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A Review on the Development of Box Type Solar Cooker

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Abstract

The continuous development of technology increases the demand of energy. Therefore the alternative devices are achieved which is based on renewable energy. Cooking is also having major portion of consumption of energy in developing countries. In this paper a thorough review of the literature on the box type solar cooker. This review paper contained the various researches attempt on box type solar cooker to increase the performance parameters. This review covers the historic overview of solar cooker. This paper has mentioned the thermal performance parameter such as efficiency, first and second figure of merit, power output etc. are used to compare the cooker's performance. And a detailed description of various geometry parameter affecting performance of solar cooker such as booster mirrors, glazing, absorber plate, cooking pots and insulating material. This review also covers the detailed literature of the solar cooker's performance parameter glazing of different types and also including the transparent insulating material.

Keywords: Box type solar cooker, figure of merit F1 and F2, Extra clear glass cover

Introduction

Solar energy has importance in the current global discussions on energy and environment. As the world becomes more environmental conscious, there is a rising deforestation and finding renewable energy options to fossil fuels. Currently, solar energy is meeting the vital energy requirements for a large percentage of the world's population particularly in developing countries. One of the essential energy needs for human living is for cooking. The major portion of energy consumption in developing countries is for cooking in the domestic sectors. In an Indian village, 95% of the energy is consumed for cooking only. Therefore solar energy is using as the cooking purpose. There has been a considerable recent interest in the design, development and testing of various types of solar cookers like box type, concentrator type and oven type around the globe. Out of these types of solar cookers, only the box type solar cookers have been used in India in mass level because the box type solar cooker is cheaper and also easy to handle and effectively working.

Box-type solar cookers are suitable mainly for the boiling type of cooking. The cooking temperature in this case is close to 100°C. A large fraction of the mass of most food products is due to water, and more water may be added in the boiling type of cooking. As a result, sensible heating up to the cooking temperature requires almost 4.2 kJ/kg °C.

Historic Overview of Solar Cooking

The history of solar cookers started early from 18th century. Experiments on solar cookers were carried out by a German Physicist named Tschirnhausen (1651–1708). In 1767, French–Swiss Physicist Horace de Saussure attempted to cook food via solar energy. Similarly in 1830 an English astronomer Sir John Herschel also attempted to cook food in an insulated box cooker. In 1876, W. Adams developed an octagonal oven equipped with 8 mirrors and after one year Mouchot designed solar cookers. He also wrote the first book on solar energy and its industrial application.

In 1930, India began to investigate solar energy as an option for avoiding deforestation. The first commercial box-type solar cooker was produced by an Indian pioneer named Sri M.K. Gosh in 1945. In 1950s, Indian researchers planed and constructed commercial solar ovens and solar reflectors, but they were failing due to high cost. In 1970_s as a result of fuel crisis, an intensive interest on renewable energy technologies was observed worldwide especially in China and India. In 1980s, especially the Governments of India and China expanded national promotion of box-type solar cookers. In 1987, Mullick et al. presented a method to analyze the thermal performance of solar cookers. In 2000, Funk proposed an international standard for testing solar cookers. It was observed that the resulting solar cooker power curve is a useful device for evaluating the capacity and heat storage ability of a solar cooker.

Literature Review

There are several procedures to improve the box type solar cooker, reported by various investigators in their literature in following manner.

Thermal Testing Procedure of Box Type Solar Cookers.

S. C. Mullick et. al. [1] (1987) experimentally present some guidelines are provided for thermal evaluation of box-type solar cookers. An experimental test has been proposed and appropriate parameters identified, which relate to the cooker and independent of the climatic variables as well as the products cooked. The test is under two conditions for obtaining two figures of merits. The first test is proposed a stagnation test without load. In this test the energy balance for the horizontally placed empty solar cooker at stagnation is

$$F_1 = \frac{\eta_o}{U_L} = \frac{(T_{ps} - T_{as})}{H_s}$$

Where $\eta_o$the optical efficiency and UL is is overall lose factor. The minimum value of F_1 is varies between0.12 to 0.16. And high value of F_1 indicates good optical efficiency η_o and low heat loss factor. The second figure of merit is tested under full load means 1kg of water equally distributed in four pots of box type solar cooker under equal interval of time of day. In this way a parameter is found which is useful in the comparison of cooker is called as second figure of merit F_2.

$$F_2 = F'\eta_o C_R$$
$$= \frac{F_1 (MC)_W}{A\tau} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right]$$

Where, F_1 is the first figure of merit, $(MC)_w$ is the heat capacity of water, A is projected area, T_{W1} and T_{W2} are the initial and final temperature of water. A high value of F_2 indicates good heat exchange efficiency factor F' and low heat capacity of the cooker interiors and vessels compared to the full load of water. There is also the discussion on the value of T_{w1} and T_{w2} due to the great uncertainty. Therefore T_{w2} should be in range of 90-95^{o}c and the curve is also plot between τ_{boil} and (100 – T_a)/H could be referred as characteristic curve of the cooker.

