

Draft Test Procedure

SOLAR COOKER – PARABOLOID CONCENTRATOR TYPE

Prepared by

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INTRODUCTION

Paraboloid concentrator cookers are available in the Indian market for sometime now. The Government of India through Ministry of Non-conventional Energy Sources has been promoting these solar cookers during 10th Plan period, and is likely to continue supporting these in the near future also. As a result, a number of manufacturers have taken up manufacturing of these solar cookers, essentially in accordance with the specifications set by the Ministry.

In view of the above, a need has been felt by the Ministry, experts, and the industry to develop and establish a standard test procedure for paraboloid concentrator solar cookers also, like an Indian Standard (IS13429:2000) was brought out by Bureau of Indian Standards for box type solar cookers. In this regard, it may be noted that

- Presently, no specific test standard is available for performance evaluation of paraboloid concentrator solar cookers
- Some work was done at IIT Delhi to develop a thermal test procedure for these solar cookers as reflected in the following publications:
 - i) *S.C. Mullick, T. C. Kandpal and Subodh Kumar, 'Thermal test procedure for a paraboloid concentrator solar cooker', Solar Energy, 46(3), 139-144, 199.*
 - ii) *Subodh Kumar, T. C. Kandpal and S. C. Mullick, 'Heat losses from a paraboloid concentrator solar cooker: Experimental investigations on effect of reflector orientation, Renewable Energy, 3(8),871-876, 1993.*
 - iii) *Subodh Kumar, T. C. Kandpal and S. C. Mullick, 'Effect of wind on the thermal performance of a paraboloid concentrator solar cooker', Renewable Energy, 4(3), 333-337, 1994*
 - iv) *Subodh Kumar, T. C. Kandpal and S. C. Mullick, 'Experimental test procedures for determination of the optical efficiency factor of a paraboloid concentrator solar cooker', Renewable Energy, 7(1), 145-151, 1994.*
- Also, some efforts have been made at the University of Arizona, Tucson, USA for characterizing solar cookers including concentrated type solar cookers. The relevant references are as follows:
 - i) *P. A. Funk and D. L. Larson, 'Parametric model of solar cooker performance', Solar Energy, 62(1), 63-68, 1998.*
 - ii) *P. A. Funk, 'Evaluating the international standard procedure for testing solar cookers and reporting performance', Solar Energy, 68(1), 1-7, 2000.*
- Performance of paraboloid concentrating solar cookers is quite sensitive to design parameters and operational conditions, and therefore, the task of evolving and implementing a test procedure for the purpose of standardization and certification is quite involved and challenging.

The present proposal takes reference to the above mentioned published work for drafting the thermal test procedure, and of IS 13429: 2000 for other tests. In addition, the inputs provided by various experts, professionals and manufacturers have also been taken into account in the formulation of the draft test procedures.

The Regional Test Centres, Solar Energy Centre of MNES, and other test laboratories engaged in testing and performance evaluation of solar thermal devices in the country are requested to conduct as many tests as possible and provide detailed feedback towards the evaluation of the desired test procedure (and eventually the formulation of an Indian Standard for the purpose of certification). The exercise would require meticulous record of all the conditions/considerations observed during testing that may directly or indirectly affect the test results, besides careful recording of the relevant characteristics of the equipment used during the experimentation.

PROPOSED DRAFT TEST PROCEDURE

1.0 SCOPE

This test procedure will be applicable to paraboloid concentrator solar cookers, also referred to as dish solar cookers, employed for outdoor cooking.

2.0 SHAPE

The typical shape is a paraboloid concentrator.

3.0 COMPONENTS

3.1 *Paraboloid Dish*

3.1.1 Paraboloid dish shall be made either of single reflector, or by joining small pieces of reflector. It shall be supported firmly with a rigid frame. Its size and shape shall be such that when exposed to sun in the normal direction, a point focus is formed.

3.1.2 The following physical parameters shall be measured and reported:

- **Diameter of the dish:** It shall be measured at the aperture at two positions, which are about normal to each other. Average of two readings shall be reported for diameter of the dish.
- **Material of the reflector and its thickness:** The measurement for thickness of the reflector material shall be made atleast at three positions, and average of these values shall be reported. In case, disruption/distortion of the dish is anticipated, the

measurement may be made after completing thermal performance tests.

- **Reflectivity of the dish:** This measurement shall be done on a separate sample of the same material obtained from the manufacturer/ supplier following the method outlined in 3.1.3.
- **Focal length of the dish:** This is equal to the linear distance from centre of the pot-holder to the vertex of dish, presuming that the cooking pot is kept at the focus of the paraboloid.
- **Rim angle of the dish:** This is the angle subtended by the line joining a point on the aperture of the dish to the focal point with the axis of the paraboloid, measured with respect to focal plane.
- **Size of focal spot:** It shall be measured with solar cooker in normal incidence position.

