A REVIEW ON PERFORMANCE IMPROVEMENTS IN BOX TYPE SOLAR COOKERS

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Abstract— Cooking is the most important energy consuming operation in the domestic sector, as energy for cooking accounts for 50% of the total primary energy consumption. According to Indian government survey, over 77% of rural households in the country were estimated to depend on firewood and chips for cooking. Over 7% used dung cake and only 9% used LPG. In urban areas, LPG was the primary source of energy in nearly 62% of households. Hence, replacing the traditional cooking methods by solar energy can be considered as an alternative for meeting the energy crisis. A solar cooker or solar oven is a device which utilizes solar energy to cook food. Based on literatures, it is observed that box type solar cooker is the simplest device to collect the incoming solar radiation and convert it into heat energy. In this paper, a review is done in order to calculate and compare the different efficiency improvement methods of a box type solar cooker. Modeling of solar cooker is done using the TRNSYS software.

***Index Terms*—box type solar cooker, finned absorber plate, performance analysis, solar cooking technology**

I. INTRODUCTION

Energy is a thermodynamic quantity which is described as the capacity of a physical system to do work. Energy is vital for our relations with the environment, and thus the research to resolve problems related to energy is quite significant since life is directly affected by energy and its consumption. Fossil fuel based energy resources still predominate with the highest share in global energy consumption. However, clean energy generation becomes more and more crucial day by day due to the growing significance of environmental issues. Currently, renewable energy resources supply about 14% of total world energy demand and their future potential is remarkable. Among the clean energy technologies, solar energy is recognized as one of the most promising choice since it is free and provides clean and environmentally friendly energy. The Earth receives 3.85 million EJ of solar energy each year. Solar energy offers a wide variety of applications in order to harness this available energy resource [1]. Among the thermal applications of solar energy, solar cooking is considered as one of the simplest, the most viable and attractive options in terms of the utilization of solar energy.

Wood is still the primary energy source in much of the developing world since it is seen the cheapest way to obtain the energy required. However, this situation causes some serious ecological problems such as deforestation in India, energy demand for cooking accounts for 50% of total primary energy consumption. According to Indian government survey, over 77% of rural households in the country were estimated to depend on firewood and chips for cooking. Over 7% used dung cake and only 9% used LPG. In urban areas, LPG was the primary source of energy in nearly 62% of households

[2]. Besides the environmental and economic burden of firewood use, there are some serious health problems originate from the utilization of firewood. It is also emphasized by the World Health Organization (WHO) that 1.6 million deaths per year are caused by indoor air pollution. Therefore, there is a rising attention concerning the renewable energy options to meet the cooking requirements of people in developing countries [1].

Solar cooking presents an alternative energy source for cooking, which is simple, safe and convenient without consuming fuels, and polluting the environment. It is appropriate for hundreds of millions of people around the world with scarce fuel and financial resource to pay for cooking fuel. Solar cookers can also be used for boiling of drinking water, providing access to safe drinking water to millions of people thus preventing water-borne illnesses. Utilization of solar cookers provides many advantageous like no recurring costs, high nutritional value of food, potential to reduce drudgery and high durability [1, 4]. Also, solar cookers have many advantages, on the health, time and income of the users and on the environment.

II. SOLAR COOKERS

A solar cooker is a device which uses the energy of direct sunlight to heat, cook or pasteurize food or drink. The main principles behind solar cooking are [2]:

1. Concentrating sunlight: A mirrored surface with high specular reflectivity is used to concentrate light from the sun onto a small cooking area. Depending on the geometry of the surface, sunlight can be concentrated by several orders of magnitude producing temperatures high enough to melt salt and smelt metal.

2. Converting light energy to heat energy: Solar cookers concentrate sunlight onto a receiver such as a cooking pan. The interaction between the light energy and the receiver material converts light to heat. This conversion is maximized by using materials that conduct and retain heat.

3. Trapping heat energy: It is important to reduce convection by isolating the air inside the cooker from the air outside the cooker. Simply using a glass lid on pot enhances light absorption from the top of the pan and provides a greenhouse effect that improves heat retention and minimizes convection loss.

A. Types of Solar Cookers

Basically, there are 3 types of solar cookers, namely, solar panel cookers, solar parabolic cookers, and solar box cookers [3]. Solar panel cookers may be considered the simplest type available due to their ease of construction and low-cost material. In solar panel cookers, sunlight is concentrated from above. Panel cookers have a flat panel which reflects and focuses sunlight for cooking and heating. This method of solar cooking is not very desirable since it provides a limited cooking power.

