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# PROPOSAL FOR NEW WORLD STANDARD FOR TESTING SOLAR COOKERS

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**Abstract**

New protocol to test solar cooker is being proposed. The earlier tests measured only the thermal efficiency. There is an urgent need to look into other important parameters of the cooker such as its stagnation capacity, cost per watts delivered, weight of the cooker, ease of handling and aesthetics. The proposal also aims at standardization of reporting the test results so that it can be easily understood by common persons who wishes to use one.

Keywords: Solar cooker tests, Exergy, Efficiency, Standardization in testing and reporting.

## 1. Introduction

Solar Cookers have a long history dating back almost to 18th century when Nicholas-de-Saussure built first ever fabricated solar box cooker. Today there are over 60 major designs and more than 100s of variations [1]. However, the solar cooking has not caught the imagination of the people, except in places where shortage of conventional fuel like fire wood and the like has become very acute [2].

The solar cookers have been subjected to several types of tests to rate its performance. Some of the tests conducted earlier 1978 have been summarized by Bowman [3]. A year later, German Appropriate Technology Group [4] conducted tests on many more types of popular solar cookers and tabulated the results. Mullik et al. [5] presented a set of tests procedures and equations to asses the thermal performance of the solar cookers especially the box type cookers. Their recommendations later got adopted by Beauru of Indian Standards (BIS), and the results were expressed as factor of merit. In the recent past, Petela [6] concentrated

**Nomenclatures**

| | |
|---|---|
| $A_{sc}$ | Aperture area of the solar cooker, $m^2$ |
| $c_{pw}$ | Heat capacity of water (4.168 kJ/kg K), kJ/kg K |
| $E_1$ | Total Energy input into solar cooker, W |
| $I_{aw}$ | Insolation falling on cooker aperture, $W/m^2$ |
| $I_i$ | Insolation total on horizontal surface, $W/m^2$ |
| $I_o$ | Average theoretical Insolation, 700 $W/m^2$ |
| $I_r$ | Effective Insolation, $W/m^2$ |
| $m_w$ | Mass of water, kg |
| $P$ | Cooking power, W |
| $P_s$ | Standardized cooking time to 700 $W/m^2$ |
| $r$ | Exergy ratio |
| $SC_t$ | Standard cooking time, s |
| $SC_{to}$ | Normalized standard cooking time to 700 or 850 $W/m^2$ |
| $SST$ | Standard Stagnation Test |
| $SST_t$ | Standard Stagnation Test theoretical |
| $t$ | Time, s |
| $T_s$ | Maximum surface temperature,$^oC$ |
| $T_{st}$ | Theoretical maximum surface temperature, $^oC$ |
| $T_{w1}$ | Initial temperature of water, $^oC$ |
| $T_{w2}$ | Final temperature of water,$^oC$ |
| $T_{wo}$ | Ambient temperature, $^oC$ |
| *Greek Symbols* | |
| $\Delta T$ | Difference in temperature between hot pot and ambient, $^oC$ |
| $\Delta T_w$ | Difference in initial and final temperature of water, $^oC$ |
| $\Delta T_o$ | Set at 50$^oC$ |
| $\varepsilon$ | Effectiveness |
| $\eta$ | Overall efficiency, % |
| $\eta_o$ | Optical heat transfer coefficient |
| $\sigma$ | Stephen-Boltzman constant, $Wm^{-2}K^{-4}$ |

on exergy aspects. However, it was in the year 2000 that Funk et al. [7] found a need to evolve an International Standard for testing solar cookers. The recommendations were later adopted by United States Agricultural Engineers as ASAE S580.

Nandwani [8] and later Mukaro [9] have conducted tests on solar cookers and have reported the thermal performance in terms of percentage efficiency. While ElSebaii et al. [10], Florida Solar Energy Center FSEC [11] and Steven Jones et al. [12] have conducted tests as per ASAE S580 for box type and panel type of cookers. But it is very difficult to tabulate comparative data as many other popular types of cookers have not been subjected to standard tests. Thus there is an urgent need to evolve a comprehensive procedure to evaluate solar cookers.

It is interesting to note that while earlier researchers [2, 3] did consider many other aspects of solar cookers such as handling, duration of cooking time and the like, along with thermal performance, recent tests concentrated only on thermal performance. Besides, the figures obtained after the tests were presented in the form of ‘Factor of merit’ rather than in a format easily comprehendible by the common person. Thus the present proposal recommends a set of tests which in the words of Shaw [13] "presenting thermal, qualitative and ergonomic data into an understandable, reproducible and rigorous testing method."