3.1.3 Reflectivity test:

Measurement of reflectivity shall be carried out on a separate sample of the reflector material obtained from the manufacturer/ supplier. This sample shall be flat in nature, and have a size of 300 mm x 300 mm. Test sample shall be installed on a suitable stand in an open sunlit space which is free from shadow. A solarimeter (or preferably a pyranometer) shall also be mounted on the same stand in a plane parallel to the plane of the sample. The vertical gap between the sample and the solarimeter shall be kept about 300 mm. Measurement of solar irradiance shall be made when i) solarimeter faces the sky, and ii) when solarimeter is inverted and faces the sample. Test shall be conducted during clear sky conditions and the conditions of near normal incidence. The data shall be recorded continuously at a time interval of one minute and for a total duration of five minutes. The values obtained during two sets of measurement shall be integrated over the total duration of measurement i.e. 5 minutes. The ratio of two values, one with solarimeter facing the sample and other being when it faces the sky shall be determined to find the reflectivity. Measurements shall be repeated at least three times, and the arithmetic mean of the three values shall be reported.

3.2 Cooking Pot

3.2.1 The cooking pot shall be a pressure cooker with ISI-mark. It needs to be coated at the bottom with a high temperature resistant black powder coating. The following details regarding its physical measurements shall be measured/observed and recorded in the test report:

- Material of construction
- Height and inner/outer diameter
- Capacity in litres
- Bottom area
- Total surface area (sides+top+bottom)

- Mass (kg)
- Coating on the outer bottom surface

3.2.2 Pot-holder shall be of adequate strength to be able to hold the cooking pot with full load without any bending. It shall be made of mild steel with high temperature resistant coating to avoid degradation.

3.3 Supporting Frame and Stand of Paraboloid Dish

3.3.1 The supporting frame of the paraboloid dish shall be made either of MS rings supported by MS strips, FRP material, or thick MS wire-mesh structure. The frame shall be rigid enough to resist any deformation of the dish shape due to wind pressure or manual handling. The MS structure will have epoxy/anti-rust coating.

3.3.2 The stand for the dish shall be made up of MS having epoxy/powder coating. The stand shall be equipped with an arrangement to hold the cooking pot firmly and also to secure itself to the ground to inhibit any undesired movement.

3.4 Tracking Mechanism

3.4.1 Tracking mechanism may be manual or automatic, allowing unrestricted rotation of the dish along its horizontal and vertical axes enabling its adjustment in the normal direction to the sun's rays. It shall be equipped with a locking arrangement to hold/fix itself at the desired position.

4.0 THERMAL PERFORMANCE TEST

4.1 Heating and cooling tests shall be conducted to evaluate characteristic performance parameters of the paraboloid concentrator solar cooker under testing. These parameters are

- Heat Loss Factor ($F'U_L$)
- Optical Efficiency Factor ($F'\eta_o$), and
- Standardized Cooking Power (P_s)

4.2 The values of each of these parameters shall be reported based on an arithmetic mean of at least five (5) test values which shall not have variation of more than $\pm 5\%$.

4.3 Heating and Cooling Tests

4.3.1 *Apparatus Required*

The following apparatus/ equipment will be required for making measurements necessary to evaluate thermal performance of the paraboloid concentrator solar cooker:

- i) Pyrheliometer for measuring intensity of direct solar radiation in the normal direction to the aperture of the paraboloid. It shall be mounted on the outer frame of the paraboloid in such a manner that no shadow is cast on the exposed area of the dish, and it is in the normal direction to the plane of aperture.
- ii) Pyranometer with shading ring, to measure diffuse component of global solar radiation. It shall be mounted on horizontal plane.
- iii) Anemometer for measuring wind speed at the level of aperture of the paraboloid.
- iv) Calibrated thermocouple for measurement and of monitoring water temperature in the cooking pot at regular periodic intervals. This may be installed through a hole (specially made for the purpose) in the lid of pressure cooker and sealing it properly with M-seal, or, some other good temperature resistant adhesive. It shall be installed in such a fashion that it remains immersed in the water without touching the walls or the bottom of the pot.
- v) Temperature sensor for ambient air temperature
- vi) Weighing balance for measuring mass
- vii) Data logging system

