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A Review Based Assessment of Solar Box-Type Cooker

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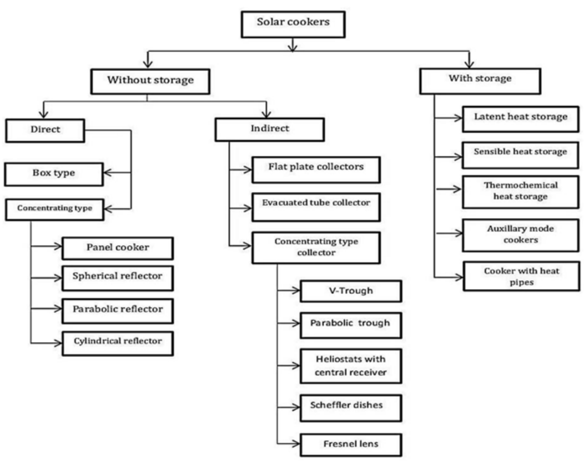
Abstract-*In this paper, a review is made on the geometry and working of a box type solar cooker, to assess the performance of SBC's, considering work of few researchers on the basis of figure of merits. As the efficiency of box type cooker is highest due to low heat losses and greenhouse effect by providing glass cover and economically cheaper, hence appropriate for rural people. SBC design referring geographical and climatic-conditions may make them more user friendly in today's context. It is observed that the design, construction and geometry of SBC play an important role in enhancing its performance. In the reviewed literatures, variety of tests for evaluating the thermal performance of SBC such as the utilizable efficiency, cooking power and figure of merits have done and tested.*
Key words : *Solar Box Cooker , cooking, Figure of Merits , green house effect , Utilizable efficiency, cooking power*

I. Introduction

Solar Cooking actually has some pretty early recorded beginnings since ancient times. There were no scarcity of fuels & hence not much attention was paid on minimizing the loss of energy caused while using firewood for cooking purpose. Almost constantly, open fire was used for transferring the heat energy to the food from the source of the fuel & this accounted the largest percentage of heat loss to the surroundings. In India a developing country, nearly 1.6 billion people use fuels like wood and coal to cook and heat their homes. Despite of government's initiatives' of alternate energy sources, energy need of rural peoples still satisfied by wood only due to numerous constraints resulting into health hazards to deforestation etcs. [1 - 6]. Solar Box-Type Cooker (SBC) is a good substitute as it is clean, eco-friendly, maintains the nutritional value of food, cost effective and fulfill their energy demands for cooking at low cost [1, 7, 8].

French-Swiss Physicist, Horace de Saussure first time in 1767 designed and used SBC for cooking; later on attempts were made across the globe for cooking purposes under various climatic conditions [9 - 14]. The first commercial SBC was produced by an Indian pioneer named Sri M.K. Ghosh in 1945. Since 50's, a number of SBC designs have been developed by different researchers using climate dependent parameter. In 1970s, as a result of the increasing fuel prices an intensive interest on renewable energy technologies was observed worldwide especially in China and India. SBC is a direct type without storage device but for comprehensiveness an attempt to categories different type of solar cookers for further reference is made as follows [fig. 1] :

Fig. 1 classification of solar cookers



II. Review On Geometry And Thermal Performance :

SBC is a system with transparent glass or plastic top, and it may have additional reflectors to concentrate sunlight into the box, the top can usually be removed to allow pots containing food to be placed inside. Geometry and thermal performance are two main aspects on which this review is drafted.

A Review on SBC Geometry :

Elements used in the solar cooker plays an important role in enhancing its performance. Booster mirrors, glazing, cooking pot and lid, insulation etc. proved effective in enhancing the performance of SBC.

a) Booster mirrors

A booster mirror reflects the extra solar radiation on the aperture area of the cooker and permit higher working temperature thus enhances the output. Voluminous work of Narasimha Rao et al. are in a sequence including analysis due to effects of single adjustable booster mirror provision to find total energy falling on the aperture for various geographical factors, effects of mirror adjustment under different orientations to evaluate energy boost, investigations for effect of elongated design rectangular apertures with one single booster mirror, on energy collection pattern plus energy accretion pattern with a plane mirror along with the effect of latitude on the energy contribution by the mirror onto the cooker aperture, discussed an algorithm to assess the contribution of solar energy on a horizontal receiver by a plane booster mirrors, prepared a FORTRAN computer code to evaluate the contribution from the booster mirrors in different orientations or tracking modes [15 - 18]. Ibrahim et al. designed and evaluated the performance of a box type solar cooker with a plane booster mirror reflector and adjusted the position for maximum solar radiation and the tilt angle of the booster reflector for maximum concentration manifested that using a transparent tight plastic cover for the cooking pot than an ordinary aluminium cover [19]. Algifri et al. dafted a method for finding a reflector performance factor and an orientation factor which depend upon the elevation angle of the sun, the solar surface azimuth angle & the reflector tilt angle to find the relationship between the reflector tilt angle, elevation angle and SBC performance [20].