Testing of Novel and Improved Hot Box Type Solar Cooker

N. M. Nahar [2] (1989) Experimental testing, the performance of novel/improved box solar cooker and compared it with solar oven and hot box solar cooker. Though a solar oven is found best in performance, it is more expensive, requires 30 min tracking and is too bulky, therefore, the simple hot box type solar cooker is improved by tilted surface of absorbing, which improve 33% more solar radiation as compare to the horizontal surface, and two adjustable mirror boosters have been provided for increasing the incident solar radiation, solar cooker is fixed over an angle iron stand and tilt can be varied by kamani. So, that it is found that the performance of the tilt solar cooker is better than the hot box solar cooker comparable with solar oven with overall efficiency of this improved hot box cooker is 24.6%.

The new solar cooker is equivalent to the solar oven, while it is superior to the hot box solar cooker. On the other hand, the cost is 33% less as compared to the solar over and 10% more as compared to the hot box solar cooker and also there is no need of frequent tracking of 30min. like in solar oven.

Michael Grupp et. al. (1991) In this paper an advanced version of the box type solar cooker, in which the pot is fixed in conductive contact to the absorber plate, allowing for better heat transfer and pot is set into the glazing. This work shows two possible variations in absorber position: the absorber is either situated on the bottom of the case or in a slightly elevated position. The elevated position has the advantage of allowing a somewhat higher concentration ratio for a given acceptance angle.

The effect of the variation of the conduction coefficient between absorber and pot has been simulated over five orders of magnitude. Whereas the variations between metallic contact and glue contact are not very important (absorber-to-pot heat transfer is sufficient), output power drops sharply for air contact, while internal temperatures rise. It can be seen that the increase in power output for thicknesses above 3 mm is small. For thin absorbers, inclined internal reflectors show higher output power, since the solar radiation is reflected towards the absorber regions next to the pot. For thick absorbers, straight internal reflectors give better results.

This cooker is tested outdoor show that 5 L of water per sq m of opening surface can be brought to full boiling in less than one hour. Results of outdoor tests show that the most decisive parameters are the metallic contact or glue give satisfactory results, whereas air contact as in the classical box cooker leads to high absorber temperatures and high losses.

Checking the Performance of Solar Cooker with Various Load and Number of Pots

S. C. Mullick et. al. (1996) says in this paper the validity of factor F_2 is verified by computing this factor from the experimental data by two different procedures under full load condition and comparing the results.

$$F_2 = F'\eta_o C_R = \frac{F_1 (MC)_W}{A\tau} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1-}T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2-}T_a}{H}\right)} \right]$$

After known the value of F_2, the time required for a small temperature rise ΔT_w may be evaluated. There is suggested that T_{w1} should be higher than the ambient temperature and T_{w2} which should be lower than the boiling point, may be either 90 or 95°C.

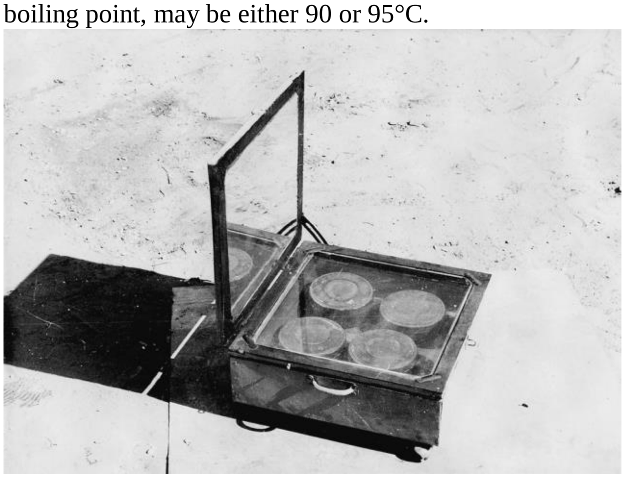

Fig.1. Hot box solar cooker.