The authors urge that the recommendations presented here should be taken as general guidelines for more down to earth tests, than the final verdict.

## 2. Background

Without going into the details of pros and cons of equations used by other researches in the past, the authors like to start off from the present International Standard Test recommended by Funk et al. [6] which is now the only standard universal test. The test specifies many important parameters and stipulations for testing. Most important being amount of water to be heated per square meter area of cooker and to measure temperature of water only up to 90°C, to avoid vagaries of water near boiling point. The following equation was used to arrive at Cooking Capacity or Power of the Cooker.

$$P = \frac{T_{w_2} - T_{w_1}}{t} m_w c_{pw} \quad (1)$$

where $t$ is 10 min (600 s). Thus $P$ represents values per second. It is assumed that same or similar vessel is used while testing all types of cookers, hence the values pertaining to cooking vessel is left out.

Finally $P$ is normalized ($P_s$) to a figure of 700 W/m$^2$ so as to get a figure easily comparable, and free from local variations of insolation, through the following equation.

$$P_s = P\left(\frac{700}{I_{aw}}\right) \quad (2)$$

While ASAE S508 provides a simple test to establish a universal figure of merit, the figure as such would not make much sense to general user.

European Committee on Solar Cooking Research (ECSCR) in 1992 recommended more exhaustive thermal testing, and considered certain other aspects of cookers such as safety factors, ease of access to cooking pot, durability and the like. The thermal testing regime specified by them under 'Basic Test' included many stipulations. Some of the important ones are listed bellow,

- Water at 40°C is placed in a pre-heated cooker for two hours around solar noon (i.e., 11.00 to 13.00 hrs) and maximum temperature is recorded.
- The cooker is fixed towards the sun and left. The time taken for the water inside to reach 80°C is recorded.
- Oil, at 40°C, is heated from 11:00-13:00 and the maximum temperature is recorded.
- Hot oil from the previous test is left to cool in the cooker out of the sun. The time taken for the oil to cool to 100°C is recorded.
- Repeat the test conducted as per first point, in non-heated cooker.
- The lid(s) of the pot is removed and the time duration for the water from the previous test to cool to 80°C with occasional stirring is recorded.

- Water at 40°C is heated with the sun at a low angle. Temperature is recorded as a function of time. This measure is intended to test cooker performance in morning and evening conditions.

These variations in the recording of temperature have not been reflected in their calculations. But as far as the reporting of test results are concerned there are no uniform standards in the above or other tests and thus the authors suggest the following

- As far as possible reporting the thermal performance test results should be presented in percentage and temperature recording to be reported in both centigrade and fahrenheit.
- Standardized nomenclature of symbols, as suggested, should be used in the equations for Solar Cooking Tests, this would enable easy verification. Any new symbols could be used, but should preferably be introduced in the following table which will be published on net.

## 3. Proposal of New Standards

In the light of the discussions made above, the authors take the liberty of presenting the following suggestions, for testing and reporting of results on solar cookers.

a. **Thermal performance test**: Result should always be expressed in percentage and temperatures recorded to be displayed in centigrade. Graphs when presented should be in color.

b. **Stagnation temperature**: This test reflects the thermal capacity and performance of the cooker.

c. **Heat loss test**: This test substantiates the stagnation test.

d. **Standard cooking time and max. load test**: Result of this test enables the user to select the right sized cooker.

e. **Tests for heat storing components**: Low cost solar cookers too can be used to store heat using materials like sand, and this is going to be an important factor in the future.

f. **Ray trace diagrams**: should be made mandatory in all test reports.

g. **Ergonomic considerations**: should also be part of test to enable better designing process.

h. **Cost/watts**: This factor would influence the user and also the local governing bodies to a great extent in selecting and popularizing of solar cookers. Considering the number of poor people in the world, the authors feel that do-it-yourself designs should receive more attention by scientist.

i. **An active user should form** part of the test and his/her observations, especially on last two points should be included in test report.

As regards the nomenclature of symbols shown above is the list of some of the most frequently used symbols in solar cooker testing. All of them are not new, but in future they could be adopted by all solar cooker scientists, so that it would be easier for others to compare and verify.

### 3.1. Thermal performance test

Stipulations made in ASAE S580 for conducting test appear to be ideal for this type of test. However care should be taken to use right type of vessels for testing for a particular type of cooker. Wherever possible, best quality solar guard (Greenhouse enclosure) should be used, even in concentrating type of cookers.