Solar parabolic cookers can reach extremely high temperatures in a very short time and unlike the panel cookers or box cookers; they do not need a special cooking vessel. However, a parabolic cooker includes risk of burning the food if left unattended for any length of time because of the concentrated power. A solar parabolic cooker simply consists of a parabolic reflector with a cooking pot which is located on the focus point of the cooker and a stand to support the cooking system.

A box type solar cookers are the most common and inexpensive type of solar cookers. These box cookers have a very simple construction and they are made of low cost materials, which essentially consist of a black painted metallic trapezoidal tray (cooking tray) and is usually covered with a double glass window. It is kept in a metal or fibre-glass outer casing and the space between the cooking tray and outer casing is filled with the insulation like glass wool. The incoming solar radiation falls onto the double glass lid and passes through it to strike the blackened cooking pots and the cooking tray. The glass covers, while transmitting radiation of short wavelength which form major part of solar spectrum, is almost opaque to low temperature radiation emitted within the box. Thus, the temperature of the box rises until a balance is reached between the heat received through glazing and heat lost by exposed surface (greenhouse effect). In addition, a plane reflecting mirror (booster mirror) of about equal size as that the aperture area is used for augmentation of solar radiation on the aperture. The cooking tray is insulated on the sides and bottom. The heat is absorbed by the blackened surface and gets transferred to the food inside the pots to facilitate cooking. Figure 1 shows the different types of solar cookers.

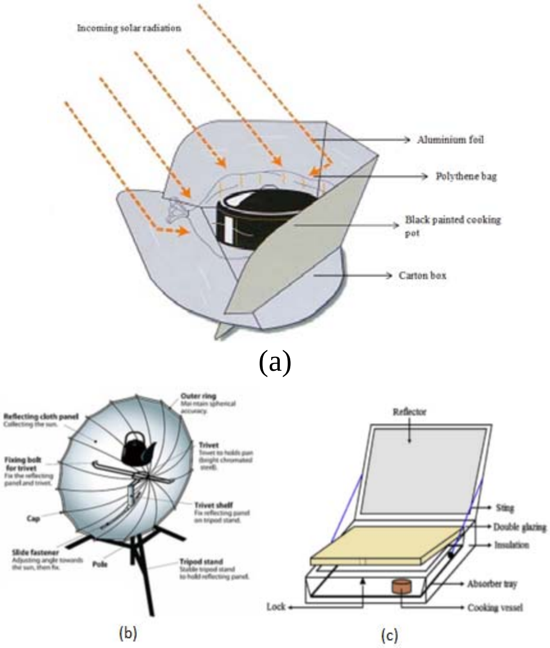

Fig. 1: Types of solar cookers (a) panel type, (b) parabolic type, and (c) box type

B. Performance of Solar Cookers

There are two thermal performance parameters called figures of merit (F_1 and F_2) associated with testing of box type solar cookers as per IS13429:2000[4]. The first figure of merit, F_1, is determined from a stagnation test under no load condition while the second figure of merit, F_2 is evaluated from tests under full load conditions taking water as the load.

The first figure of merit, F_1 of a box type solar cooker is defined as the ratio of optical efficiency to the overall heat loss coefficient of the box type solar cooker. Experimentally,

$$F_1 = \frac{T_{ps} - T_{as}}{G_s} \quad (1)$$

where,

T_{ps} - Cooker tray temperature (°C)

T_{as} - Ambient air temperature (°C)

G_s - Intensity of solar radiation (W/m^2) at stagnation test condition

The second figure of merit, F_2, of box type solar cooker is evaluated under full load condition and can be expressed as:

$$F_2 = \frac{F_1 (M_w C_w)}{A(t_2 - t_1)} \ln \frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{G_s}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{G_s}\right)} \quad (2)$$

where,

F_1 - First figure of merit

M_w - Mass of the water (kg)

C_w - Specific heat of water (4186 J/kg K)

T_a - Ambient temperature (°C)

G_s- Incident solar radiation (W/m^2)

T_{w1} - Initial water temperature (°C)

T_{w2}- Final water temperature (°C)

A - Area of solar cooker (m^2)

