Assessment of Thermal Performance of Box Type Hybrid Solar Cookers with Battery Operated Coils for Night Cooking

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Abstract— A fabricated box type solar cooker applications and its designs given here. Two designs of cookers were tested. The first type was a fabricated solar cooker with painted black all side and second type has a battery operated fabricated solar cooker with two coils each of 50Ws arranged in parallel (50W, 100W). These designs were examined under two modes of operations: a solar cooker alone and solar cooker with coils attachment. The cooker alone had recorded average thermal efficiencies of 30.41% at the average solar intensity of the day and the cooker had recorded average thermal efficiencies of 29.7% and 31.9% respectively for 50W and 100W coils with the 12 volt battery supply.

Keywords: Box Type Solar Cooker, Battery, Coil, Thermal Efficiencies

I. INTRODUCTION

Now a day's fuel price hicks vary rapidly so need to search for alternative cheaper source of energy is necessity. Therefore, solar energy is becoming a feasible option for us. Solar cookers are rather important applications in thermal solar energy conversion. The use of solar cooker for cooking purposes is spreading widely in most developing countries and in particular in villages and remote areas. Current designs of solar cookers normally used are box cookers, concentrators, and flat plate collector cookers. The solar cooker must be high quality, light weight, affordable, user friendly, stackable and a family size. The basic purpose of a solar box cooker is to heat things up - cook food, purify water, and sterilize instruments. A solar box cooks because the interior of the box is heated by the energy of the sun. Sunlight enters the solar box through the glass. It turns to heat energy when absorbed by the dark absorber plate and cooking pots. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. Sufficient temperature for cooking and pasteurizing water is achieved. Capacity of heat increases with the properties of material (density and weight) is increased. Because of this additional heat storage capacity rocks, bricks, heavy pans, water, or heavy foods will take longer to heat up so interior of a box including heavy materials. In the box, incoming energy is gathered as heat in these materials.

Major amount of energy consumption in the rural areas accounts for cooking in developing countries. [5] Solar cookers seem to be a good substitute for cooking with conventional natural sources like wood and animal dung. Most commonly used solar cookers are solar panel type, box type and parabolic type. [11] Achievable temperature in box type solar cooker is lower than that of the parabolic reflector type solar cooker as it utilizes only thermal energy. [1] Reflector type cookers require the tracking of the sun after every 15 min which restricts its popularity. The cooker direction has to be changed for better efficiency according to movement of the sun. Use of this type of cooker becomes tedious job for a user to follow the track of the sun. [3] As this cooker has open ends, blowing of winds reduces the efficiency of cooking drastically. User's eyes and skin can also be damaged due to direct reflection from the reflectors of the cooker. [6]

Different types of solar cookers and ovens have been designed, developed and tested by many scientists. [12] Solar cookers with booster mirrors which are relatively faster than the conventional box type solar cookers have also been developed. [8] Community type solar cookers for indoor cooking which are having very attractive features have also been developed. [7] Number of scientists have put in efforts in development and testing of solar cookers of box type [4], concentrator type [9][10] and oven type. [2] Solar ovens can achieve very high temperature range of 200–500 °C and are used for frying purpose but they are very bulky and costly which make them less convenient for use. [13]

Experimentally the performance of a forced convection mixed-mode solar dryer to dry fresh apricot slices was analyzed at different working conditions. The moisture pick-up efficiency and the overall thermal efficiency of the dryer were about 10% and 11% respectively. [14] Designed and tested a high concentration ratio (11.12) solar box cooker prototype to cook food at high temperature (> 200 °C) with good optical efficiency and thermal insulation. [15] Reviewed the principle and classification, parameters influencing the performance of a solar cooker along with energy and exergy analysis. [16]

Cooking pot was placed over the copper balls and through the trapezoidal duct hot air with the help of halogen bulb of 200W was given inside the cooker box. The temperature inside the duct was obtained around 167 °C. [17] The developed system can cook food within 80 min with appropriate back-up (about 130 to 170 W) [18]. It takes 46 min to reaches 99 °C temperature of the food. The highest temperature of near upper and bottom surface of the inner tube reaches 290 °C and 170 °C. The efficiency of the system for utilizing energy is 18.9% [19]

