TESTING OF SOLAR BOX COOKERS: A REVIEW

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Abstract:- For testing and rating of solar cookers, various recommendations are available in the literature including that from BIS. These standards have been reviewed to find out the variations in recommendations and similarities in these codes. The aim of this paper is to carry out a critical review of methods of testing of such cookers. The review includes various testing standards for solar box cookers. The emphasis in the present presentation is basically on the solar box cookers used for domestic applications. There is still need of development of a new testing code which must be acceptable to consumers from different regions around the world with different weather, ambient, atmospheric conditions and their variations.

Index Terms:- Solar box cooker, Testing, BIS, ASHRAE, ASAI.

I INTRODUCTION

1.1 *Solar Cooking*

Since firewood shortages are likely to become common in India, the cost of fuel for low-income families has significantly increased. The replacement of firewood and dung cake by commercial energy sources – coal, coke, kerosene, gas, or electricity – is not a practical consideration because at present prices, they are out of reach to low -income households.

Therefore, there is an urgent need to develop an appropriate technology for cooking based on renewable energy sources. Fortunately, India is blessed with ample amounts of solar radiation. Therefore, an appropriate solar cooker seems to be a good substitute for cooking in India.

Food cooked in the sun is specially tasty and healthy because of the constant influx of mild heat from all around. There are no hot spots to burn the food in one place while it goes uncooked in another. Cooking in the sun is cleaner than on fire.

Over the past forty years, a number of designs of solar cookers have been developed. Solar cooker designs generally fall into one of the two categories. One category is the box-type cooker which essentially consists of a rectangular enclosure insulated on the bottom and sides, and having one or two glass covers on the top. Solar radiation enters through the top and heats up the enclosure in which the food to be cooked is placed in shallow vessels. Temperatures around 100˚C can be obtained in these cookers on sunny days and pulses, rice, vegetables, etc., can be readily cooked.

A solar cooker which can serve the needs of a community has also been developed. It consists of a flat-plate collector with booster mirrors used for heating oil, a pebble bed filled storage vessel, hot plates, interconnecting tubes and a set of three valves. The unit works on the thermosyphon principle and can operate in three modes. In mode I, solar energy is used directly for cooking. The heated oil flows from the collector to the hot plates, gives up its heat for cooking and returns to the bottom of the collector. In mode II, solar energy is not needed immediately for cooking and is stored in the pebble bed storage. In mode III, solar energy is not available and the stored energy is used for cooking.

The advantage of such cooker is that it yields a higher temperature than the box-type cooker because of the use of a selective coating on the absorbing surface and booster mirrors. In addition, the cooking area can be at a small distance from the collector and need not be in the sun. Cooking is also possible in the evening because of storage.

The second category of solar cookers developed is those in which the radiation is concentrated by a paraboloid reflecting surface. The cooking vessel is placed at the focus of the paraboloid mirror and is thus directly heated. These cookers require some form of tracking. Temperatures well above 200˚C can be achieved in such cookers. Various types of reflecting surfaces have been used. These include glass mirrors, aluminium sheet and aluminium foil. The main disadvantage with these cookers is that although they can cook all types of food items, they require continuous attention. Another disadvantage is that except for glass, the reflectivity of all other surfaces decreases with the passage of time.

1.2 *Solar Cooker – Box Type (IS: 13429, 2000)*

Typical shape of a box type solar cooker is given in Fig.1.

Components

The Indian standard specifies the various components along with their requirements, which are produced below.

Cover Plate

The cover plate is double glazed. Spacing between inner and outer glazings is kept 10±2 mm. The solar transmittance of cover plate consisting inner and outer glazings together should be minimum 65 percent at near normal incidence. The glazings should be free from bubbles and rough surface. Provision on the side should be made to keep the cover plate at inclined position for loading and unloading of the cooking pots.

Cooking Tray

The tray is usually made of aluminium/copper having minimum thickness of 0.5 mm. Inner surface of the cooking tray is to have mat black finish.

Gaskets and Sealants

The material is generally neoprene/ethylene propylenediene monomer (EPDM)/silicon rubber of minimum 2 mm thickness to seal the closed lid and tray.