b) Cooking vessels and lids

The major design factors of the cooking vessel are shape, size and the material it is made from. All these affects how quickly it heats up and how well it retains the heat along with the vessel lid. Khalifa et al. conducted experiments with insulated receivers containing transparent tempered glass Pyrex pots and provided with a single glazed insolation window at the bottom and a Teflon coated black aluminum plate placed inside, the pot was utilized for absorbing the incoming radiation, and then conveying the collected energy to the food [21]. Gaur et al. developed a modified concave shaped lid instead of plain lid and reduced the cooking time by 10-13% with increase in temperature of SBC by 27% [22]. A.V. Narasimha Rao et al. carried out a test by keeping a vessel on the mild steel lugs and improved the convective heat transfer in the vessel and found a rise in temperature by 3-5℃ [23]. Authors experimentally investigated regarding positioning of vessel, found their proposition reduced cooking time with hike in temperature of more than 20℃ [24, 25]. Geometrical shapes and corresponding arrangements were experimentally tested, proposed and reported by different researchers [26 - 28].

c) Insulation

Insulation is used to gain high temperatures for cooking, inside the SBC, for low conduction of heat from the inner box structure to outer box structural materials, establish on the walls and the bottom [21]. Inference from the reporting of researchers indicate that locally available materials perform better Insulation, as they differently applied, tested, experimented to show enhancement in SBC’s performance [22 - 25].

d). Absorber tray

It is a black coated tray which absorbs sunlight and conduct heat into the pot. Many modifications proposed and reported by the authors on an absorber tray for performance enhancement of SBC’s. Different publications establishes that performance enhancement of SBC’s resulted through; tilt in absorbing surface, using colored trays, thickness of plate, exposure of bottom sides, shape of tray, exposing bottom, layering the casings, spacing between glass cover & absorber plate and use of other heat absorbing materials [26 – 31].

e). Geometrical shape of a cooking chamber

The work of several authors who have designed, modified and tested different shapes of the chamber to respective SBC’s successfully improved the performance to attain reduced cooking time resulting enhance performance [32, 33].

f). Creating greenhouse effect inside the cooking chamber

It is well known that cooking with SBC is time consuming even after receiving enough sunlight [34]. For creating greenhouse effect inside SBC authors used CO_2 gas as a participating medium resulting into increased density of medium accordingly convective mode of heat transfer increased due to the participating medium in its cooking chamber. Sodium bicarbonate with HCl or lemon juice used for improving SBC performance [35 - 37].

B Review on SBC Thermal Performance :

Solar energy is free and clean, and have many advantages, many people will attract towards the solar cooker, if its performance will be meliorated either by using a rugged performance parameter, which is needed by prominent designs or by using a computer or mathematical models. The availability of a thermal performance parameter for comparing the performance of solar cookers is still an issue which is open and unsolved. There has been an appreciable interest in the design, development and testing of SBCs [38]. The improvements in its design and evolution of performance techniques begin in the 20^{th} century and it is very important that contribution of Indian researchers have enriched the development story of SBC's to its academic peak. Mullick proposed figure of merits (FoM) [39], which are more or less independent of climatic conditions and accepted all over the world by researchers, efficiency use proposed by Nahar [37] and Funk's proposal was of cooking power [41] for performance evaluation of SBC, are few of the pioneer proposals in performance evaluation of SBC's. Khalifa et al. [42] discussed some of the performance parameters like utilizable efficiency (η_u), characteristic boiling time (t_c) and specific boiling time (t_s), to grade the SBC thermal performance. Overall utilizable efficiency was discussed by Khalifa et al. [42] for box type solar cooker is calculated by using the following expression:

$$\eta_u = \frac{Qf}{Qin} \qquad (1)$$

where, Qf is the useful heat stored in the food for a temperature rise. For relatively constant direct normal radiation GNR, collector area Ac, and cooking time , solar input Qin, can be expressed as:

$$Q_{in} = G_{NR} A_c t \qquad (2)$$

Vaishya et al. [43] suggested a new test method which is based on the measurement of stagnation temperature and insolation. He suggested the characterized cooker box by equation:

$$K = \frac{Iin}{(Is - ia)} = U/(\tau \alpha) \qquad (3)$$

Where, I_{in} = solar intensity on cooker box solar intensity on cooker box, α = solar absorptance, dimensionless, τ = glass cover transmittance, dimensionless, T_a = ambient temperature, °C, Ts = stagnation temperature in cooker box, °C, U = overall heat loss coefficient, W/m^2°C, K = ratio of overall heat loss coefficient and transmittance absorptance product, W/m^2°C.