$(t_2 - t_1)$ - Time (s) taken to reach the temperature T_{w2} from T_{w1}

C. Energy analysis of solar cookers

Energy analysis of a solar cooker is based on the principle of conservation of energy [5]. In this regard, the input energy to the cooker and the energy output of solar cooker has to be determined. For G is the amount of illumination intensity falling on the solar cooker, A is the aperture area of the solar cooker and Δt is the period of time; the amount of energy received by the solar cooker (E_{in}) is calculated by the following expression:

$$E_{in} = G A \Delta t \quad (3)$$

On the other hand, energy output of the solar cooker shows itself as the increase in energy that the water has due to the temperature growth. From this point of view, energy output of the solar cooker (E_{out}) is given as follows:

$$E_{out} = M_w C_w (T_{wf} - T_{wi}) \quad (4)$$

where, M_w is the mass of water in the cooking vessel, C_w is the specific heat capacity of the water, T_{wf} is the final water temperature and T_{wi} is the initial water temperature. After determining the input and output energy expressions for the solar cooker, energy efficiency can be calculated by the following expression:

$$\eta = \frac{E_{out}}{E_{in}} = \frac{M_w C_w (T_{wf} - T_{wi})}{G A \Delta t} \quad (5)$$

III. PERFORMANCE IMPROVEMENTS OF BOX TYPE SOLAR COOKERS

To overcome the reduced efficiency of box type solar cooker, many efficiency improvement strategies have been adopted with an aim to achieve increased cooking power and reduced cooking time, thereby improving the overall efficiency of a box type solar cooker.

Rikoto and Garba [6] proposed the usage of cooking pot with fins. The experimental testing of the solar cooker was conducted, in which, during each test, both cooking pot were placed side by side on the absorber of the solar cooker and loaded with the same mass of water 75cl at the same temperature for water heating test. The temperatures of the water in each pot as well as ambient temperature and global solar irradiation were recorded at 15 minute intervals using a multi-channel data logger system. Global components solar radiation was measured using pyranometer. Both the two pot were filled with water was placed in the cooker, and was closed with double glazing cover until test end. The cooker was manually oriented according to azimuth at an interval of 15 mm in order to collect a maximum of solar radiation. The cooking vessel used in the experiment is shown in Fig.2. It was found that the temperature of the water in the finned cooking pot was always higher than the temperature of water in the unfinned cooking pot. The time taken for attaining boiling temperature (95°C) by the two cooking vessels was 112 min for the finned, and 126 min for the unfinned pot and finned cooking pot respectively. The initial water temperature in the finned cooking pot and in the unfinned cooking pot were the same 39.6°C. The water in the finned cooking pot attained boiling temperature nearly 15 min earlier than time water in the unfinned cooking pot. It is found that, in case of unfinned cooking pot the water temperature has reached only 95.2°C in 135 min, whereas it reached 97.8°C in the same time for the one, which used finned cooking pot.

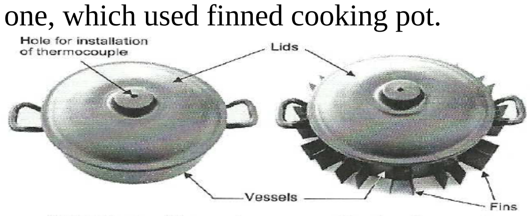

Fig. 2: Finned and unfinned cooking vessels

The reduction in cooking time is consistent with the increase of the heat transfer surface area by fins attached to the external surface of the cooking pot. The finned cooking pot presents some kind of limitations also. Due to the projected fin structures, no. of cooking pots that can be used is limited. Hence only limited quantity can be cooked using this method.

Kahsay *et al.*[7] proposed the performance improvement of box type solar cooker using internal reflectors. The result of the theoretical analysis predicts that the performance will be higher in the cooker with internal reflector than the same cooker without reflector. A box type cooker incorporating internal reflectors is shown in fig.3. The steady state analysis shows that for the cooker with reflection the temperature of the bottom absorber plate is higher than the cooker without reflector. The standard stagnation temperature (SST) and the cooking power were higher in the cooker with reflector as compared to the cooker without reflector. The aperture area of cooker under test was 0.142m^2, and the initial water temperatures under both cases were 24°C. The mass of water considered is 0.5 litres. The experimental result also indicates that the standard stagnation temperature of the cooker with reflector is higher than the cooker without reflector. The difference is on average about 22(°C). In comparison the stagnation temperature of the cookers found from experiment is much less than the theoretical prediction. This is due to an unaccounted heat loss factors in the theoretical prediction such as leakages around the cooker doors and around the edge of the outer wooden box. However, the stagnation test also indicates that the cooker with reflector performed better. Also, around 28% increase was found in the cooking power and thereby improving the efficiency around 27%. The problem faced was that the reflector material adds cost and weight to the solar cooker. Also, more frequent tracking is required to avoid shading due to reflectors.