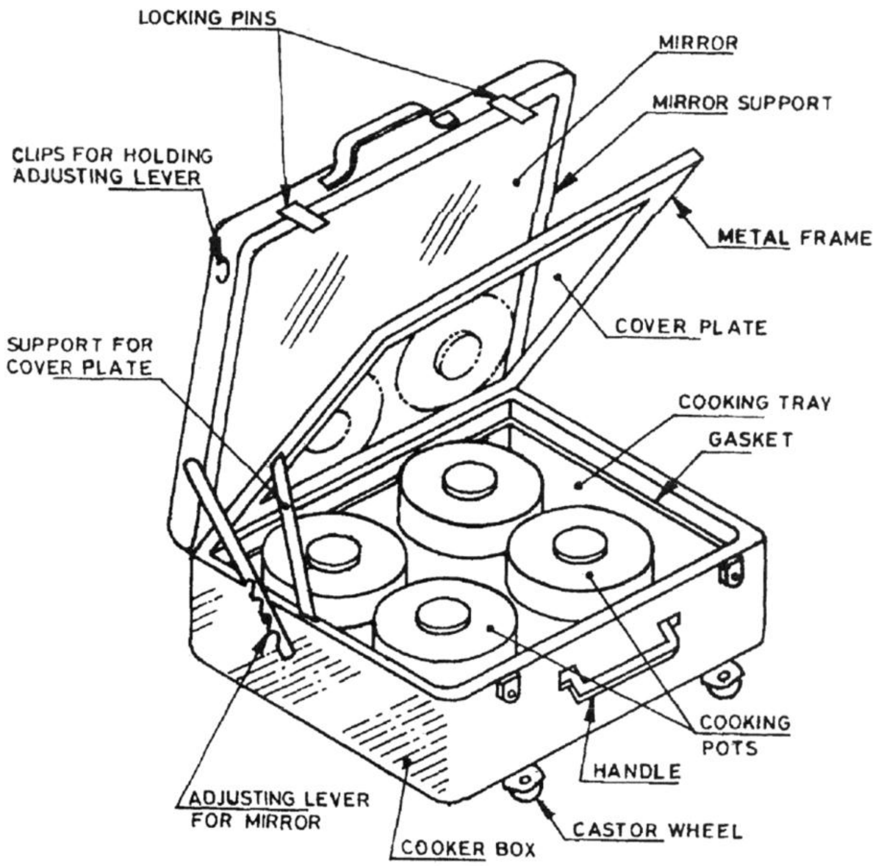

Fig. 1 Schematic of a typical box type solar cooker (IS: 13429, 2000).

Insulation

Insulation is provided at sides and bottom including edges. Thermal resistance (*R*) of insulation material should be minimum 0.96 m^{2}°C/W. This is derived after determining thermal conductivity (k) value at 100˚C mean temperature. The thermal resistance value (*R*) of insulation for nonmetallic body cookers is 0.58 m^{2}°C/W minimum provided the cooker meets the requirements of thermal performance test.

Mirror

Mirror should be free from bubbles and waviness having minimum 65 percent solar reflectance. The reflecting area of mirror must not be less than the glazing area. Provision on the sides is made to keep the mirror in any inclined position.

Cooking Pots with Lid

The solar cooker is generally supplied with the aluminium alloy/stainless steel pots with suitable lids. Solar cooker cooking pot is coated with mat black surface on outside.

II ASHRAE STANDARD 93-77: METHODS OF TESTING TO DETERMINE THE THERMAL PERFORMANCE OF THE SOLAR ENERGY DEVICES, GENERAL REQUIREMENTS

2.1 *Scope*

This standard applies to non-concentrating and concentrating solar collectors in which a fluid enters the collector through a single inlet and leaves the collector through a single outlet. The heat transfer fluid (transfer fluid) may be either a liquid or a gas but not a mixture of two phases.

This standard contains methods for conducting tests outdoors under natural solar irradiation and for conducting tests indoors under simulated solar irradiation. This standard provides test methods and calculation procedures for determining steady state and quasi-steady state thermal performance, time constants and angular response characteristics of solar collectors.

This standard is not applicable to those collectors in which the thermal storage unit is an integral part of the collector to such an extent that the collection process and the storage process cannot be separated for the purpose of making measurements of these two processes.

2.2 *Definitions*

Absorber: The absorber is that part of the solar collector which receives the incident radiation energy and transforms it into thermal energy. It may possess a surface through which energy is transmitted to the transfer fluid; however the transfer fluid itself can be the absorber.

Absorber Area: The absorber area is the total heat transfer area from which the absorbed solar irradiation heats the transfer fluid or of the absorber media if both transfer fluid and solid surfaces jointly perform the absorbing function.

Air Mass: The air mass is the ratio of the mass of atmosphere in the actual earth-sun path to the mass which would exist if the sun were directly overhead at sea level.

Angle of Incidence: The angle of incidence is the angle between the direct solar irradiation and the normal to the aperture plane.

Aperture Area: The aperture area is the maximum projected area of a solar collector through which the unconcentrated solar radiant energy is admitted.

Area, Gross Collector: Gross collector area is the maximum projected area of the complete collector module including integral mounting means.

Collector, Concentrating: A concentrating collector is a solar collector which uses reflectors, lenses or other optical elements to concentrate the radiant energy passing through the aperture onto an absorber of which the surface area is smaller than the aperture area.