Quantity of water taken for testing has a bearing on aperture size and performance of the cooker. Care should be exercised in arriving at aperture size of a cooker. In case of box type - aperture of cooker is sum of area of reflector and 'glazed window'. In case of panel cooker, aperture is to be taken as area of rectangle formed by the folded assembly rather than the total area of reflecting area when the cooker is totally unfolded. The suggested quantity of water to be heated for testing is pegged at 7 kg of (fresh) water/m$^2$ of solar cooker aperture appears to ideal.

The final figure obtained through Eq. (2) gives standardized 'cooking power' per second, $P_s$. But it would be difficult to express the result of such a test in percentage.

To calculate efficiency in percentage, some more data, like total amount of 'heat' or insolation reaching the cooker is required. This can be arrived at through Eq. (3)

$$E_1 = I_{aw} A_{sc} \tag{3}$$

From this and obtaining all the other values as shown in Eq. (4), the efficiency, $\eta$, can be calculated

$$\eta = \frac{m_w C_{pw} (T_{w2} - T_{w1})}{A_{sc} \int_0^t I_{aw} \Delta t} \tag{4}$$

The test results can now be expressed in percentage.

According to Patella [6], Exergy is an important parameter evaluating thermal systems, hence the authors suggest incorporation of this parameter as well. In which case the calculations are to be performed through Eqs. (5) and (6). This aspect need be evaluated by designers of new types of cookers, and need not be a part of regular tests.

$$r = \frac{m_w c_{pw} \left[ (T_{w1} + \Delta T_w - T_{w1}) - T_o \ln \frac{T_{w1} + \Delta T_w}{T_{w1}} \right]}{m_w c_{pw} (T_{w1} + \Delta T_w - T_{w1})} \tag{5}$$

Simplifying this further one arrives at the Eq. (6)

$$r = 1 - \frac{T_o}{\Delta T_w} \ln\left( 1 + \frac{\Delta T_w}{T_{w1}} \right) \tag{6}$$

Where r, is the ratio of energy growth to energy growth (gain) of water. Low Exergy ratio is obtained because the significant degradation of Energy, especially in Solar driven devices, where relatively high temperature of source (~6000 K) is degraded to low temperature gains.

Effectiveness, $\varepsilon$, which is a very important and useful parameter of the cooker, can then be evaluated as in Eq. (7). Thus effectiveness in terms of efficiency in percent illustrates as to effectiveness of solar cooker in converting the insolation falling on it to heat energy.

$$\varepsilon = \left[\frac{I_{aw} - I_r}{I_o}\right] \times 100\% \tag{7}$$

where,

$$I_r = r\, I_{aw} \tag{8}$$

Wind speed and ambient temperature are known to affect the performance of solar cooker. In fact some researchers prefer to discard data obtained if the wind speed or ambient temperature varies than that stipulated. So, to ensure reproducible result, authors recommend that these thermal tests be performed in laboratories with suitable simulators, rather than in open.

### 3.2. Stagnation temperature (theoretical, practical)

Stagnation temperature test is an important parameter, because it depicts the ability of a cooker to develop and retain maximum temperature, which in turn reflects on the quality of design and performance. This would enable the designer/manufacturer to use the right material to increase the performance of the cooker.

Many authors have recommend use of empty vessel to conduct such a test, or just the cooker without any vessels. Authors recommend use of a known weight of steel or a piece of metal (as Black body) for such a test. Final verdict on this aspect is left to the international experts.

The following equation enables calculation of Standardized Stagnation Temperature:

$$SST = \frac{700 \times (T_s - T_{wo})}{I_o} \tag{9}$$

Some researchers like Shaw [13], have suggested the insolation value at 850 W/m$^2$ as in above equation for standardizing the values, but as suggested in ASAE S580, 700 W/m$^2$ can also be used.

If the insulation of a box cookers is not of good quality, or if the green house enclosure of the panel cooker is too large in comparison to vessel/plate or if the reflector in a parabolic cooker is not of the right shape or quality, then it would get reflected in this test. For example, many inventors have developed square shaped parabola, or split parabola (as in Pappilion cooker) Kundapur [1]. Which design performs better? In other words, this test would ascertain the quality of manufacture, in terms of design and performance.

The value obtained through above test should be compared with the theoretical estimates made for the type of cooker using following Eqs. (10) and (11).

$$SST_t = \frac{700 \times (T_{st} - T_{wo})}{I_o} \tag{10}$$

where,

$$T_{st} = \sqrt[4]{\frac{7 \times 700}{\sigma}} \tag{11}$$

In the theoretical estimate of stagnation temperature we have assumed 7 kg as the test specimen weight for average theoretical insolation of 700 W/m$^2$.