4.3.2 Procedure for Heating Test

- a) Heating test is conducted to determine Optical Efficiency Factor ($F'\eta_o$) and Standardized Cooking Power (P_a) of the paraboloid concentrator solar cooker. For this test, the cooking pot with a predefined amount of the water (as the cooking load) is mounted at the focus of the paraboloid. The paraboloid concentrator is exposed to unobstructed solar radiation and is adjusted in a manner that the bright spot of the concentrated solar radiation falls on the centre of the bottom of the cooking pot.
- b) The following measurements shall be made at an interval of at least 5 minutes and recorded:
 - i) Intensity of direct solar radiation on the aperture plane of the paraboloid concentrator (I_b)
 - ii) Diffuse solar radiation on horizontal surface
 - iii) Water temperature in the cooking pot (T_w)
 - iv) Ambient air temperature (T_a)
 - v) Wind speed at the level of aperture of the paraboloid (V)
- c) Temperature of water in the cooking pot shall be monitored continuously till the water temperature reaches 95°C. Tracking shall be done to keep the bright spot onto the centre of the bottom of cooking pot.

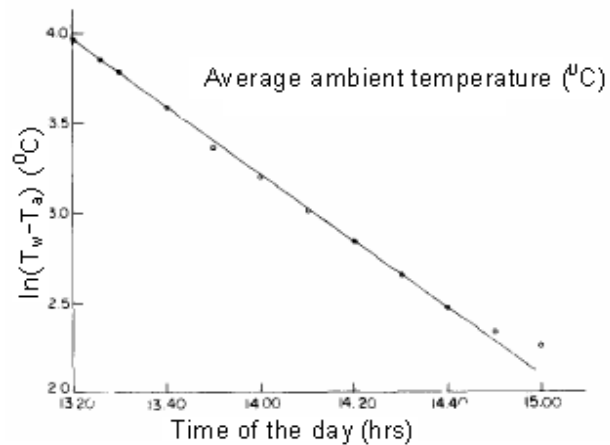
4.3.3 Procedure for Cooling Test

a) As soon as the water temperature reaches 95°C during heating test, the concentrator shall be shaded by an adequately sized umbrella (with dark colour, preferably black) so as to ensure total blockage of solar radiation. It shall be ensured that the shading arrangement causes least interference in the heat loss process from the cooking pot. Measurement and continuous recording of parameters (iii) - (iv) referred in 4.3.2 (b) above shall be done at every two minutes interval for the first half an hour and later at five minutes interval till the water temperature reaches close to the ambient air temperature. It shall be made sure that the difference between water temperature and the ambient air temperature at the end of the cooling test is less than (1/e)th of the difference between the water temperature and the ambient air temperature at the beginning of the cooling test.

4.3.4 Analysis of Test Results

Cooling Test

a) For each set of the data points, the value of $[\ln(T_w - T_a)]$ shall be calculated, and a plot with this value on Y-axis and time on X-axis shall be drawn, as shown in the adjoining figure. Different points of the plot shall be fitted to a least square linear regression equation. The slope of the line equals to $(-1/\tau_0)$, where τ_0 is defined as the time-constant for cooling.



b) Substituting known values of time-constant for cooling (τ_0), surface area of the cooking pot (A_{pot}), and total thermal capacity of the cooking pot in the following expression, the value of the heat loss factor ($F'U_L$) of the cooker shall be evaluated:

$$F'U_L = \frac{(MC)'_w}{A_{pot} \tau_0} \quad (1)$$

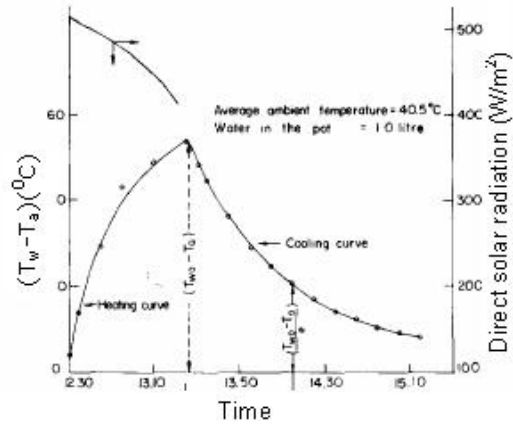
where

- A_{pot} = Total surface area of the cooking pot, m^2
- $(MC)'_w$ = Total heat capacity, which is equal to the sum of the heat capacity of cooking pot ($M_{pot}C_{pot}$) and the water ($M_w C_w$), J/K
- C_{pot} = Specific heat of the material of cooking pot, J/kg K
- C_w = Specific heat of water, J/kg K
- M_{pot} = Mass of empty cooking pot with lid, kg

M_w = Mass of water kept in cooking pot during the test, kg

Heating Test

a) The variation of $(T_w - T_a)$ with time shall be plotted using the data points recorded during heating test as shown in the figure. The optical efficiency factor ($F'\eta_o$) of the paraboloid concentrator cooker shall be calculated for each 10-minute interval of the test using Eq. (2) given below. For the first test interval, initial value of the water temperature shall be used for T_{wi} , and the value of water temperature at the end of 10-minute interval for T_{wf} . Subsequently, the value of T_{wf} for the first interval shall be used as T_{wi} for the second interval. This process shall be continued for subsequent test-intervals.