Collector, Flat Plate: A flat plate collector is a non-concentrating solar collector in which the absorbing surface is essentially planar.
Concentration Ratio: The concentration ratio of a concentrating solar collector is the ratio of the aperture area to the absorber area.
Cover, Collector: The collector cover is the material covering the aperture to provide thermal and environmental protection.
Irradiation, Instantaneous: Instantaneous irradiation is the quantity of solar radiation incident on a unit surface area in unit time, measured in W/m^2.
Irradiation, Integrated Average: The average integrated irradiation is the solar radiation incident on a unit surface area during a specified time period divided by the duration of that time period.
Instantaneous Efficiency: The instantaneous efficiency of a solar collector is the amount of energy removed by the transfer fluid per unit of gross collector area during the specified time period divided by the total solar radiation incident on the collector per unit area during the same test period, under steady state or quasi-steady state.
Pyranometer: A pyranometer is a measuring instrument used to measure the total solar radiation incident upon a surface per unit time per unit area. This energy includes the direct radiation, the diffuse sky radiation and the solar radiation reflected from the foreground.
Pyrheliometer: A pyrheliometer is a meter used to measure the direct radiation on a surface normal to the sun's rays.
Solar Collector: A solar collector is a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing through it.
Standard Air: Standard air is air weighing 1.2 kg/m^3, and is equivalent in density of dry air at a temperature of 21.1˚C and a barometric pressure of 1.01×10^5 Pa.
Temperature, Ambient Air: Ambient air temperature is the temperature of the air surrounding solar collectors being tested.
Total Incident Radiation: Total incident radiation is the total solar radiant energy incident upon a unit surface area during a specified time period, expressed in J/m^2.
Transfer Fluid, Heat: The heat transfer fluid is the medium, such as air, water or other fluid, which passes through the solar collector and carries the absorbed thermal energy away from the collector.

2.3 *Mounting*

A solar collector can be mounted in a stationary position with a fixed azimuth[1] and tilt angle[2] (measured from the horizontal) or it may be adjustable as to tilt to follow the annual changes in solar declination[3]; it may also be designed to track the sun in altitude[4] and azimuth (altazimuth mounting) or in its apparent daily rotation about the earth (polar or equatorial mounting).

2.4 *Solar Radiation Measurement*

A pyranometer can be used to measure the total short wave radiation from both the sun and the sky and a pyrheliometer can be used to measure the direct normal insolation.

The instruments should have the following minimum characteristics, which are consistent with or superior to those of a first class pyranometer or pyrheliometer as classified by the World Meteorological Organization (WMO):

1. **Change of response due to variation in ambient temperature:-** The instruments should be equipped with a built-in temperature compensation circuit and have a temperature sensitivity of less than ± 1 % over the range -20 to + 40˚C.
2. **Variation in spectral response: -** Pyranometer and pyrheliometer errors caused by a departure from the required spectral response of the sensor should not exceed ± 2 % over the range of interest. The WMO specification for a first class pyranometer is ± 1 %.
3. **Nonlinearity of response:-** Unless the pyranometer is supplied with a calibration curve relating the output to the irradiation, its response should be within ± 1 % of being linear over the range of irradiation existing during the tests.
4. **Time response of pyranometer and pyrheliometer:-** The time constant of pyranometer, defined as the time required for the instrument to achieve a reading of 63.2% of its final reading after a step change in irradiation, should be less than 5 seconds. The time constant for the pyrheliometer should be less than 25 seconds.
5. **Variation of response with angle of incidence:-** Ideally the response of the pyranometer is proportional to the cosine of incident angle of the direct solar radiation and is constant at all azimuth angles. The pyranometer's deviation from a true cosine response should be less than ± 1 % for the incident angles encountered during the tests.
6. **Precautions for effects of humidity and moisture:-** The pyranometer should be provided with a means of preventing accumulation of moisture that may condense on surfaces within the instrument and affect its reading. An instrument with a desiccator that can be inspected is required. The ambient relative humidity and condition of desiccator should be observed prior to and following any daily measurement sequence.

Note:

1. The pyranometer should be calibrated for solar response within 12 months against other pyranometers whose calibration uncertainty relative to recognized measurement standards is known. Any change of more than ± 1 % over a year period warrants the use of more frequent calibration or replacement of the instrument.
2. When the pyrheliometer is available, it may be used to determine the direct component of the irradiation incident on a tilted pyranometer. The diffuse component may also be determined by shading tilted pyranometer from the direct irradiation. At non-horizontal altitudes, ground features which can affect readings, should be noted and their effect on calibration should be documented.

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[1] Azimuth angle is defined as the coplanar angle between a line pointing due south and a line pointing towards the sun, as seen from a stationary observer.
[2] Angle between the collector normal and a plane tangent to the earth upon which the collector is sitting.
[3] Angle made by the line joining the centres of the sun and the earth with its projection on the equatorial plane.
[4] Angle of the sun's position relative to a plane tangent to the earth upon which the observer is standing.

2.5 *Wind Velocity*

The wind velocity should be measured with an instrument and associated readout device that can determine the integrated average wind velocity for each test period to accuracy of ± 0.8 m/s.

III THERMAL TEST PROCEDURE FOR BOX TYPE SOLAR COOKERS (Mullick et al. , 1987)

Mullick et al. (1987) carried out thermal evaluation of box type solar cookers and proposed suitable thermal tests and also identified appropriate parameters, which pertain to the solar cooker and are relatively independent of the climatic variables as well as the products cooked.

