

# The Water Boiling Test for Solar Cookers – WBT SC

Version 1.0.4 as per June 2016. It replaces version 1.0.3 of July 2014

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## Abstract

The solar cooker community has been moving together since the mid 1980s – the time when serious solar cooking devices were introduced to the world in a large variety. Albeit several test protocols exist already, a test which allows comparison and evaluation depending on the water boiling performance data at various specified locations has not been consolidated yet. The “Water Boiling Test for Solar Cookers” (WBT SC) closes the gap of uncertainty. It is designed to test the cooking abilities only, easy to understand and conduct. The WBT SC allows also the comparison with other cookstoves and even open fireplaces.

Keywords: Water Boiling Test, Solar Cooker

## Introduction

The following WBT SC takes all existing test protocols into consideration, compares and consolidates them, eliminates duplications, makes it easy to understand and to apply for everybody, and allows to run the test with a minimum of necessary devices. The entries and results can be used for comparison and evaluation purposes. Concerned persons and institutions can easily adapt the WBT SC and supplement single segments, if required. The authors will translate it to various languages, like French, German, Kiswaheli and Spanish, in the near future. Any help is appreciated.

Thanks to Prof. Ajay G. Chandak of Promoters, Researchers and Innovators in New and Clean Energy (PRINCE), director of International Solar Energy Society (ISES) and Prof. Wilson O. Ogola of the Technical University of Kenya for their patience and detailed communications and guidance.

Always remember: **Safety first!**

## Fixed and variable parameters

The WBT SC has a fixed parameter: the amount of water. This will be 1 liter for smaller or weaker solar cookers, and 2.5 liters for larger ones.

The variable parameters are

- a) location's latitude and altitude
- b) position of the sun
- c) type of cooker
- d) aperture area
- e) reflector material
- f) insulation, if any
- g) heat trapping material
- h) date and time
- i) initial water temperature
- j) local boiling point

To avoid confusions, the test should not be conducted if the sun is less than 30° above horizon (zenith angle more than 60°), and if the ambient and/or water temperature is less than 0°C (32°F).

The accessories to run the test are:

- a) a solar cooker, standing on a horizontal surface
- b) a blackened pot, with black lid
- c) a thermocouple or thermometer
- d) an appropriate amount of water
- e) a precision scale to weigh the water
- f) a ruler to measure the aperture area

In case it is undesirable to drill a hole for the temperature measuring device in the lid, any other blackened cover can be used instead.

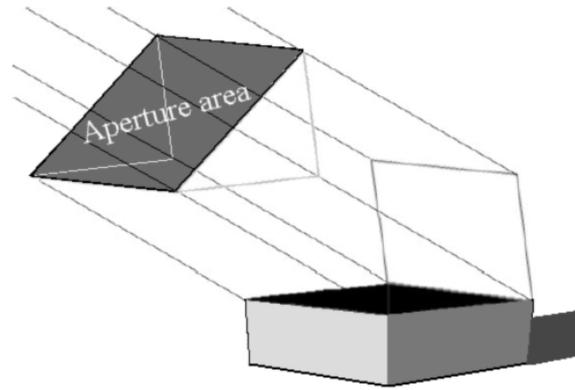
### The protocol and sequential procedures

1. Note location (name, coordinates, altitude), aperture (intercept) area and characteristics of the materials.
2. Fill 1 or 2.5 liters of water into the pot, put the lid on it and fix the thermometer 5cm (2 inches) above bottom of the pot. Note the initial water temperature.
3. Note time and position of the sun above horizon, place the pot onto the solar cooker's pot support. Note the ambient temperature.
4. Note water temperature in full °C every ten minutes.
5. Note, simultaneously, the tracking and/or positioning sequences of the cooker/reflector.
6. Note the time as soon as 65°C (149°F) is reached as an "intermediate result".
7. Note the time as soon as the water comes to a rolling boil.
8. Note position of the sun at the end of test.