This paper contained the effect of number of pots on F_2 at constant load. The value of F_2 is calculated for one, two, and four number of pots and found that F_2 increases with number of pots. This is due to an improvement in the heat-exchange efficiency factor (F') with number of pots. This paper is also evaluated experimentally the performance with loads of 1.0, 1.5, 2.0 and 2.5 kg of water is equally distributed in the four pots. It is found that F_2 increases with load and this is because of an improvement in heat capacity ratio C_R, as mass of water in the pots increases. Result shows that the value of F_2 is lower with lower load and lesser number of pots.

Development and Testing Of a Double Reflector Hot Box Solar Cooker with TIM

N. M. Nahar [5], (2001) Expresses design development and testing of double reflector hot box solar cooker with a Transparent Insulation Material (TIM). It is compared with a single reflector hot box solar cooker without TIM during the winter season at Jodhpur. A 40mm thick honeycomb made of polycarbonate capillaries was encapsulated between two glazing sheets of the cooker to avoid or minimize convective losses from the cover glasses. The energy saving is estimated to be 1485.0 MJ of fuel equivalent per year.

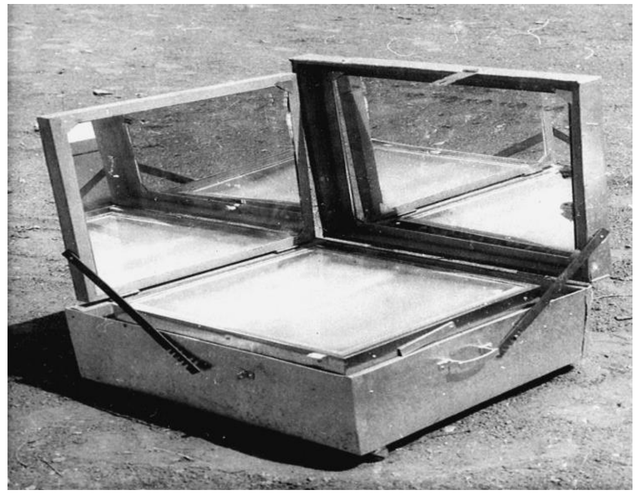

Fig.2. Double reflector with TIM solar cooker

In this work two reflectors are used to improve the performance of the hot box solar cooker during the cold weather and the tracking is avoided for 180 min. (3 hours). So, cooker is kept in such a way that one reflector is facing south and other is facing east in forenoon and in afternoon one is facing south and other is facing west. The efficiencies of solar cookers with and without a TIM had been found 30.5% and 24.5% respectively, during the winter season at Jodhpur. This solar cooker is capable of cooking for about 5 persons, and it will save 50% of cooking fuel per meal. Therefore, it will save 2.25 MJ of energy per meal and 1485.0 MJ of fuel equivalent per year. The payback period varies between 1.45 and 3.86 y depending upon the fuel so this is also economical.

The Role of Efficient Orientation Of Box Type Solar Cooker In The Performance

Abdulla H. Algifri et. al. [6] (2002) experimentally present for obtaining the impact of efficient orientation of reflector of box type solar cooker at Aden city (Yemen) located at latitude angle 12.88 north and 458 longitude angle in this paper. To measure the improvement in the heat gain a performance factor F is introduced. It is defined as the ratio of the energy reflected by the reflector and falling on the glass cover to the energy falling on the cover due to direct radiation.

$$F_p = \rho * I_d * A_T * F_O / I_d * A_T * \sin\alpha$$

In order to find out the effectiveness of the reflector on the performance of the cooker orientation factor F_0 which, defined as the ratio of the energy intercepted by the reflector to the maximum theoretical possible energy which could be intercepted by the reflector.

$$F_0 = I_d * A_T * f * \cos\beta / I_d * A_T$$
$$F_0 = f * \cos\beta$$

In this experiment the reflector tilt angle R, starts from 60^0 to 180^0 and elevation angle of the sun α is from 0.0^0 to 90^0 and solar surface azimuth angle γ (0.0^0 to 180^0).