Box type solar cookers are suitable mainly for the boiling type of cooking. A large fraction of the mass of most of the food products is due to water, hence, the cooking temperature is close to 100˚C.

3.1 *Solar Cooker Performance Parameters*

The complete thermal analysis of the cooker is complex due to the 3-dimensional transient heat transfers involved. However, the standardization procedure should be reasonably simple in order to make implementation easy. The earlier procedure followed consisted of determination of either (1) cooking times of different food products, or of (2) the time required for sensible heating of a known quantity of water up to the boiling point. The second method is a better approach because it does not involve uncertainties due to variations in the quality of ingredients used and the judgement of the observer as to when exactly the food is completely cooked. However, the time for sensible heating depends on the climatic variables – solar radiations and ambient temperature. To permit evaluation of solar cookers and comparisons between cookers, cooker parameters must be defined that are more or less independent of the climatic variables.

Mullick et al., for evaluating the box type solar cooker, identified cooking parameters as **first figure of merit F_1** and **second figure of merit F_2**, which are independent of climatic variables.

In the procedure proposed by Mullick et al., the first test is a stagnation test without load and the first figure of merit is obtained. The second test involves sensible heating of a full load of water in containers and from this; second figure of merit is obtained.

3.1.1 *Determination of first figure of merit*

In a solar cooker the operation is transient. A quasi- steady state is achieved when the stagnation temperature is attained. The energy balance for the horizontally placed empty solar cooker at stagnation is

$$\eta_0 H_s = U_L (T_{ps} - T_{as}) \tag{1}$$

where η_0 is the optical efficiency, U_L is the overall heat loss factor, T_{ps} is the plate stagnation temperature, H_s and T_{as} are respectively, the insolation on a horizontal surface and ambient temperature at the time stagnation temperature is reached.

A high optical efficiency and a low heat loss factor are desirable. The ratio of optical efficiency to heat loss factor can serve as one figure of merit F_1 for thermal performance and may be defined as

$$F_1 = \frac{T_{ps} - T_{as}}{H_s} \tag{2}$$

It can be obtained from the simple stagnation test without load. An approximation made in the above analysis is that the heat loss factor is assumed constant.

A lower permissible limit of the value of F_1 may be specified to ensure a minimum level of thermal performance. For example, if it is stipulated that F_1 should equal or exceed 0.12, in a region where solar radiation and ambient temperature are H_s = 800 W/m^2 and T_{as}=15˚C, respectively, we would have

or $$T_{ps} \geq 111^\circ\text{C} \tag{3}$$

That is, the plate temperature would equal or exceed 111˚C. By specifying a suitable minimum value of F_1 (probably between 0.12 and 0.16), depending on the climate, it may be ensured that the stagnation temperature is sufficiently high so that the boiling type of cooking is possible.

3.1.2 *Determination of second figure of merit*

The second test proposed by Mullick et al. consists of heating water sensibly in containers up to 100˚C. Since the maximum energy is required during sensible heating, this period should be as small as possible so that cooking time is minimized. The second figure of merit is, therefore, obtained from this sensible heating test.

Analysing over an infinitesimal time interval during the sensible heating of water, the time taken, *dτ,* for a water temperature rise dT_w is

$$d\tau = \frac{(mc)'_w \, dT_w}{\dot{Q}_u} = \frac{(mc)'_w \, dT_w}{AF'\left[\eta_0 H - U_L (T_w - T_a)\right]} \tag{4}$$

where $\dot{Q}_u$ is the rate of useful heat gain by water, A is aperture area, H the insolation on a horizontal surface, and F' is the heat exchange efficiency factor. $(mc)_w$ is the product of mass of water taken and its specific heat capacity. $(mc)'_w$ includes also the heat capacity of the utensils and a certain portion of the cooker interiors. Replacing the ratio η_0/U_L by the factor F_1, we obtain

$$d\tau = \frac{(mc)'_w \, dT_w}{AF'\eta_0 \left[H - \frac{1}{F_1}(T_w - T_a)\right]} \tag{5}$$

Assuming that insolation H and ambient or surrounding air temperature T_a are constant (as would strictly be the case only if experiments were performed with the help of a solar simulator in an air-conditioned laboratory), above equation can be integrated over the time interval τ during which water temperature rises from T_{w1} to T_{w2} :

$$\tau = -\frac{F_1(mc)'_w}{AF'\eta_0}\ln\left[\frac{H-\frac{1}{F_1}(T_{w2}-T_a)}{H-\frac{1}{F_1}(T_{w1}-T_a)}\right] \quad (6)$$

As seen from Eq. (6) the value of τ is a function of the climatic conditions, i.e., solar radiation intensity and ambient temperature during the time of test and it does not have a unique value for the cooker under test. It would be preferable to obtain the value of the cooker parameter $F'\eta_0$. Rewriting Eq. (6) as

$$F'\eta_0 = \frac{F_1(mc)'_w}{A\tau}\ln\left[\frac{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)}\right] \quad (7)$$

