Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2017
(ICMERE2017) 18 – 20 December, 2017, Chittagong, Bangladesh

ICMERE2017-PI-000

DESIGN AND FABRICATION OF A WALL INTEGRATED BOX TYPE SOLAR COOKER

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Abstract*- There has been a significant recent interest in the design, fabrication, and testing of various types of solar cookers such as box type, concentrator-type, and oven type around the globe. The primary purpose of this paper is to propose an innovative design of a solar cooker and also to evaluate its thermal performance by testing a manufactured prototype. The solar cooker is equipped with two fixed parabolic reflectors, and it was constructed with locally available low-cost materials. The detailed structure of the designed cooker was studied and compared with its efficiency and economy in production. The thermal analysis was carried out by taking temperature and solar radiation data at different times of a particular day. The experimental results exhibited the cooking capability and thermal efficiency of the designed solar cooker. For the design features, it was remarkably efficient and durable. The various tests were carried out under the climatic conditions of Chittagong a tropical region of Bangladesh.*

Keywords: Solar Radiation, Specific Heat, Reflector, Thermal Efficiency, Solar Cooker.

1. INTRODUCTION

The sun is the source of maximum energy we get on earth. Most of the energy we use has gone through numerous transformations before it is finally used, but it is also possible to tap this source of solar energy as it reaches to earth.

A solar cooker is a device, which cooks food with the help of solar energy and can save the conventional fuels to a significant amount. It, however, supplements the cooking fuel but cannot replace it in total. It is possible to cook mid-day meal for 4 to 5 persons in a conventional box solar cooker and if one needs either full or part late afternoon meal could also be cooked. The principal use of solar cookers is to cook food and sterilized water, although additional uses are continually being developed. The primary goal of this study is to construct an innovative and yet simply designed wall integrated solar cooker which is capable of cooking effectively.

2. PREVIOUS STUDIES

C. Lertsatitthanakom has been carried out the experimental investigation of the conical solar cooker. It was a simply designed and low-cost conical-type solar cooker. The energy efficiency of the cooker was experimentally evaluated. The experiments were conducted on a bright day in October 2003 in Mahasarakham [1].

Negi and Purohit have designed, fabricated and tested a laboratory model of a box-type solar cooker employing a non-tracking concentrator. The concentrator consists of two planar reflectors suitably positioned in an east-west configuration on an inclined framework which is adjusted seasonally [2].

U.S. Mirdha and S.R. Dhariwal have developed and tested an improved box type solar cooker on a tilted collecting surface. It was equipped with one vertical fixed and two tractable mirrors [3].

H. Hoedt has been carried out the experimental investigation on informal strategy for dissemination of solar cookers. The Scheffler Reflector is a parabolic lived locus reflector, mainly used for institutional cooking [6].

S. Dutta has been carried out the experimental investigation of the inclined box-type solar cooker. A highly efficient inclined box solar cooker was designed and fabricated. In the proposed box type cooker the beam radiation was always perpendicularly accessible for its adjustable inclined position and for the proper implementation of two reflectors the cooking time was remarkably reduced than that of a typical box type cooker [7].

Recently A. Harmim, M. Merzouk, M. Boukar, M. Amar have designed and fabricated a wall integrated box solar cooker which is a box type solar cooker integrated with a wall [4].

This paper proposes an innovative and yet simply designed wall integrated box type solar cooker. A solar cooker integrated with building wall would be very comfortable and suitable to use for its daily users. Besides well designed parabolic reflectors were used to increase the solar thermal efficiency of the cooker. The designed cooker was manufactured using low-cost locally available materials. The manufactured prototype was tested for evaluating its solar thermal efficiency and cooking capability.

3. THEORY

To evaluate the solar thermal performance of the solar cooker the following terms and formulas are essential.

(a) Specific Heat: When heat energy is added to a substance, the temperature will change by a certain amount. The relationship between heat energy and the temperature is different for every material, and the specific heat is a value that describes how they relate. Equation (1) shows the relationship among heat energy **Q** in Joules, the mass of a substance **m** in kilograms, specific heat **c** in Joule per kilogram per kelvin and temperature difference ΔT in degree Kelvins.

$$Q = m \times C_p \times \Delta T \quad (1)$$

(b) Power: Power is defined as heat energy per unit time. Equation (2) relates Power P in Watt, Heat energy Q in Joules and time t in seconds.

$$P = \frac{Q}{t} \quad (2)$$

(c) Efficiency: Efficiency is the ratio of energy output to energy input.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100\% \quad (3)$$

4. METHODOLOGY

In this study, a theoretical analysis was done to obtain the critical dimension to design the solar cooker. CAD model was prepared using the dimensions. Finally, a prototype was manufactured with locally available low-cost materials. The prototype was tested and analyzed to evaluate its thermal performance. A block representation of the methodology is shown below.