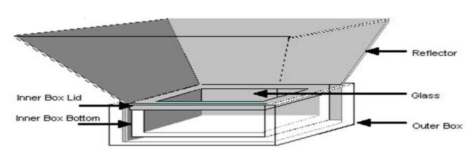

Fig. 3: Box type solar cooker incorporating internal reflectors

Nahar et al.[8] carried out some studies on utilization of transparent insulation material (TIM) in solar box cookers (fig.4). A 40 mm thick honeycomb made of polycarbonate capillaries was encapsulated between two glazing sheets of the cooker to minimise convective losses from the window so that even during an extremely cold but sunny day two meals can be prepared, which is not possible in a hot box solar cooker without TIM. The use of one more reflectors resulted in an avoidance of tracking towards sun for 3 h so that cooking operations could be performed unattended, as compared to a hot box solar cooker where tracking ahead of the sun is required every hour. Under an indoor solar simulator, they tested a hot box solar cooker with glazing surface consisting 40 and 100 mm thick TIM. The stagnation temperature with the 40 mm TIM was found to be 158°C, compared with 117°C without the TIM. A double reflector hot box solar cooker with TIM was designed, constructed, tested and its performance was compared with a single reflector hot box solar cooker without TIM.40 mm thick honeycomb made of polycarbonate capillaries was placed between two glazing surfaces in order to minimize the heat loss due to convection. The efficiencies were determined to be 30.5% and 24.5% for the solar box cooker with and without TIM respectively. The disadvantage of TIM is that its melting point is about 120°C. If a cooker were to be left in a stagnation condition, the TIM would melt down under Indian conditions, where even during the winter, stagnation temperatures as high as 161°C have been observed. Therefore, when a solar cooker with TIM is not being used for cooking, both reflectors should be put over the cooker like a lid so that solar radiation will not enter the cooker.

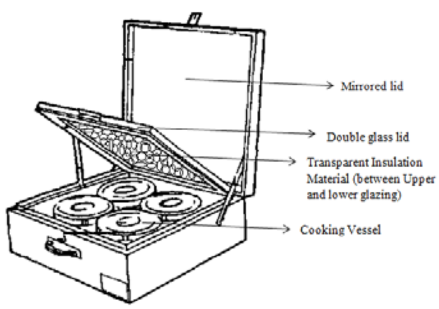

Fig. 4: Box type solar cooker incorporating TIM

Shrestha et al.[9]investigated the effect of using stone pebbles as thermal energy storage. A thermal performance of box type solar cooker with stone pebbles inside the cooker was tested with methodology described in ASAE international test standard. For the comparison, the cooker was put to test without stone pebbles, with un-coated stone pebbles and with black coated stone pebbles, as shown in fig.5. During the experiment, absorber plate temperature of cooker, ambient air temperature, water temperature, stone pebble temperature and solar radiation were recorded. The stone pebbles for the experiment were collected from a local river. The mass of stone pebbles used for the testing were 7.5kg. The temperature obtained is higher for the test without stone pebbles. But the temperature increase is sharp and drops near to ambient temperature soon after the sun set. Also the value of temperature peaks when intensity of solar radiation is highest for the day. In case of test with stone pebbles, the more at nature of temperature profile is obtained indicating storage of thermal energy in stone pebbles. The first figure of merit (F1) was calculated for all of the no-load tests and second figure of merit (F2) was carried out for all of the load tests. The first figure of merit is higher for cooker with stone pebbles. Further, this figure is higher for test carried out with black coated stone pebbles than that for without black coating. The second figure of merit is inversely related with the time for raising temperature of water. Due to the absorption of solar energy by stone pebbles during initial period, the time required to raise the temperature of water increased considerably thereby the value obtained is much lower for test with stone pebbles than without stone pebbles.