However, $F'\eta_0$ cannot be computed since $(mc)'_w$ is not known. An approximate calculation shows that the heat capacity of utensils is small compared to that of their contents. The heat capacity of the cooker interiors to be considered is difficult to specify. The problem is circumvented by introducing an additional parameter for the cooker – the heat capacity ratio, $C_R = (mc)_w/(mc)'_w$. Eq. (7) can now be rewritten as

$$F'\eta_0 C_R = \frac{F_1(mc)_w}{A\tau}\ln\left[\frac{1-\frac{1}{F_1}\left(\frac{T_{w1}-T_a}{H}\right)}{1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)}\right]$$

$$=F_2 \quad (8)$$

The above parameter $F'\eta_0 C_R$ can be calculated from Eq. (8) since $(mc)_w$ the heat capacity of water in the containers is known. This parameter serves as the second figure of merit, F_2.

Note: Suitable vessels should be supplied by the manufacturer along with the cooker and are to be considered a part of the cooker being tested, since the thermal conductivity of the vessel material as well as the wall thickness influence heat transfer to the contents of the vessel. Moreover, tests should be carried out with a "full load" as specified by the manufacturer, so that the heat capacity ratio C_R has a more or less unique value. The factor F_2 as calculated from Eq. (8) can be expected to pertain to the cooker. It is seen from Eq. (8) that the important factor "τ" (the measured time for sensible heating of water between two known temperatures) has not been ignored. It has been normalized suitably with respect to the climatic variables so that the factors finally reported are relatively independent of the climatic variables.

The first figure of merit ensures that the glass covers have a good optical transmission and the cooker has a low overall heat loss factor. However, for good performance, it is equally important that there is a good heat transfer to the contents of the vessel and the heat capacity of the cooker interiors is small. This implies that the system to be considered should consist of the cooker and the vessels together and tested with a "full load". The heat exchange efficiency factor F', which indicates the effectiveness of the heat transfer from the plate or the vessel top to the contents of the vessel (water in the present case), cannot be measured by tests similar to those for a flat plate collector since there is no arrangement for liquid flow or for obtaining a steady state withdrawal of energy from the cooker. Therefore, a novel factor is proposed for this purpose.

The upper limit of the water temperature, T_{w2}, for the time period analyzed could have been taken as 100˚C, the boiling temperature. However this has a drawback. Since the rate of variation of water temperature approaches zero as the water temperature approaches 100˚C, there is a great uncertainty in deciding the termination point of time interval τ. Therefore, the upper limit of sensible heating (T_{w2}) should be fixed in the temperature range 90˚C – 95˚C, and this value should be used consistently.

The selection of initial temperature of water for the sensible heating period, T_{w1}, can be made in two alternative ways. One alternative is to take T_{w1} equal to T_a, the ambient temperature. This would simplify Eq. (8) to

$$F'\eta_0 C_R = \frac{-F_1(mc)_w}{A\tau}\ln\left[1-\frac{1}{F_1}\left(\frac{T_{w2}-T_a}{H}\right)\right] \quad (9)$$

However, this procedure may not be the preferred one since the value of heat loss factor in F_1 is that measured at stagnation.

The second alternative is to take T_{w1} at some value (say, midway) between the ambient and the boiling point. In this case the range of temperature for analysis is reduced and the assumption of a constant heat loss factor is a closer approximation to the actual situation.

Mullick et al. (1987) recommend that the magnitudes of T_{w1} and T_{w2} should be fixed by the standardizing agency to ensure consistency.

3.2 Characteristic Curve of a Solar Cooker (Fig. 2)

From Eq. (8)

$$\tau = \frac{-F_1 (mc)_w}{F_2 A} \ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)}{1 - \frac{1}{F_2}\left(\frac{T_{w1} - T_a}{H}\right)} \right] \quad (10)$$

Therefore the time for sensible heating from ambient temperature up to 100 ºC, τ_{boil} is

$$\tau_{boil} = -\frac{F_1}{F_2} \frac{(mc)_w}{A} \ln \left[1 - \frac{1}{F_1}\left(\frac{100 - T_a}{H}\right) \right] \quad (11)$$

So a characteristic curve of a box solar cooker can be developed between τ_{boil} and (100 - T_a)/H, knowing its figures of merit (F_1 and F_2), as shown in Fig. 2.

Characteristic curve of a solar cooker describes the sensible heating period of a solar cooker under any given climatic conditions (i.e., H and T_a).