Theoretical analysis to find out the physical dimensions of the cooking system.

⇩

Preparation of the CAD model of the system using the dimensions achieved from theoretical analysis.

⇩

Manufacturing of the designed system using locally available low cost materials.

⇩

Testing and collection of data to analyze the cooking system.

⇩

Analyze the data to obtain the performance of the solar cooker.

5. CAD DESIGN

The CAD model was prepared using SOLIDWORKS 2016 (Student Edition).

Fig. 1: Complete CAD model of wall integrated solar cooker.

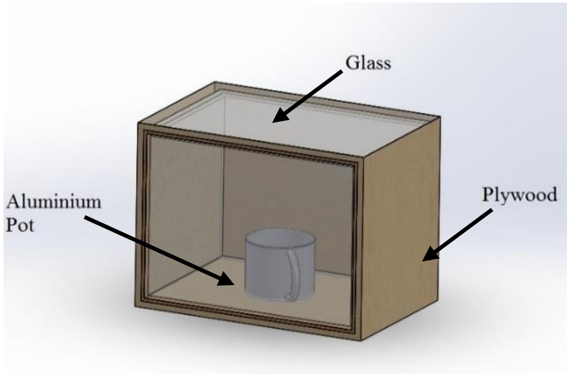

Fig. 2: Schematic view of cooker with aluminum Pot.

The crucial parts of a wall integrated box type solar cooker are an insulated metal box painted black from inside, two glass sheet, aluminum sheet as reflector and wall with two parabolic reflectors. Two parabolic reflectors (upper and lower) fixed on the walls were made of aluminum sheet. The reflector increases the efficiency of solar cooker by reflecting more sunlight inside the box.

It is a familiar fact that a black painted surface absorbs more heat than a white surface. So, the inside surfaces of the metallic box used as solar cooker were painted black to increase absorption of heat. This box is covered by two transparent sheets of glass. For insulation cork sheets were used. There was also aluminum foil inside the box to increase the heating effect.

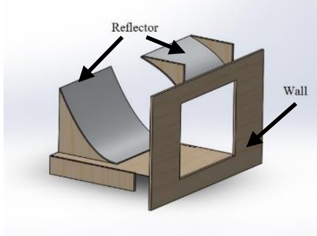

Fig. 3: Schematic diagram of wall with two reflectors.

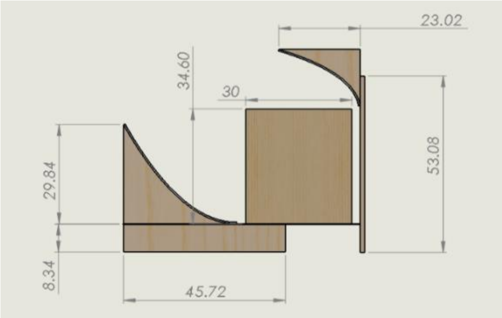

Fig.4: Right view of wall integrated solar cooker (all the dimensions are in centimeter)

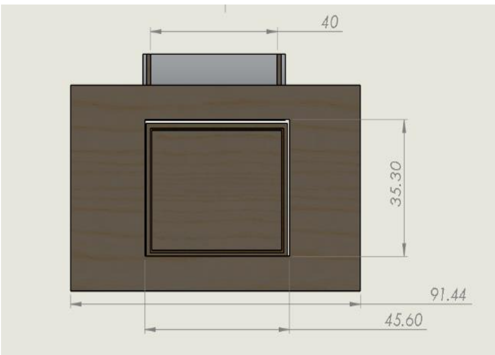

Fig. 5: Rear view of wall integrated solar cooker (all the dimensions are in centimeter)

Figure (4) and Figure (5) shows the detailed drawing of the wall integrated solar cooker. By following these drawing the solar cooker was manufactured.