The result reveals that at lower elevation angle and at smaller reflector angle the heat gain through the reflector is higher (i.e. higher value of F_p). It also can be concluded that when elevation angle reaches its maximum value $\alpha = 90^0$the performance factor and the orientation factor are independent of solar surface azimuth angle and are only affected by the reflector tilt angle. It is found that by result the reflector tilt angle and the elevation angle are related by the relationship $\boldsymbol{3R - 2\alpha = 180^0}$ at the solar surface azimuth angle is zero. And solar cooker gives best performance, which satisfy this condition. It can be concluded that by using the detailed results the optimum position for any place, for any day of the year and for any specific time of the day can be found.

Design Optimization and Estimation of Performance Evaluation of Solar Cooker

O. V. Ekechu Kwu et. al. [7] (2002) utters in this paper the design philosophy, construction and measured performances of a plane-reflector augmented box-type solar cooker. In this paper present the performance of improved and traditional solar cookers are checked by performance parameter first and second figure of merit and steam relief line is added which help to let off steam from the cooking chamber and a specular plane reflector, which increases the magnitude of solar radiation incident on the cooker surface. The cooker consists of an aluminum square shaped tray, painted matt black as the absorbing surface and cooking chamber. The plane reflector is used with cooker. Provision is made for four cooking vessels each capable of holding up to 1 kg of water. The overall instantaneous insolation, I_T incident on a unit horizontal surface area of the solar cooker with a single reflector is given as,

$$I_T = I_b + I_d + I_r$$

The solar cooker performance has been rated using the first and second figure of merit and sensible heat tests were also carried out to determine the time required to boil given quantities of water and the cooking times of various food items. Measurements were taken at intervals of 30 min and 10 min for the no-load and sensible heat tests respectively. The time for sensible heating from ambient temperature T_a to 100°C can be evaluated from,

$$t_{boil} = \frac{F_1(MC)_W}{AF_2} ln\left[1 - \frac{1}{F_1}\left(\frac{100 - T_{av}}{I_{av}}\right)\right]$$

The results justify the modification of solar cooker and performance was improved greatly with the plane reflector in place. Thermal performance tests show stagnation absorber plate temperatures of 138°C and 119°C for the cooker with and without the plane reflector in place respectively.

Subodh Kumar [8] (2005), presents a simple test procedure to determine the design parameters which help in predicting the thermal performance of box type solar cooker. The double-glazed solar cooker of aperture area 0.245 m2 with a fiber body is used for experiment in may month and the performance is determine by using two figures of merit F_1 and F_2. The present work is focused on a thermal test procedure to determine the design parameters, F'η_o and heat capacity, (MC)' of the cooker are calculated using the linear regression analysis of experimental F_2 data for different load of water such as 1.0, 1.5, 2.0, 2.5 and 3.0 kg. The heat capacity of box-type solar cooker can be find out by given equation,

$$F_2 = F'\eta_o C_R = F'\eta_o \left[\frac{(MC)_w}{(MC)' - (MC)_w}\right]$$

Fig.3. Experimental arrangement for determination of F_1 and F_2

The heating characteristic curves (or time required for the pot water temperature to reach certain temperature) of the cooker for a given load of water can be predicted with the known values of design parameters (F'η_o, F'U_L, and (MC)') and climatic parameters ($\bar{H}, T_a$).

$$d\tau = \frac{(MC)'_W dT_W}{[F' \eta_o \bar{H} - F'^{U_L(T_W - T_a)}]A}$$

The close agreements between the predicted and experimental heating characteristic curves as well as F2 reveal that the proposed methodology is capable of predicting the thermal behavior of the solar cooker. The mathematical formulation is quite general and can easily be used with the reasonable accuracy and confidence, thus avoiding the time-consuming large-scale experimentation. It may also be used as an important tool by the standardizing agency for certification of various designs and sizes of the box-type cooker.

U. S. Mirdha et. al. [9] (2007) expresses the various possible designs of tilted surface cookers with various positions of booster mirrors in the north–south direction as well as in the east–west direction are analyzed, so that a final design of the solar cooker has been achieved, which has been practically implemented. The glazed surface of the improved cooker has been kept at an angle $\boldsymbol{\beta = \phi_{can}}$ with a rear window opening and fixed on a south facing provides higher cooking temperature for a fairly large duration of the day for countries of northern hemisphere. A north facing mirror is also fixed at an angle $\boldsymbol{\alpha = \frac{\pi}{2} - \theta_{max}}$ so that, even in extreme winter, the shadow of this mirror does not fall on the collecting surface and get optimum collection throughout the day and east-west tracking is also required. By using combination of side booster mirrors three different reflections will be received by the collecting surface. The net enhancement in collection by these side mirrors is given by$\mathbf{F_{T_RSide} = F_{RSide\ 1} + F_{RSide\ 2} + F_{RSide\ 3}}$

Fig.4 Proposed improved solar cooker and conventional solar cooker of the same base dimensions installed at Jodhpur, India

For comparison, a conventional box type solar cooker of exactly the same material and dimensions was also fabricated. Comparison of experimental results, show clearly that the proposed new cooker can provide higher temperature throughout the day and round the year. For higher thermal load, the performance of new design is substantially improved. It can be used successfully for preparation of two meals in a day. Thus, a more efficient and user friendly solar cooker has been developed successfully.