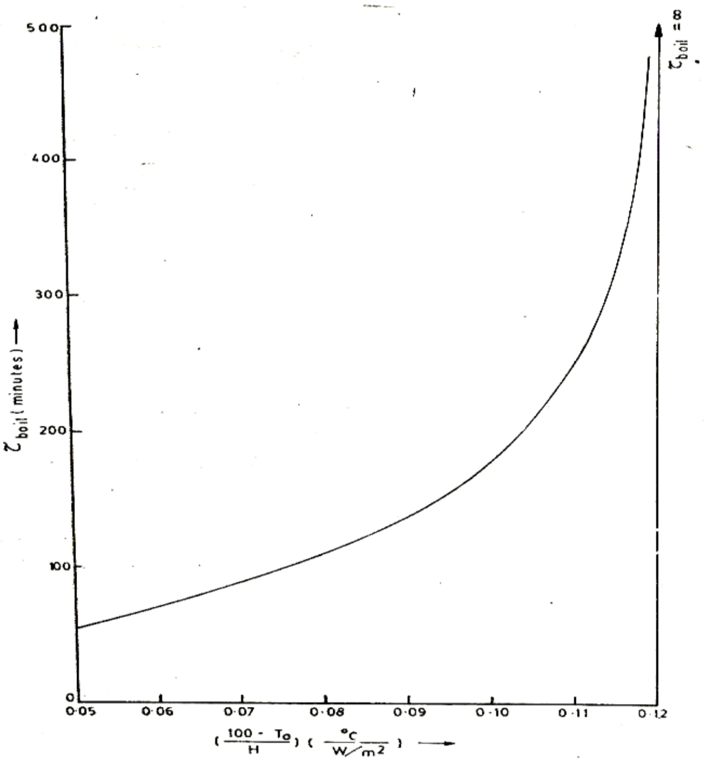


Fig. 2 Characteristic curve of a solar cooker (Mullick et al., 1987).

IV SOLAR COOKER – BOX TYPE – TEST METHOD (IS: 13429 part 3:2000)

4.1 *Rubber Gasket Leakage Test*

Insert a piece of paper in between the gasket and the cover plate in at least four positions along each side of the cooker. The paper used should be approximately 50 mm wide and maximum 0.05 mm thick. Ensure that the cover plate is properly tightened. The paper exhibits a firm resistance to withdrawal by hand at all points tested.

4.2 *Cover Plate Leakage Test*

Leakage from cover plate may occur from upper and lower sides. Therefore, the cooker is tested for following two tests:

a) ***Leakage test for upper side of cover plate***

Ensure that the cover plate is properly tightened. Pour a thin film of water on the cover plate. After one hour, examine the cover plate for any signs of water entry between the two glass sheets. This test is done in the shade.

b) ***Leakage test for lower side of cover plate***

Fill the cooking pots with water and keep them in the cooking tray. Tighten the cover plate. Place the cooker in open around 10 AM for exposure to sun rays for 4-5 h. Then place the cooker in shade for 15 min to allow any vapour to condense. Examine the cover plate for any signs of water vapour entry between the gap of inner and outer of cover plate.

4.3 *Rain Penetration Test*

The basic apparatus is a 5 mm spray nozzle. The closed cooker is sprayed water on all sides using a spray nozzle at a pressure of 0.1 MPa. Spray from the nozzle is directed downwards from the cooker top and also towards the four corners of the cooker. The water is sprayed on the cooker top and corner for 10 min. After the test, external surface of the cooker is wiped dry and the cooker is inspected visually for any entry of water vapour.

4.4 *Mirror Reflectivity Test*

The apparatus required for this test are two pyranometers and a stand with two axis tracking arrangement for holding the mirror and a pyranometer parallel to the mirror at a distance of about 30 cm. The stand should have a pointer (10-15 cm long pin) fixed normal to its plane.

Place the stand in an open space free from shadow and reflected radiations from the surroundings. Fix the mirror on the stand parallel to its plane. Also fix one of the pyranometers (P_1) in such a way that its sensor faces towards the mirror. Place the other pyranometer (P_2) horizontally near the stand for using it as a reference pyranometer.

Adjust the stand for normal incidence in such a way that shadow of the pointer is not there. Tilt the stand about 10° from the normal position and adjust the position of pyranometer (P_1) on it in such a way that radiation reflected from the mirror falls on the pyranometer sensor. Record the readings R_1 and R_2 of the pyranometers P_1 and P_2 respectively.

Without changing the tilt of the stand, reverse the pyranometer P_1 so that its sensor faces the Sun and is parallel to the mirror. Record the readings R_3 and R_4 of both the pyranometers P_1 and P_2, respectively. The two readings of the reference pyranometer P_2 (R_2 and R_4) should not have changed by more than 5 percent. The experiments should be performed in clear weather and the global radiation recorded should be more than 600 W/m^2.

Calculate the reflectivity of the mirror from the relation $R = R_1/R_3$. Repeat the test six times. The average of the six values of the R will give the reflectivity of the mirror.

4.5 *Exposure Test*

The basic apparatus consists of solar pyranometer, along with a recording device. The solar cooker is left to stagnate which may lead to the following possible degradation:

a) Breakdown of rubber or plastic material;
b) Outgassing from the insulating material;
c) Discoloration or peeling of black paint on the cooking pots and cooking tray;
d) Depositions of water vapour, dust or any other material inside the double glass lid; and
e) Cracking of glazings and/or mirror and/or body.