6. EXPERIMENTAL SETUP

The solar cooker was fabricated with locally available low-cost material by following the finalized CAD model. It comprised of two parts: the cooking box and the wall with integrated reflector. The cooking box is comprised of two boxes one placed inside another. The outer box was made of 12 mm thick plywood, and inner box was made of aluminum foil. A 6 mm gap was maintained in between the boxes, and the gap was filled with cork sheet for insulation. Top and the front face of the cooking box was covered by a layer of 5 mm thick plain glass for solar radiation to pass. An aluminum pot with water was placed inside the box by opening the top glass cover for data collection purposes. The box can be operated from the other side of the wall. The aluminum sheets were used as reflectors and were attached to the wall.

Fig 6: Box cooker with an aluminum pot.

Fig. 7: Complete setup of the solar cooker.

The reflectors were parabolic in shape to produce better-concentrating effect of solar radiation on the cooking box. Both the reflectors were fixed with the walls. Standard thermometer and solarimeter were used for measurement of the temperature and solar radiation data of the system. The data was taken with fifteen minutes interval for 135 minutes in the climate conditions of Raozan, Chittagong a tropical region of Bangladesh.

7. RESULTS AND DISCUSSIONS

To take the collector surface temperature and water temperature two thermometers were used. For collecting solar radiation data solarimeter was used. The data was taken in the mid of October 2017.

7.1 Data Analysis-Without Reflector

Ambient Temperature = 35ºC
Amount of water = 1 liter
From Eq. (1), $Q = m \times C_p \times \Delta T$
Where, m = 1 liter = 1 kg & Total time = 135 minutes
Initial water temperature, $T_1 = 28°C$
Final water temperature, $T_2 = 50°C$

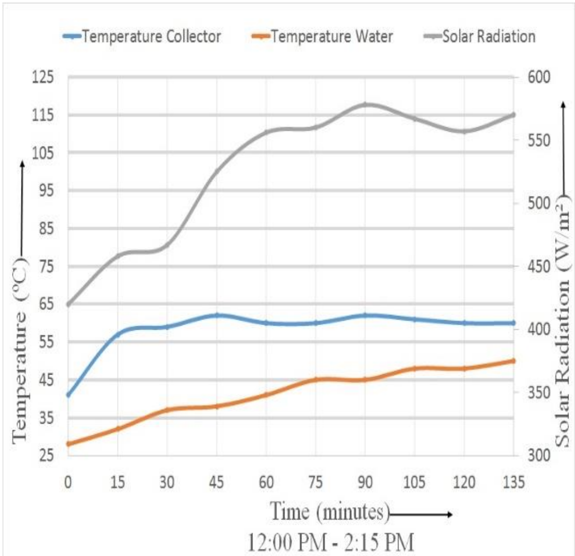

Fig. 8: Time vs. collector temperature, water temperature, and solar radiation curve.

At First, the experiment was done with the cooker box without the reflector. From the above graph, we can see

that the temperature increases with respect to time. When solar radiation is 570 w/m^2 then the collector temperature is 60ºC, and the water temperature is 50ºC at 02:15 PM.
By table A-9[5],
At, T= (50+28)/2 =39°C
C_p= 4.174 kJ/kg
Heat gained by water, Q= m × C_p × (T_2 –T_1) = 91.83 kJ
At time 135 minute using Eq. (2), we get P = 11.34 Watt
From Solarimeter, solar radiation at 55°C = 570 W/m^2
For the box, solar radiation input = 68.4 Watt
For two aluminum pot, output = 22.68 Watt
Now from Eq. (3) Solar Cooker Efficiency = 33.16 %

7.2 Data Analysis-With Reflector

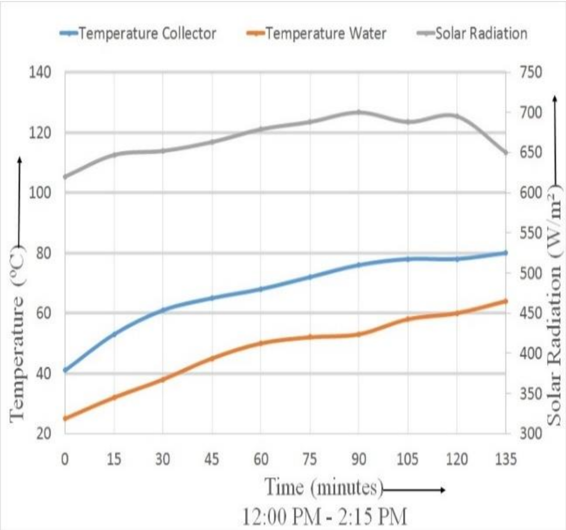

Fig. 9: Time vs. collector temperature, water temperature, and solar radiation curve.