### 3.3. Heat loss test

This test would substantiate the finding of Test 3.2. A known quantity of hot water at 800$^o$C is kept in the cooker (or Green house enclosure as the case may be) and loss of temperature is recorded till the water reaches say 40$^o$C. The result expressed as loss of $^o$C/min would form a good comparative parameter.

In parabolic type of cooker, this test may not make sense unless a ‘green house enclosure’ is used.

### 3.4. Standard cooking time or maximum load test

Maximum cooking load per batch should be specified by the designer or manufacturer of the cooker. When this is done it would be easier for the tester to load the unit with specified quantity of water to test the cooker. Some scientists have suggested loading only water. But the authors recommend use of actual food material along with adequate quantity of water, and recording the temperature reached as well as actual cooking time. Taste of food should also be ascertained, because, rice cooked, for example, in sub-substandard cooker would be taste rather bland compared to that cooked in a good quality cooker.

$$SC_t = \frac{m_w c_{pw} \Delta t}{\eta_0 A_{sc} I_{aw}} \tag{12}$$

In Eq. (12), $\eta_o$ is the optical heat transfer coefficient – a proportionality constant that combines several factors relevant to transfer of energy through optical materials of the cooker, like glass and material of the cooking vessel. Naturally this factor would be of greater importance to box and panel type cookers.

### 3.5. Test for heat storing components

Heat storing components/materials are going to be a part of the solar cooker of the future, because some amount of heat can be easily stored for at least warming the food in the evening. It then becomes essential for the scientists to suggest suitable materials and their heat storing capacities. Götz [14], of ULOG, has used molten tin for storing heat in Scheffler’s cooker. The tin melts during the day and stores heat for the night. Steel blocks also have been used and the heat stored is high enough to fry chapathi’s (rolled flat bread from wheat floor), during night. Schwarzer et al. [15] have used pebbles. Others have suggested oil Fraber [18]. Variety of materials has been used, but which is better, if not best, has to be ascertained. While doing so, the storing capacity of the enclosure/cooker has also to be estimated. Time factor as suggested in the test 3.4 can be used here and when the data obtained is tabulated, along with the cost per unit (like US$/kg), one gets an idea as to the best available heat storing material. Heat transfer coefficients can also be plotted along.

Most of the data obtained through these tests can be plotted. From such a data sheet, one could get easily get a clear picture as to the efficiency of different types of cookers.

### 3.6. Ray trace diagrams

Ray trace diagrams are not new in optical instruments, but rarely a mention has been made with reference to solar cookers. Such diagrams become essential for panel type and parabolic cookers of different designs. They would be more attractive and illustrative for the user (Fig. 1) (McCluney [17,18]).

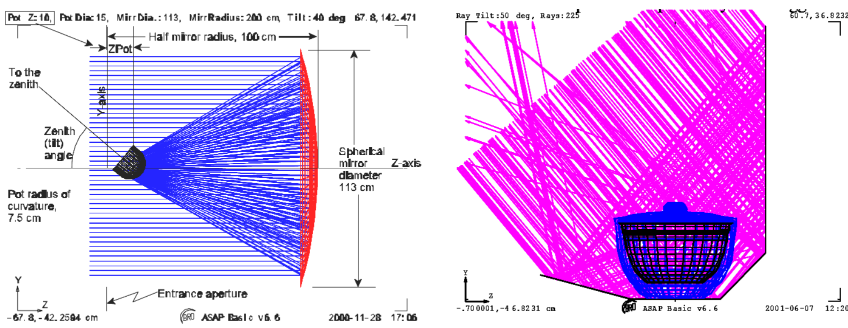
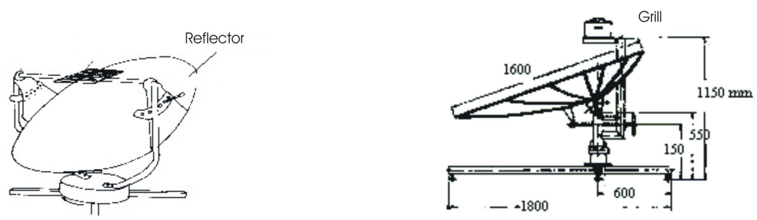



**Fig. 1. Sample of Ray Trace Diagrams**

Such diagrams could be made very effective if produced in Flash program, as is done by Pardeshi of India [14]. Florida Solar Energy Centre (FSEC) [11] has used this technique while trying to improve Panel cooker.