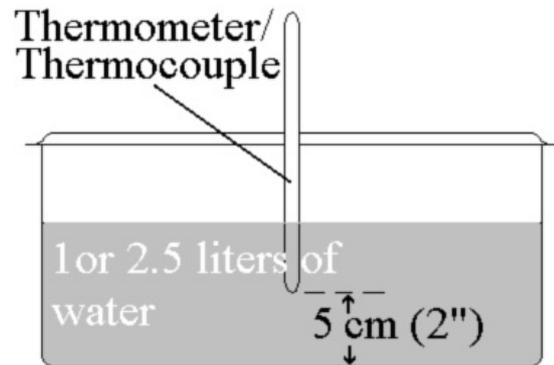
The test shall not be conducted earlier than two hours after sunrise and not later than two hours before sunset at clear sky. In contrary to the standard ASAE S-580 an insolation average of  $500\text{W/m}^2$  at clear sky has to be taken into consideration for calculation purposes, since the energy contents of the radiation cannot entirely be used for cooking purposes. This is valid especially in the case when the radiation has to interfuse a heat trap, such as a glass lid or container, a plastic oven bag, a polycarbonate pot skirt, etc.

Another deviation compared to the ASAE standards is the application of the position of the sun above horizon, instead of the zenith angle. The reason is, that the WBT SC claims a closer proximity to "normal" people and their everyday language. Also, when programs for smartphones and tablet PCs like "Sun Surveyor" and "Solar Track" are applied, you will find the position of the sun above horizon and not the zenith angle. The zenith angle is easy to obtain, though. Just subtract the sun's elevation angle from 90.

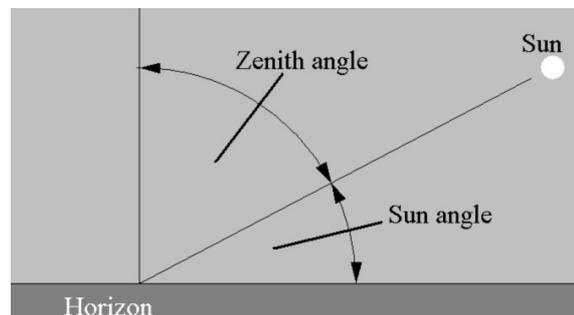
Further single explanations are extensively explained in the annex.



The above picture shows the aperture area of a box cooker.



The lower tip of the thermometer or thermocouple shall be mounted and fixed 5 cm (2 inches) above the bottom of the pot. (ASAE S-580: 1 cm above bottom).



The WBT SC requires the knowledge of the sun angle.

## Annex

### Explanations to test protocol's entries, in the sequence listed before:

1. Location and coordinates are necessary to compare with locations on the same latitude. The altitude is essential to identify the local boiling point, as water boils faster, the higher the altitude is. As a rule of thumb please note that every 300 meters (984 feet) the boiling temperature decreases by 1°C. The aperture (intercept) area shall be measured with a ruler, placed perpendicular to the sun rays.
2. The tip of the thermocouple or thermometer must be 5cm (2 inches) above the bottom of the pot to verify the average water temperature. A clothespin is an easy-to-apply tool to fix the measuring device.
3. Date, time and elevation angle of the sun above horizon allow inferences to the atmospheric mass. Thus, the insolation can be calculated easier. The ambient temperature has influence on the cooking time.
4. The thermometer/thermocouple shall remain 5cm (2 inches) above the bottom of the pot throughout the test.
5. The tracking sequence allows inference to attendance sequences once the solar cooker is in regular use. This should be mentioned in the box "Observations" of the work sheet.
6. The notation of the elapsed time to reach 65°C (149°F) shows the time to pasteurize water. Water pasteurization is one of the most important applications of solar cookers.
7. The test is completed once the water comes to 5°C below local boiling point. Depending on the altitude, this will be 95°C (203°F) or less.
8. The average sun angle above horizon can be calculated easily once the position of the sun at the end of test is noted.

Box cookers shall be pre-heated to a temperature of 80°C. In case the test must be interrupted, the obtained final water temperature and time shall be noted.