Mullick et al. [39] provided some guidelines for thermal performance evaluation of SBC. He proposed experimental tests & identified appropriate parameters, which were related to the cookers and independent of the climatic variables as well as the products cooked. The tests were conducted under two conditions for obtaining two figure of merits: In first test, they kept their solar cooker in sunlight without vessels and obtained the first figure of merit by using the expression:

First Figure of Merit $F_1 = \frac{Tps - Tas}{H_S}$ (4)

Where T_{ps} is plate surface temperature and T_{as} is atmospheric temperature and H_s is heat incident on the absorber surface. The minimum value of F_1 varies between 0.12 to 0.16 m^2 ℃/W.

While, they obtained the second figure of merit by operating the solar cooker with a full load of vessels with 1 kg water by using the expression: Second figure of Merit

$$F_2 = \frac{F1\,(M\,C)_W}{A_t} \ln\left\{\frac{\left[1 - \frac{1\,(Tw\,1 - Ta\,)}{F1\;H}\right]}{\left[\,1 - \frac{1\,(Tw\,2 - Ta\,)}{F1\;H}\right]}\right\} \qquad (5)$$

The minimum value of F_2 is 0.254 m^2 ℃/W. To estimate the first figure of merit (F_1) and second figure of merit (F_2), they required to measure the intensity of solar radiation falling at the surface of the cooker, ambient temperature, wind speed, initial water temperature, final water temperature etc. They recommended that experiment should be done within 1:30 h of the solar noon with the intensity of solar radiation above or equal to 600 W/m^2. Initial temperature of water should be higher than the ambient temperature and the final temperature of water should be lower than the boiling point. Mullick et al. [39] found that, F_2 increases, with increase in number of pots, if load is kept constant and equally distributed. Kammen [44] adopted the parameter free index and use this index to compare the heating times, thermal stability, and thermal capacity while cooking foods of the two constructed oven types. They also manifested that their index is useful in rating the efficiency of the oven at a given moment or as a running index of oven performance. The index can be expressed as:

$$P\ I = \frac{\int_{to}^{to} [Tov - Tamb]dt}{\int_{to}^{ti} [Tamb]dt} \qquad (6)$$

Funk [45, 46] discussed two types of test variables. They are mainly uncontrolled (weather) variables and controlled (cooker) variables. Wind, ambient temperature, pot contents temperature, insolation and solar altitude and azimuth are the uncontrolled variables while loading, tracking, temperature sensing are the controlled variables. From Funk's definition, cooking power maybe expressed as:

$$P = \frac{Tw2 - Tw1}{dt}\ mw\ Cw \qquad (7)$$

Where, P is the cooking power, m_w is the mass of water, C_w is specific heat of water, and dt is time interval. The various parameters for evaluating the performance of SBC are given in the table 1 below

Table 1.: Various parameters for evaluating Box type cookers performance

Author name	Performance parameter	Expression	Recommended values
Vaishya et al. (1985)[43]	Performance characteristic, K	$K = \frac{Iin}{(Is - ia)} = U/(\tau\alpha)$	≤ 10.0 W/m^2 °C
Mullick et al. (1987)[39]	First figure of merit, F1 Second figure of merit, F2	$F_1 = \frac{Tps - Tas}{H_S}$ $F_2 = \frac{F1\ (M\ C)w}{A_t} \ln\left\{\frac{[1 - \frac{1\ (Tw1 - Ta)}{F1\ H}]}{[1 - \frac{1\ (Tw2 - Ta)}{F1\ H}]}\right\}$	0.12-0.16 m^2 °C/W 0.254-0.490 m^2 °C/W
Kammen (1990) [44]	Parameter index, P.I.	$P\ I = \frac{\int_{to}^{to} [Tov - Tamb]dt}{\int_{to}^{ti} [Tamb]dt}$	1.86
Funk (2000) [45,46]	Cooking power, P Standard cooking power, Ps	$P = \frac{Tw2 - Tw1}{dt}\ mw\ Cw$	Details not available 45 W at = 50°C
Nahar (2003) [37]	Efficiency of cooker, η	$\eta = \frac{(MCw - M1Cu)(Tw2 - Tw1)}{AC \int_o^t t\ dt}$	27.5%
El Sebaii & Ibrahim (2005) [47]	Utilizable efficiency,ηu	$\eta_u = \frac{Tw2 - Tw1}{A\ Iave\ dt}\ m\ Cw$	26.7% at

III. Discussion

From the literature, it is observed that the major design factors of the SBC are cooking vessel of various shape, size and the material it is made from. All these factors affect how quickly it heats up and how well it retains the heat along with the vessel lid. Most of the authors are proposed square, rectangular and hexagonal geometry for SBC [10, 11, 12]. Some of the authors suggested parabolic reflectors for SBC. It is observed from the literature survey that parabolic reflector and using mild steel lugs increases the performance of the collector and reduce the cooking time. But it also increases the costs of SBC and also required tracking for small duration of time.