A Non-Tracking Type Multipurpose Domestic Solar Cooker/Hot Water System

Naveen Kumar et. al. [10] (2009) present truncated pyramid geometry based multipurpose solar device which could be used for domestic cooking as well as water heating. Cooking tests approved by two figures of merits F_1 and F_2, were calculated and their values were 0.117^0Cm2/W and 0.467, respectively, which meet the standards for SBC, set by BIS, thereby qualifying the device for efficient solar cooking. The performance of the design was also evaluated as a hot water system and the maximum efficiency was found to be 54%. The day-time and average night-time heat-loss coefficients were found to be 5.7 W/^{0}Cm2 and, 3.74 W/^{0}Cm2, respectively, which are comparable to those of flat-plate collector based solar hot water systems. However, the proposed solar cooker with price about Rs. 4500/- and the cooking time reduced to 1.25 h could be appealing to the consumers. In addition, due to the larger depth of the proposed design, it is possible to heat 20–25 l of water to/above 60 ^{0}C, which is sufficient for one person to bathe. A simple economic analysis illustrate that this kind of multi-purpose design could be financially viable and physically useful.

Using a Finned Absorber Plate in Box Type Solar Cooker

A. Harmim et. al. [11] (2010) present a comparison between a finned absorber plates box type cooker and a simple box-type cooker. The finned absorber enhances the rate of heat transfer to the air inside the cooker. Fins are of rectangular constant cross-section (50 cm by 0.08 cm) and have a length of 5 cm; they are spaced at 4 cm. For comparative purpose a series of experiments have been performed under Adrar prevailing weather conditions in July 2008. The comparison of the performances of the two cookers indicates that the cooker equipped with the finned absorber plate provides higher stagnation temperature and faster boiling of water that the cooker equipped with a conventional absorber plate.

The following two tests have been performed Stagnation and water heating test. During the tests, it was observed that the stagnation temperature of the internal hot air of the cooker equipped with finned absorber plate "B" was always higher than ordinary absorber plate "A". The attached fins on the absorber plate increase its temperature by radiation absorption due to different multiple reflections. The maximum air temperature attained in the cooker "B" was 135.5^0 C and that in the cooker "A" was 125.6^0 C. The stagnation temperature for cooker "B" was 7% more superior to cooker "A".

During the various tests, cooking vessels were filled by the same quantity of water (1.5 L) at the same temperature. It was observed that the water heated by the cooker "B" reaches more quickly the boiling point (99.5^0 C) compared to that heated by the cooker "A". The reduction of heating period was 18 min, i.e. about 12% less time than cooker "A" to reach boiling point. The temperatures of the cooker "B" equipped with finned absorber plate were higher than those of ordinary cooker "A". Air temperature in the cooker "B" was also higher than cooker "A" due to the improvement of heat transfer between absorber plate & internal air by the fins attached on the absorber plate.