II. DESCRIPTION OF THE SOLAR BOX COOKER

The solar cooker box was manufactured from M. S. Sheet of 4 mm thickness and of 360mm x 360mm x 360mm in dimension with single reflecting mirror and single coated glazed mirror. The solar cooker was black pained with locally available burger black board paint. The solar cooker was surrounded with wooden sheet of thickness 6 mm to reduce the heat loss during the heating from the coil to store the heat

within the cooker. Coli is attached at the bottom side of the cooker to get high temperature gradient during heating.

III. EXPERIMENTAL SYSTEM SET-UP

The experimental tests on the solar cookers were carried out during the successive days from the 21/03/2019 to 23/03/2019. Each experiment starts from 9:30 am in the morning to 17:00 pm in the evening. The electrical and electronic parts were tested and calibrated before being used on the various designs on both solar cookers.

Fig. 1: (A) Experimental setup of fabricated solar cooker with measuring instruments, (B) Experimental set up with coil arrangements with battery and measuring instruments

IV. PERFORMANCE TESTING

A. Testing of Fabricated Solar Cooker

On dated 21/03/2019 the fabricated solar cooker was tested at home location of mehsana from the morning 11:00 am to 4:00 pm. The single port with 750 gm of water and 250 gm of rice were placed inside the cooker. Absorber plate, inside box, water and ambient temperature was measure every 15 minutes (900 seconds) with the help of solar radiation.

B. Testing of Fabricated Solar Cooker with 50 Watt Coil

On dated 22/03/2019 the fabricated solar cooker was tested at home location of mehsana from the night 07:00 pm to 9:30 pm. The single port with 750 gm of water and 250 gm of rice were placed inside the cooker. Absorber plate, inside box, water and ambient temperature was measure every 15 minutes (900 seconds). 50 watt coil with battery operated supply was given from the bottom of the solar cooker to cook the rice in night.

C. Testing of Fabricated Solar Cooker with 100 Watt Coil

On dated 23/03/2019 the fabricated solar cooker was tested at home location of mehsana from the night 07:00 pm to 9:30 pm. The single port with 750 gm of water and 250 gm of rice were placed inside the cooker. Absorber plate, inside box, water and ambient temperature was measure every 15 minutes (900 seconds). Two parallel 50 watts coils (100W) with battery operated supply were given from the bottom of the solar cooker to cook the rice in night.

D. Efficiency of the Cooker

The overall thermal efficiency of the solar box cooker is expressed mathematically by [20, 21] and reported by [22] as follows:

$$\acute{\eta}u = \frac{Mw\ Cw\ \Delta T}{Iav\ Ac\ \Delta t_z} \qquad \ldots\ldots(1.1)$$

Where $\acute{\eta}_u$ represents overall thermal efficiency of the solar cooker; M_w, mass of water (kg); C_w, Specific heat of water (J/kg/^{o}C); ΔT,, temperature difference between the maximum temperature of the cooking fluid and the ambient air temperature; A_c, the aperture area (m^2) of the cooker; Δt, time required to achieve the maximum temperature of the cooking fluid; I_{av}, the average solar intensity (W/m^2) during time interval Δt.

E. Efficiency of the Hybrid Cooker

Efficiency of the hybrid cooker was calculated by taking the ratio of output power Po and input power Pi. The temperature measurements of water were recorded at an interval of 15 min (900 s). Initially temperature of water increases very rapidly then it remains nearly constant. Eqs. (2) and (3) give the formulae to calculate the input power Pi and output power Po respectively of a solar cooker. The efficiency of the solar cooker can be calculated by,

$$P_i = VI \qquad \ldots\ldots(1.2)$$

$$Po = Mw\ Cw\ \Delta T \qquad \ldots\ldots(1.3)$$

$$\acute{\eta}u = \frac{Po}{Pi} \qquad \ldots\ldots(1.4)$$

V. RESULTS AND DISCUSSION

A. Results of Fabricated Solar Cooker

The result of fabricated solar cooker is recorded. The average ambient temperature for the test day was 32.5°C. Maximum absorber plate temperature of 91°C was recorded after 3 hours 30 minutes of test started and at an average insolation value of 668 W/m^2. The result shows that heat loss from absorber plate of the cooker is minimal and the absorber plate temperature is retained for a long time. This is desirable for heating water since major mode of heat transfer to the cooking vessels is by conduction from absorber plate.