The solar cooker is left open in an unshaded area for at least 30 days having daily irradiation level of at least 4 kWh/m^2 on a horizontal surface. These days need not to be consecutive. The cooking pots inside the cooker are empty. The mirror is placed vertically and the cooker is oriented to face south. The cooker may be kept inside during rains.

4.6 *Thermal Performance Test*

The thermal performance test is conducted under the following conditions and values of F_1 and F_2 are calculated. The values of F_1 and F_2 is reported based on arithmatic average of at least 3 test values which should not have variation more than 0.002.

(a) *Stagnation temperature test*

The apparatus required for this test are a Pyranometer and a temperature sensor along with a measuring/recording device. The hot junction of the thermocouple (with radiation seal) should be fixed at the mid-point of tray with proper thermal contact and without protruding out. The no load test is carried out on a clear day in following steps starting before 10 AM so that the stagnation temperature is achieved near solar noon or just after noon.

a) Place the solar cooker without pot in open sun condition,
b) Cover the reflector of the solar cooker with a black cloth,
c) Monitor the cooker tray temperature at an interval of 5 min continuously. Also measure intensity of total solar radiation, ambient temperature and wind speed at the level of glazings of solar cooker, and
d) When the cooker tray temperature has reached a quasi steady state, note down the final steady cooker tray temperature (T_{ps}) and the corresponding outside ambient air temperature (T_{as}) along with the solar radiation (H_s) at that time. The steady state conditions are defined as 10 min period when:

1) variation in cooker tray temperature is ±1˚C.
2) variation in solar radiation is ±20 W/m^2.
3) variation in ambient temperature is ±0.2°C.
4) solar radiation is greater than 600 W/m^2.

F_1, which is defined as the ratio of optical efficiency to the heat loss coefficient $\alpha\tau/U_L$, is calculated as follows:

$$F_1 = (T_{ps} - T_{as}) / H_s \tag{11}$$

where τ = transmittance of glass,
α = absorptance of cooking tray,
U_L = heat loss coefficient of the cooker, and
H_s = solar radiation during steady state.

(b) *Load test: sensible heating of water*

Sensible heating test should be conducted for calculating figure of merit F_2. Pyranometer and temperature sensor along with the measuring/recording device are used. Weigh the empty cooking pots and then fill with 8 litres of water per square metre of aperture area. Water at ambient temperature is equally distributed in all the cooking pots if they are of the same size. If sizes are different, then water quantity in each cooking pot should be in proportion to their bottom area. Reweigh and calculate the exact mass of water. Place the pots in the cooker from which the mirror has either been removed or covered with cloth.

Place temperature probe of thermocouple in the largest of the cooking pots with the measuring tip submerged in the water. The temperature probe lead should be sealed where it leaves the cooking pots and the cooker.

The ambient temperature and wind speed at the level of glazings of solar cooker are measured throughout the test.

The test starts in the morning between 10 AM and 10:30 AM of local solar time. If radiation and temperature are measured by spot checks, these should be no more than 5 min apart.

Constant monitoring at 30 s intervals or less is desirable with averages of radiation recorded over 2 min intervals. Following measurements should be taken:

a) Water temperature measured along with the exact time of that measurement should be recorded;
b) Continue the data recording until the water temperature exceeds 95°C;

c) Locate initial and final temperature/time data pairs. The initial temperature is 60°C and the final temperature is 90˚C. These will be noted as T_{w1} and T_{w2} respectively and the corresponding times τ_1 and τ_2 respectively;
d) Calculate the average ambient air temperature (T_a) between the times τ_1 and τ_2 ;
e) The experiment should be conducted in clear weather. Check that the radiation recorded between the two points always exceeds 600 W/m^2;
f) Calculate the average radiation (H) over the time τ_1 and τ_2 ; and
g) Calculate the second Figure of merit F_2 using Eq. (8).

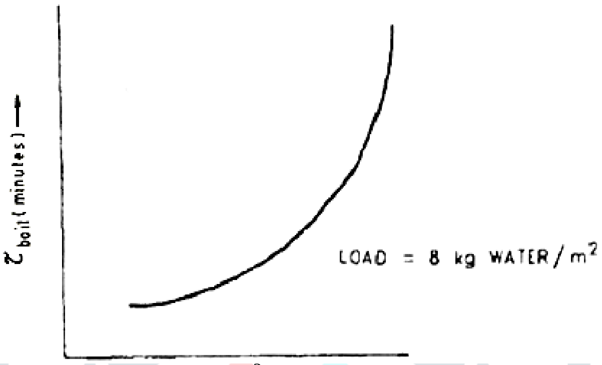
4.7 *Standard Boiling Time*

Knowing F_1 and F_2, standard boiling time in minutes is calculated as follows.

$$\tau_{boil} = \left(\frac{-F_1 (mc)_w}{60 F_2 A} \right) \ln \left(1 - \frac{X}{F_1} \right) \tag{12}$$

where $X = (100 - T_a)/H$

The standard boiling time is calculated for different values of X. A plot of τ_{boil} versus X is provided as shown in Fig. 3, which is similar to Fig. 2. It should be mentioned that the actual boiling time with mirror in position would be less than this time.



