the working fluid (water) of about 110^0C was attained around 11:45 hours and 12:45 hours on the day of investigation in 16/4/2009. In figure 2, it was about the same temperature at 11:30 hours, 12:30 hours and 13:30 hours (1:30pm) on 23/04/2009. However figure 3 indicates that the same maximum temperature of the working fluid (water) inside the box cooker was lasts long as 12:00 hour to 15:00 hour (3:00pm) on 25th April 2009. Where as internal volume of the cooker was 1536 inches^3 and area was 256 inches^2.

Global radiation values for the days of experiment are collected from Renewable Energy Research Center (RERC), University of Dhaka. Table 1, 2 and 3 shows that the average global radiation of the three successive investigated days was 769.50, 760.60 and 630.00.

According to table 1 and 2 it is evident that the temperature inside the solar box cooker remains at least about 54^0C over the ambient temperature during the investigation period, which is 8^0C more on 25th April 2009.Required minimum food cooking temperature[16] is 82^0C. The result of the performance tests carried out in this work suggested that this temperature was attained during the period of investigation.

In this study the efficiency of the solar box cooker has been calculated based on the conducted test result by water boiling and the expression shown as the equation (A) above. The average efficiency 30.78%, 31.85% and 33.92% were estimated on three investigated day respectively.

This is therefore suggested that the developed solar box cooker is quite good for optimum use in our rural areas which comes with a simple, cheap but effective and acceptable cooking solution for rural people.

V.Conclusion and Recommendation

Bangladesh is blessed to have bright sunlight during two third period of a year. If we can use it properly for power generation, pollution will be reduced and the power crisis will be reduced. However it will require huge amount of money to build. Solar cooker s a small device with zero maintenance cost can save big amount of wood, leaf and oil. Rural women will utilize the saved time into other economic activities and this standard will be enhanced. Moreover the urban people can take advantage of it when gas crisis occurs or fuel price increases. The solar cooker can contribute in the development of a nation especially in the case of third world countries like ours.

For the better performance of the device more reflectors should be included as part of the cover to increase the amount of isolation on the absorber.

It is recommended the fixing of required thermometers at appropriate places throughout the periods of investigation without the need to constantly open the glass covers of the solar device is recommended.

We also suggested the use of more accurate temperature measuring instrument like thermocouples and platinum-resistance thermometers for conducting the various temperature measurements in future.

Fuel shortages and power breakdown without notice, even commonly used other cooking devices have caused some disappointments during their uses where a solar oven cooker can be an effective alternative solution.

Introduction of box type solar oven cooker into the rural areas and urban poor dwelling will greatly reduce the felling of trees. As an alternative of firewood it will certainly cheek the effect of deforestation and desert encroachment on our climate.

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