Narasimha Rao et al and Ibrahim et al designed and evaluated the performance of a box type solar cooker with a adjustable plane booster mirror reflector for maximum solar radiation. Many other researchers also experimentally and theoretically evaluated the effect of adjustable booster mirror reflector and also evaluated the tilt angle of the booster reflector for maximum concentration, [15 - 18]. The performance of the SBC is depends upon the heat absorbed by the water in the cooking pot and heat losses from the SBC to the surrounding. The insulation is used to gain high temperatures for cooking, inside the SBC, for minimizing heat losses to the surrounding, establish on the walls and the bottom [36]. Cooking with SBC is time consuming even after receiving enough sunlight [35]. For creating greenhouse effect inside SBC authors suggested to use CO_2 gas as a participating medium resulting into increased density of medium accordingly convective mode of heat transfer increased due to the participating medium in its cooking chamber. Sodium bicarbonate with HCl or lemon juice used for the process in improving SBC performance [21-23].

Few experimental tests and procedures of different authors have discussed in earlier section, Khalifa et al. [42] suggested performance parameters like utilizable efficiency (η_u), characteristic boiling time (t_c) and specific boiling time (t_s), to grade the SBC thermal performance. The utilizable efficiency is evaluated experimentally by energy absorbed by water in the cooking pot to that of energy incident in the cooking pot. Nahar and other authors [31, 36, 37] also suggested improved test procedure for evaluating the efficiency of SBC. Vaishya et al. [43] proposed a test method which is based on the measurement of stagnation temperature and solar insolation. Kammen [44] adopted the parameter index to compare the heating times, thermal stability, and thermal capacity while cooking foods. The index manifested is useful for rating the efficiency of the SBC.

Mullick et al. [39] has proposed experimental tests & identified appropriate parameters, which were related to the cookers and independent of the climatic variables as well as the products cooked. The tests were conducted under two conditions for obtaining two figures of merits. Funk [45, 46] discussed two types of test variables mainly uncontrolled (weather) variables and controlled (cooker) variables and proposed method for evaluating the cooking power.

From the above discussion it is seen that the performance of SBC is depends on design of SBC, geometrical parameters and also solar insolation. The most of the researchers suggested variety of construction, design, tests and experimental procedure for evaluating the thermal performance of SBC. Some are advocated the procedure for evaluating the efficiency of SBC, some for cooking power and some suggested figure of merits. All these parameters such as cooking power, efficiency and figure of merit, are evaluated by pronouncing heat absorbed by either the cooking pot or water kept in the cooking pot and heat incident on the SBC. The test procedures suggested by Mullic et al [39] is still best suited for evaluating the thermal performance of not only SBC but is applicable to other types of solar cookers also.

The contribution of Indian researchers is most appreciable in the area of design and construction of the SBC and also in evaluating the thermal performance of the SBC. The booster mirror, insulation from all the sides and shape and size of the SBC increases the efficiency and cooking power. But also increases the costs of the cooker. The SBC suggested by Narasimha Rao et al [15 – 18] with adjustable mirror is still best suited for Indian environment and is still in use. The cost may be reduce by constructing the SBC using locally available material insulation.

IV. Conclusion

In this study, a review is made on the basis of geometry and working of a box type solar cooker, to assess the performance of SBC’s, considering work of few researchers. The geometrical parameters such as design and construction of SBC and its effect on the thermal performance parameters such as figure of merits, cooking power and efficiency studied from the literature. It is observed that

1. The design, construction and geometry of SBC play an important role in enhancing its performance. The rectangular or square SBC gives better performance than other shape.
2. Booster mirrors, glazing, cooking pot and lid, insulation etc. proved effective in enhancing the performance of SBC. But it also increases the costs of the cooker.
3. The literature suggested variety of tests for evaluating the thermal performance of SBC such as the utilizable efficiency, cooking power and figure of merits. All these parameters evaluated by pronouncing heat absorbed by either the water kept in the cooking pot and heat incident on the SBC.
4. The test procedure suggested by Mullick et al is still best suited for evaluating the thermal performance of not only SBC but is applicable to other types of solar cookers also. As other authors have suggested different parameters, but detailed measurements for Mullick’s suggestion helps in deriving rest of the other parameters.

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