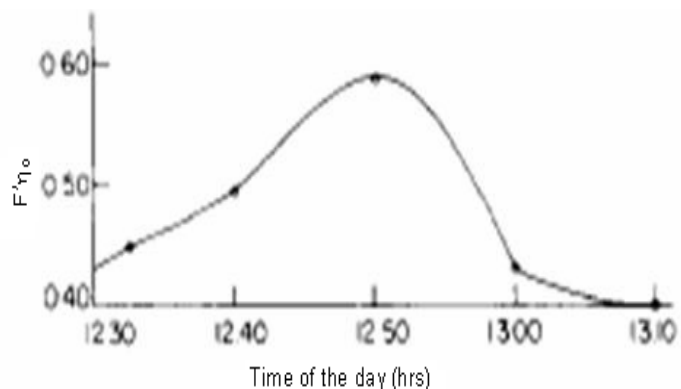


$$F'\eta_o = \frac{\left(\frac{F'U_L}{A_{aperture}}\right) A_{pot} \left[\left(\frac{T_{wf} - T_a}{I_b}\right) - \left(\frac{T_{wi} - T_a}{I_b}\right) e^{-\tau/\tau_0} \right]}{1 - e^{-\tau/\tau_0}} \quad (2)$$

where

- T_{wi} = Temperature of water in the cooking pot at the beginning of the interval, C.
- T_{wf} = Temperature of water in the cooking pot at the end of the interval, C.
- τ = Duration of the interval (e.g. 10 minutes or 600 s), s.
- I_b = Intensity of beam radiation incident on the aperture of the concentrator, averaged during the interval, W/m^2 .
- T_a = Ambient air temperature averaged during the interval, C.
- A_{pot} = Total surface area of the cooking pot, m^2 .
- $A_{aperture}$ = Aperture area of the paraboloid concentrator cooker, m^2 .

b) A graph showing the time variation of $F'\eta_o$ shall be plotted as shown in the figure. Average value of $F'\eta_o$ by applying Eq. (2) over the entire period of



sensible heating shall also be computed.

c) The cooking power of the solar cooker may be calculated by multiplying the temperature rise of water in each 10 minute test-interval by the product of mass and specific heat capacity of water. The standardized cooking power (P_s) corrected to direct solar irradiance level of 700 W/m^2 shall be calculated for each 10-minute test interval as follows:

$$P_s = \frac{(M_w C_w)(T_{wf} - T_{wi})}{600} \cdot \frac{700}{I_b} \quad (3)$$

d) Mean temperature difference for each of the test-interval shall be calculated as follows:

$$\Delta T = \frac{1}{2}(T_{wi} + T_{wf}) - T_a \quad (4)$$

e) A plot of standardized cooking power on Y-axis and ΔT on X-axis, as calculated for each test-interval using Eqs. (3) and (4) shall be drawn. A least square linear regression of the plotted points shall be used to find the relationship between cooking power and the mean temperature difference. The intercept indicates the maximum cooking power for test cooker. For this plot, at least 30 data points shall be used. The standardized cooking power at 50°C shall be calculated from the regression equation, and reported.

4.3.5 Standard Boiling Time and Cooker Characteristic Curve

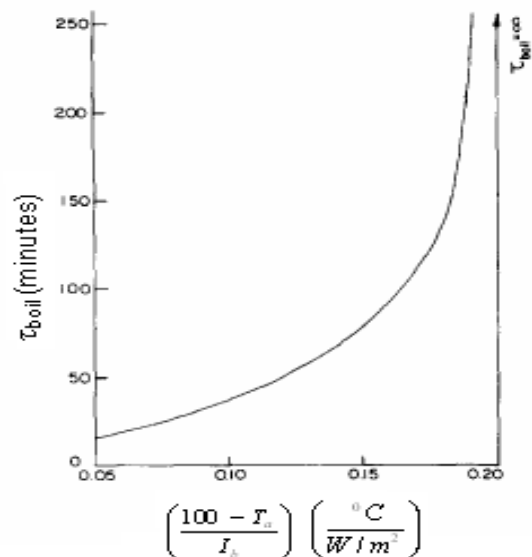
a) The standard boiling time (in minutes) of the given cooker, which is characterized by $F'U_L$ and $F'\eta_o$ as determined above, may be calculated using the following expression for the typical conditions of solar irradiance and ambient air temperature for a location:

$$t_{boil} = \tau_o \ln \left[1 / \left[1 - \left(\frac{F'U_L}{F'\eta_o} \right) \left(\frac{A_{pot}}{A_{aperture}} \right) \left(\frac{100 - T_a}{I_b} \right) \right] \right] \quad (5)$$

In order to have a characteristic curve for boiling time, a plot of t_{boil} versus $\left(\frac{100 - T_a}{I_b} \right)$ shall be provided as shown in the figure.