### 3.7. Ergonomics and ease of use

This is a user's prerogative and apart from the scientist or designer actively working on or designing the cooker, the user too should be actively consulted in this regard. For example, scientists who have conducted comparative test have expressed difficulties in using a Chinese Parabola and even regular Parabolic cooker like SK-14, but how does a common house holder feel about it? Chinese design was specially created to offset some of the difficulties encountered while using a regular parabolic cooker, but the Chinese design is not well known. But does Chinese design (Fig. 2) is advantageous to user? Some experiments conducted here indicate that Chinese design has many advantages, especially easy access to cooking vessel. The cooking vessel can be easily covered by a special 'green house' enclosure. Besides orientation of the cooker is also easy, but the design is a bit complicated and may be this is the reason why this design has not become popular even in China.




Parabolic cooker Chinese type Eccentric Parabola

**Fig. 2. Regular and Eccentric Parabolic Cookers.**

## Cost/watts

Before a calculation pertaining to Cost/watt is attempted it would be essential to calculate efficiency of a cooker and then estimate cost per watts delivered by the cooker in standard currency like Euro or US$. Simple comparison conducted by authors indicates that a panel cooker is far better to box type cooker on cost to watt basis.

## 3.8. User opinion

Many of the tests recommended, hardly give any scope for the user to record his/her opinion. A knowledgeable user has to be given a chance to express his opinion and suggest changes in the design. When this is done the development of cooker would be faster.

## 4. Conclusion

Summing up, there is an urgent need to evolve a set of universal standard tests to evaluate solar cookers and their components, and presentation of results in a manner understandable even to the common users.

## References

1. Kundapur Ashok (1988). Review of solar cooker designs. *TIDE*, 8(1) 1-37. (also http://www.solcooker.net).
2. Solar Cooker International, http://www.solarcooking.org.
3. Bowman, T.E.; and Blatt, J.H. (1978). *Solar cookers, history, design, fabrication, test and evaluation*, Florida Institute of Technology.
4. GATE (1979). Comparison between different systems of solar cookers, *German Appropriate Technology Exchange*.

5. Mullick, S.C.; Kandpal, T.C.; and Saxena, A.K. (1987). Thermal test procedure for box-type solar cooker. *Solar Energy*, 39(4), 353-360.
6. Patela Richard (2005). Exergy analysis of solar cylindrical parabolic cooker. *Solar Energy*, 79(3), 221-233.
7. Funk, P.A. (2000). Evaluating the international standard procedure for testing solar cookers and reporting performance. *Solar Energy*, 68(1) 1-7.
8. Nandwani, S.S.; Steinhart, J.; Henning, H.M.; Rommel, M.; and Wittwer, V. (1997). Experimental study of multipurpose solar hot box at Freiburg, Germany. *Renewable Energy,* 12(1), 1-20.
9. Mukaro, R.; and Tinarwo, D. (2008). Performance evaluation of a hot box reflector solar cooker using a microcontroller based measurement system. *International Journal of energy research*, 32(14), 1339-1348.
10. El-Sebaii, A.A.; and Ibrahim, A. (2005). Experimental testing of box type solar cooker using the standard procedure of cooking power. *Renewable Energy*, 30(12), 1861-1871.
11. FSEC (2002). *Solar oven testing and development project*, Florida Solar Energy Center, http://www.fesc.ucf.edu/solar/.
12. McMillan, C.; and Jones, S. (2001). Tests of the solar funnel and bowl cookers in 2001 (http://www.solarcooking.org/funneltest01.htm).
13. Shaw, S. (2002). *Development of a comparative framework for evaluating the performance of solar cooking devices*. Thesis submitted at Rensselaer Polytechnic Institute, USA, 2002 (http://www.solarcooker.org/ Evaluating-Solar-Cookers.doc).
14. Ravindra Pardesi (2003). http://www.angelfire.com/80s/shobhapardeshi/ ParvatiCooker.html.
15. Schwarzer K.; and Vieira da Silva, M.E. (2003). Solar cooking system with or without heat storage for families and institutions. *Solar Energy*, 75(1), 35-41.
16. McCluney, Ross, FSEC (2001). http://www.fsec.ucf.edu/en/research/solarthermal/ solar_cooker/documents/reflectordesignreport4.pdf
17. McCluney, Ross, FSEC (2001). http://www.fsec.ucf.edu/en/research/ solarthermal/solar_cooker/documents/analysisreport1.pdf.
18. Fraber E.A. et al., (1975). Heat Transfer aspect of solar powered cooking device with 24 hour Service. Proc. of 21 *Annual Technical Meeting*, Vol. 1.