$X = (100 - T_a)\ /H$, °C m²/W→
Fig. 3 A typical plot of τ_{boil} versus X [IS 13429 (Part 3):2000].

V. AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS STANDARD (ASAE S580)

This standard was originally developed by Dr. Paul Funk as an international testing standard for solar cookers. The need for such a standard was recognized and addressed at the Third World Conference on Solar Cooking, in 1997 (Funk, 2000). The goal of this standard was to produce a simple, yet meaningful and objective measure of cooker performance that was not so complicated as to make testing in less developed areas prohibitive. ASAE S580 monitors the average temperature inside a pot of water while the cooker is operated under a set of guidelines given in the standard for tracking procedure, thermal loading, etc. Temperature measurements are made of the water and averaged over 10 minute intervals. Ambient temperature and normal irradiance (solar energy flux per area) are also measured and recorded, at least as often as load temperature. Under conditions of high wind, low insolation, or low ambient temperature, tests are not conducted. The primary figure of merit used by ASAE S580 is the Cooking Power, P. This is calculated through the following equation.

$$P = \frac{(T_2 - T_1)}{600} mc_p \tag{13}$$

where
P = cooking power (W)
T_2 = final water temperature
T_1 = initial water temperature
m = mass of water (kg)
c_p = specific heat of water (4.186 kJ/kgK)

Equation (13) is divided by 600 to account for the number of seconds in each 10-minute interval. P is normalized to a figure of 700 W/m^2 through the following equation:

$$P_s = P\left(\frac{700}{I} \right) \tag{14}$$

where I = interval average insolation (W/m^2)
P = cooking power (W)
P_s = standardized cooking power (W)

P_s is plotted against ΔT and a regression linear regression is performed. For standard reporting procedures, a temperature difference of 50°C is used (i.e. T_{water} - $T_{ambient}$ = 50°C) and the corresponding P_s is reported as the “Cooking Power” (ASAE, 2003).

While ASAE S580 accomplishes its goals of providing a simple test to establish an understandable and universal figure of merit, Shaw expresses the opinion that the test is lacking in several areas. ASAE S580 does not address issues other than thermal performance of the cooker. The single figure of merit is practically valueless for assessing why a cooker achieved a certain performance, as it leaves out any direct measurement of heat losses. Therefore, any use of the ASAE standard to analyze the performance of a cooker, rather than simply compare its performance to another cooker would be very difficult. From a qualitative perspective, ASAE S580 does not address ease of use, safety, or financial issues associated with the cookers under test. Once again, this was never implied as a goal of the standard but it should be realized that this information could be equally important to any party interested in solar cooker evaluation.

VI. CONCLUSIONS

In last two decades, a lot of efforts have been directed towards development of efficient family and community solar cookers. For testing and rating of solar cookers, various recommendations are available in the literature including that from BIS. Mathematical modeling of solar cooker has been tried by some of the researchers. However, the results of these studies are not consistent with the experimental results because of many simplifying assumptions made for writing heat balance equations. It is difficult to estimate the convection heat transfer coefficient because of complex natural convection conditions. Estimate of view factor for radiation heat exchange has also been approximated only. Uncertainty in estimate of thermal contact resistance between the absorber and vessel bottom is also present.

The various codes from ASHRAE, BIS, ASAE and suggested by some researchers are available. The performance parameters for the solar box cooker suggested by these standards are first and second figure of merit, F_1 and F_2, respectively, and the cooking power.

BIS recommends F_1 and F_2 as performance parameters, which have been argued by some researchers as complicated and less universal. Hence, as a single measure, the cooking power parameter has been proposed by some researchers. The factor F_1 and F_2 are good predictive tools for researchers and engineers while cooking power may be preferred by the consumers.

In addition to the performance parameters, standards and researchers have recommended calculation of standard boiling time. The other important test recommended is stagnation temperature test to ensure high temperature sustainability of cooker materials. Mirror reflectivity and glazing transmittance tests recommended by BIS is of interest for designers. A good reflectivity and high transmissivity ensure a good design of solar cooker.

The standards recommend certain requirement of weather, ambient and other parameters for tests, such as minimum solar insolation, maximum wind velocity, ambient temperature range and solar radiation variations, percentage of diffuse radiation, time and duration of testing, tracking frequency, loading per square meter of aperture area, etc. However, different codes and researchers do not agree on the values of all these parameters.

Looking to the disagreement regarding the performance parameters and test conditions between various codes and researchers, there is a need of development of a new testing code which is acceptable to consumers from different regions around the world with different weather, ambient, atmospheric conditions and their variations.

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