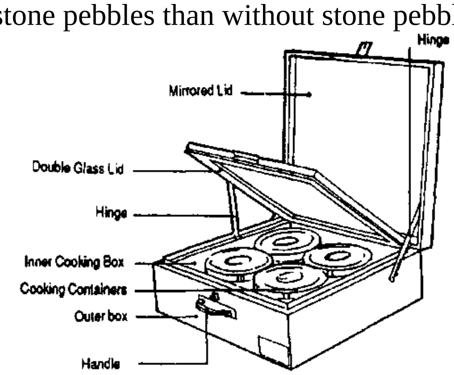

Fig. 5: Box type solar cooker incorporating stone pebbles

The first figure of merit is higher when cooker is loaded with stone pebbles indicating decreased heat loss. Further this figure is found larger for the test with black coated stone pebbles. However, the second figure of merit is found to be smaller for the test with stone pebbles which depicts the slower rate of increase of temperature. This fact is, however, advantageous when keeping food for long time is concerned. The experimental results of both no-load test and load test shows that with stone pebbles inside the cooker, the time for cooking food can be delayed by considerable amount of time about two hour after the noon, thus making the cooker suitable for evening meal at about 7:00 to 7:30 pm. The limitation faced by this method was that the stone pebbles adds the weight of the solar cooker, and hence the manual tracking becomes difficult.

IV. SIMULATION AND RESULTS

For modeling a solar cooker, TRNSYS software is commonly used [10]. Since solar cooker is as such not available in TRNSYS as a component, simulation is to be done on certain assumptions. Solar cooker is similar in principle to a flat plate collector, except that the flat plate collector has additional components like pump, storage tank, auxiliary heater, etc. A solar cooker can be considered as a flat plate collector itself without any pump, storage tank, or auxiliary heater. Hence, the main assumption is that the solar cooker is a at plate collector with zero mass flow rate. It means that, the water is stationary and a constant amount of water is always present in the collector. This is the same case as that of a solar cooker.

The TRNSYS model of a box type solar cooker is shown in fig.6.

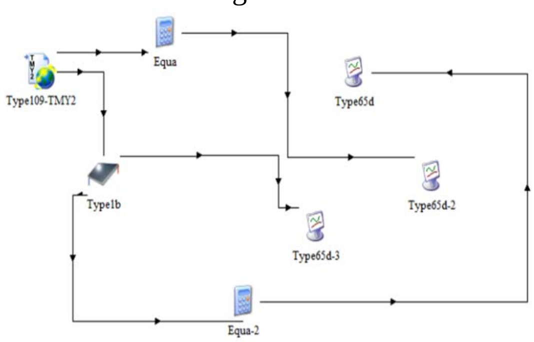

Fig. 6: TRNSYS Model of a Solar Cooker

The radiation (fig.7) and final water temperature (fig.8) curves were plotted with respect to time.

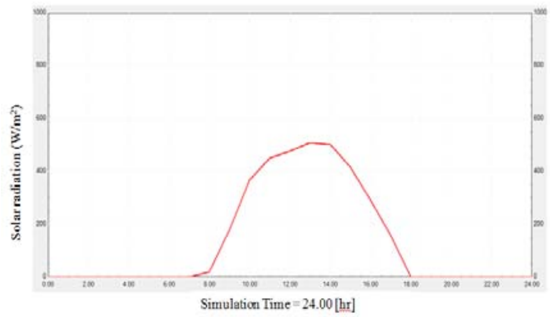

Fig. 7: Solar radiation v/s time curve

From the radiation v/s time, it is clear that the solar radiation increases in the morning and reaches the peak radiation around solar noon. Then it begins to decreases during the evening time.

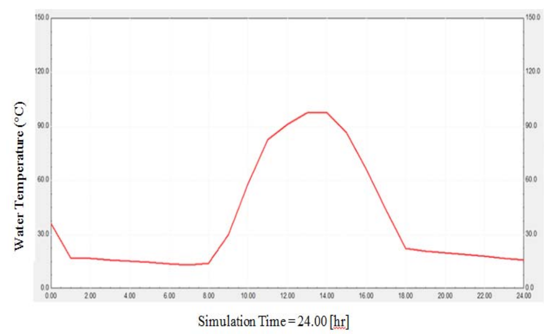

Fig. 8: Final water temperature v/s time curve

The final water temperature or the outlet temperature curve also follows the same pattern. The water begins to boil around solar noon. The maximum attainable final water temperature obtained from the simulation is about 92°C.

V. CONCLUSIONS

In this paper, an analysis on different performance improvement methods of box type solar cooker was done. Also, detailed description of various types of solar cookers, performance analysis and energy assessment of solar cookers were presented. Each discussed methods has certain kind of disadvantages. Future works can be done by changing properties of absorber plate and by using latent heat storage materials for keeping food for a long time.

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