4.3 Test Conditions for Heating and Cooling Tests

4.3.1 The following conditions need to be satisfied by the observations considered



for determination of the performance parameters of paraboloid concentrating solar cooker:

Parameter	Test Condition
I_b	$> 600 \text{ W/m}^2$. (The variation in the value during the test period shall be monitored and reported)
T_a	Between 20°C and 40°C
Wind speed	Less than 0.5 m/s
Mass of water	3 kg/m^2 of aperture area
Test period	1000 hrs to 1300 hrs

5.0 REPORT FORMAT

5.1 For the purpose of test reports to the client, a report format is enclosed at Annexure.

5.2 For the purpose of firming up the draft test procedure for evaluating optical and thermal performance of paraboloid concentrator solar cookers, the following aspects are considered important:

- Collection of authentic test data to get better insight into the role of different casual variables on the performance evaluation of the paraboloid concentrator solar cookers, and
- Identification of test and operational conditions under which, to the extent possible, an unambiguous and repeatable test results could be obtained to characterize paraboloid concentrator solar cookers.

5.3 It is, therefore, necessary that the data is collected from different test laboratories for consolidation and further analysis. In this regard, it is suggested that the data sets may be stored in Excel sheets, giving name of the Test Laboratory, details of test conducted, date and sample details, etc., and sent to **Director (ST), Ministry of Non-conventional Energy Sources**, after completion of each test by e-mail (ashvinikr@nic.in, ashvini_sec@yahoo.com).

ANNEXURE

NAME OF TEST LABORATORY

**ADDRESS
TELEPHONE/FAX/E-MAIL**

**Test Report for the Sample of Paraboloid Concentrator Solar
Cooker as submitted by the Manufacturer/Supplier**

1. **Name and Address of
Manufacturer/ Supplier**
2. **Details of Contact of
Manufacturer/ Supplier** Telephone:
Fax:
E-mail:
3. **Details of the sample
submitted Model, if any.** Paraboloid concentrator solar
cooker along with pressure
cooker as the cooking pot

Model name may be given, if
provided by the manufacturer.
4. **Latitude and longitude of the
Test laboratory**
5. **Dates and duration of test**
6. **Number of pages in the test
report**
7. **Specifications of the sample and test results**
(All dimensions are in mm)

S. No.	Specifications/ Tests	Results
1.	Shape	Paraboloid dish
2.	Paraboloid Dish	
	- Construction	Single piece/ Made up of small pieces of reflector material
	- Diameter of the dish	
	- Reflector material and its thickness	
	- Reflectivity	
	- Focal length	
	- Rim angle	
	- Size of focal spot	
3.	Cooking Pot	
	- Type	Pressurized/ Non-

		pressurized
	- Is it ISI-mark?	Yes/ No
	- Material of construction	
	- Height	
	- Inner and outer diameter	
	- Capacity (litres)	
	- Bottom area (m ²)	
	- Total surface area (m ²)	
	- Coating on outer surface	
	- Weight (kg)	
4.	Pot Holder	
	- Material	
	- Thickness	
	- Coating	
5.	Tracking Mechanism	
	- Manual or automatic	
	- Description	
	- Locking arrangement provided to hold reflector at a desired position	
6.	Supporting Frame for Dish	
	- Material	
	- Thickness and other details	
	- Epoxy/ anti-rust coating	Yes/no
7.	Stand for Dish	
	- Material	
	- Thickness and other details	
	- Epoxy/ anti-rust coating	
	- Provision for grouting provided	
	- Quality of holder of cooking pot	
8.	Thermal Performance Test	
	- Average heat-loss coefficient (F'U _L)	
	- Average optical efficiency factor (F'η ₀)	
	- Time Constant factor (τ ₀)	
	- Cooking Power Equation	
	- Standardized Cooking Power at 50 °C	
	- Standard boiling Curve	Enclosed
9.	Remarks	

Signature
Name and Designation of Authorized Signatory
Test Laboratory