At this time the experiment was done with the cooker box with the reflector. From the above figure, we can see that the temperature rises sharply with respect to time. When the solar radiation was 650 w/m^2 then the collector temperature was 80ºC, and the water temperature was 64ºC at 02:15 PM.
Ambient Temperature = 35ºC
Amount of Water = 1 liter
From Eq. (1), Q = m × C_p ×ΔT
m = 1 liter = 1 kg & Total time = 135 minutes
Initial water temperature, T_1 = 25°C
Final water temperature, T_2 = 64ºC
By table A-9[5],
At, T= (64+25)/2 =44.5°C
C_p= 4.174 kJ/kg
Heat gained by water, Q= m × C_p × (T_2 –T_1) = 162.8 kJ
At time 135 min, using Eq. (2), P = 20.1 Watt
From Solarimeter, solar radiation at 64°C = 650 W/m^2
For the box, solar radiation input = 78 Watt
For two aluminium pot, output = 40.2 Watt
Now, Using Eq. (3), Solar Cooker Efficiency = 51.54 %

The temperature of the collector is higher with the reflectors compared to without reflector arrangement. Because of reflectors, there are more heat gains in the collector. The temperature of the water is also higher with the reflectors. Because of reflectors, there are more heat gains in the water.

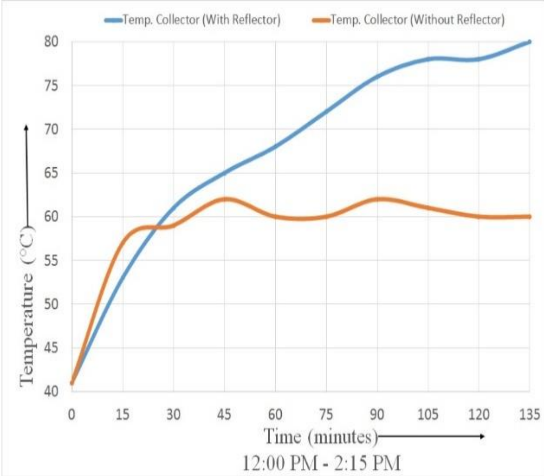

Fig. 10: Collector temperatures with and without the reflectors.

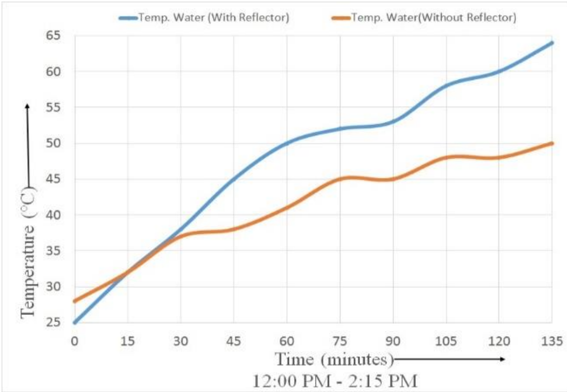

Fig 11: Water temperatures with and without the reflectors.

As we can see, the efficiency is also higher with the reflectors because of the increased heat gain. Reflectors concentrate more sunlight into the collector that's the reason for its higher efficiency.

8. CONCLUSIONS

Higher water temperature and overall efficiency were achieved by using a suitable arrangement of the parabolic reflector to a wall integrated simple box type solar cooker. A 28% increase in final water temperature was achieved using the parabolic reflectors. The increase in overall solar thermal efficiency was 55.42%. More improved results can be obtained by replacing the fixed parabolic reflector with a sun tracking moving one. A little modification to the material, shape, size, and position of the parabolic reflector can also be accomplished to get better results. Finally, the construction materials of the cooking box can be altered to attain better solar thermal efficiency.

9. ACKNOWLEDGEMENT

This work was partially supported by the Chittagong University of Engineering & Technology (CUET) as an undergraduate project.

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11. NOMENCLATURE

Symbol	Meaning	Unit
Q	Heat Energy	Joule
P	Power	Watt
C_p	Specific Heat	J/kg.K
m	Mass	Kg
T	Temperature	ºC
t	Time	Seconds