B. Results of Fabricated Solar Cooker with 50 Watt Coil

The result of fabricated solar cooker with 50 watt coil is recorded. The average ambient temperature for the test day was 29°C. Maximum absorber plate temperature of 70.1°C was recorded after 2 hours 15 minutes of test started and remains same thereafter.

C. Results of Fabricated Solar Cooker with 100 Watt Coils

The result of fabricated solar cooker with 100 watt coil is recorded. The average ambient temperature for the test day was 29.5°C. Maximum absorber plate temperature of 110°C was recorded after 2 hours 15 minutes of test started.

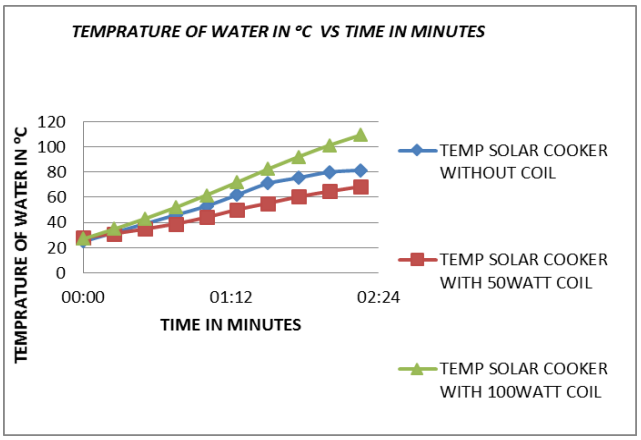

Fig. 2: Variation of water temperature and time taken to reach the water temperature

The graph of water temperature v/s time to reach the water temp is shown. After 02 hours and 15 minutes maximum temp of water reached the higher temp at 85.1°C, 68.5°C and 109.3°C of solar cooker alone kept in open space, supplied with 50W and 100W respectively.

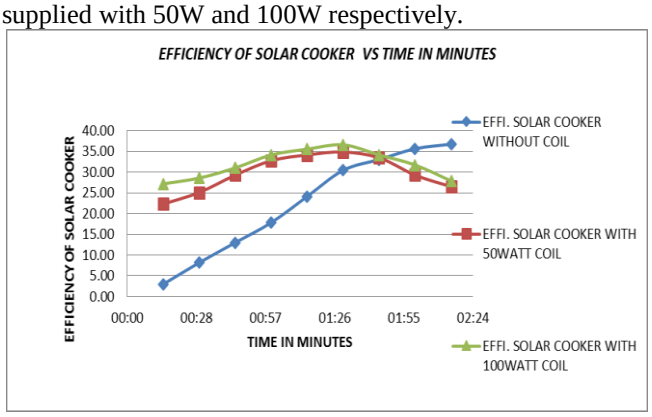

Fig. 3: Variation efficiency of solar cooker and time taken to efficiency of solar cooker

The graph of water temperature v/s efficiency of solar cooker is shown. After 03 hours and 30 minutes maximum efficiency of fabricated solar cooker at 40.83%, 01 hours and 30 minutes maximum efficiency of 50W coil with solar cooker at 34.85% and with 100W coil with solar cooker at 36.59%.

VI. CONCLUSION

The novel prototype Improved Box type Hybrid solar cooker specially designed for small family reveals 31.9% efficiency with 100W coil power supplied by 12 volt battery within least time compared with 50W and solar cooker alone placed at open space. The cooking time is reduced considerably by incorporating the heating effects with the use of coils. Improved Box type Hybrid solar cooker offers novel and user friendly features cooking at any time convenient to the user, fast cooking, four to five meals preparation in a day and night.

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