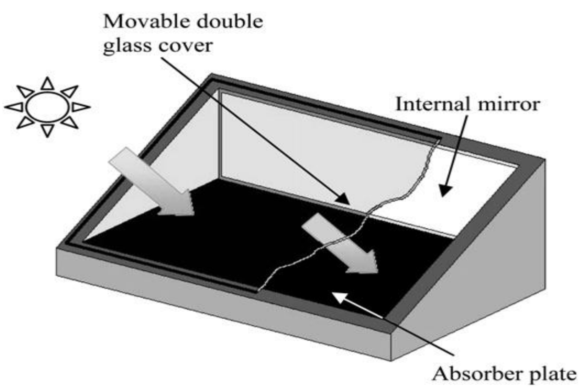

Fig.5 Schematic sketch of the box-type solar cooker used in the present study

Pranab J. Lahkar et. al. [12] (2012) says that Cooker opto–thermal ratio (COR) is being proposed as a new and common TPP for different cookers. A single step and less time consuming test procedure is being proposed which enables estimation of COR and consequently performance comparison between different cooker types. COR is defined as the ratio of the optical efficiency–concentration ratio (η_oC) product and the heat loss factor (U_L). A high η_oC product and a low U_L are required to optimize performance. COR appears to be similar to F1 proposed by Mullick et al. [1]. But three things must be noted here – Firstly, it has been derived analytically from the HWB equation for concentrating collectors. Secondly, it is pertinent to have a TPP which indicates the holistic performance of the cooker. Thirdly, the proposed test procedure is based on the measurement of load (standard fluid) temperature only which makes it simple and conforms to the main objective of this work.

In the present work experimental data is fitted in the HWB equation which is subsequently used to determine the parameter set $F'\eta_o$and F'U_L/C. It is possible to do it for both BC and CC. Finally the ratio of $F'\eta_o$ to F'U_L/C gives the values of COR as

$$COR = \frac{\eta_o C}{U_L}$$

This proposed experimental method is the same for all cooker types. However, in this paper the analysis was limited to only two types of cooker i.e. Box Cooker and Parabolic Concentrator Cooker. A high value of COR gives a high value of T_{fx}. From the results mean value of cooker opto-thermal ratio for concentrating type and box type was found to be 0.155 and 0.136, respectively. COR helps the user to select a cooker as per his/her requirement. COR should not change with variation in intensity of radiation, wind speed, and ambient temperature (external variables).

A Gravity Based Tracking System for Box Type Solar Cookers

Suhail Zaki Farooqui [13] (2013) presents a one-dimensional tracking mechanism for box type solar cookers along the azimuth, which does not require any external power source and tracking energy is drawn from the gravitational potential energy stored in a spring which is attached to water container. As water is discharged at a constant rate from the container, the spring slowly returns to its un-stretched position dragging the solar cooker along with it. The weight of the water in the container required to give the spring a full stretch is to be given

$$W = K(2\pi R/3)\ (Newton)$$

The range of movement of the sun during the most feasible six hours of solar cooking period, along the altitude has been worked out for a location in the northern hemisphere, for the entire year. The proposed mechanism is innovative, simple, low cost, easy to handle and almost maintenance free. Result indicates that the optimum length of the booster mirror is equal to twice the width of the cooker box.

Experimental results of 6 h of tracking operation along the azimuth direction, for a fully loaded (16.3 kg solar cooker with load) prototype system with R = 30 cm and k = 28.73 N/m. Results are averaged over five readings obtained at 9 min intervals, on consecutive days from November 5 to 9, 2012, during 9:00 to 15:00 h, local time. Experimental results and performance analysis of a prototype indicate that if the system is set for 3 h at a time, it tracks the sun more accurately.

Methodology

There are several work had done on box type solar cooker by using the single, double and more than two mirror as the reflector. There are several researches had done on the cover of cooker like using the transparent insulating material (TIM) etc. but some of these are not very effective to increase the performance of the cooker and some are not possible to manage in daily practice. Therefore economical work will be done in the paper by using the water white glass (extra clear glass) of 5mm thickness as compared to the normal glass as the cover of box type solar cooker, which provide the better transmittance than other glass. The whole cover is made up of double glazing of same thickness and 12mm gap is provided between them. In this experimental work we are also changing the absorber plate material by cooper, which provide high conductive rate between the pots and absorber plate.

In this new work the comparison will done between new proposed solar cooker and conventional solar box cooker by using the two figure of merits, which are reliable performance factor. Both the cookers are of same dimension and shape. After calculating these figures of merits the required time to reach the specific boiling temperature of water can be determined of box type solar cooker. These factors are as $F_1 = \frac{\eta_o}{U_L} = \frac{(T_{ps} - T_{as})}{H_s}$

$$F_2 = F'\eta_o C_R = \frac{F_1 (MC)_W}{A\tau} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right]$$

Conclusion

From the review it is concluded that every element of a solar cooker have great importance and direct effects the performance of cooker in any climate conditions. For quality cooking no one parameter has been eliminated among these. From the review it is concluded that objective parameters are those parameters which can provide all the necessary information of the cooker related to cooking, on the basis of which the best cooker suitable for a particular climate and geographic location may be selected. And the performance parameter F_1 and F_2 are capable to guide the consumer to choice which box type solar cooker is more useful for them.

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