The compilation of the WBT SC is an easy-to-understand and easy-to-conduct excerpt of various previous test protocols:

- a) Indian Standard IS 13429, 1992, as displayed by H. P. Garg in his paper "Solar cooking technology and promotional programme in India", presented at the second world conference on solar cookers, Heredia, Costa Rica, July 12-15, 1994.
- b) Solar cooker tests of the European Committee of Solar Cooker Research (ECSCR) to evaluate cookers for a co-operative project of the South African department of minerals and energy with the German semi-governmental organization gtz (now: GIZ). The tests were conducted in Almeria, Spain in the years 1991 and 1994. Source: Grupp, M. et al., Solarkocher in Entwicklungsländern (Solar cookers in developing countries), gtz, Eschborn, 1999, <http://www.giz.de>
- c) ASAE standards S 580 and S-580.1, American Society of Agricultural and Biological Engineers (ASABE), <http://www.asabe.org>
- d) Chandak, A. G., Solar concentrating cookers, test protocol: 4<sup>th</sup> draft dated July 5<sup>th</sup>, 2010.
- e) Chandak, A. G., Solar cookers other than concentrating cookers, test protocol dated July 5<sup>th</sup>, 2010.
- f) Evaluation of Solar Cookers, VITA report no. 10, Office of technical services, US department of commerce, Washington, DC, USA.<sup>1</sup>
- g) The Water Boiling Test (WBT) Version 4.2.3, Cookstove Emissions and Efficiency in a Controlled Laboratory Setting, US Environmental Protection Agency (US EPA). <http://www.cleancookstoves.org>

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<sup>1</sup> The VITA solar cooker evaluation was conducted in the early 1960s, but published several years delayed in 1971.

### Units and conversions

For worldwide application, the WBT SC is set up in metric units. To obtain Anglo-american units for private purposes please apply the following conversions:

1 inch = 2.54cm = 25.4mm

1 foot = 30,48cm = 304.8mm = 0.3048m

1 ounce = 28.349523g = 0.02835kg

1 pound = 0.45359237kg

1 BTU = 1,055.0559J = 1.055kJ = 252cal

°F = (°C \* 1.8) + 32

°C = (°F - 32) / 1.8

Specific heat capacity of water is determined as 4.1868kJ(kg · K), which equates to 1 kcal. Due to conversion disparities the US National Bureau of Standards displays it 4.1833. Since the specific heat capacity varies by temperature, this little difference can be neglected.

To heat water, the formula

$$Q = c * m * \Delta t$$

shall be applied. Q stands for the energy to be provided, c = specific heat capacity, m = mass (in g or kg),  $\Delta t$  is the temperature difference in °C. Please feel free to replace  $\Delta t$  by  $(T_2 - T_1)$ , where  $T_1$  is the initial temperature and  $T_2$  shows the final temperature.

To keep the WBTSC simple for everybody's application, energy calculations are not included intentionally. These are, for example, heat losses, efficiency, etc. If required, please ask the authors for extensions or add-ons.

**Intentionally, the WBT SC has an optional amount of 2.5 liters of water, corresponding to the WBT 4.2.3. It enables you to compare the performance of a solar cooker directly with a cook stove, such as a rocket stove, a micro gasifier or even with an open three stones fire**

### The authors

Bernhard S. Mueller owned the solar cookers manufacturer “Mueller Solartechnik” from 1996 until 2012 and is a writer of books, brochures and articles on poverty-oriented energy solutions<sup>2</sup>. He is founding member of SCInet, member of EG-Solar and ISES and was member of the American Society of Agricultural and Biological Engineers (ASABE) until 2012. Presently he is a member of the German NGO Lernen-Helfen-Leben (LHL).

Faustine L. Odaba is engaged in solar cooker matters since 1990. She was a key person in the dissemination of solar cookers to refugee camps in Kenya and neighboring countries. Ms. Odaba is founder and CEO of the Kenyan NGO “NAREWAMA” with the major tasks to disseminate solar cookers, hay baskets and other environment and money saving items to low-income persons and families. She was honored in 2010 as first non-US citizen with the “Order of Excellence” of Solar Cookers International (SCI).

Both authors work closely together on various social programs in Kenya and surrounding countries. Bernhard Mueller coordinates NAREWAMA's activities in Europe.

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<sup>2</sup> Mueller, B. S., Das Solarkocher-Handbuch, 240 pages, German, ISBN 978-3-8442-4471-7, epubli GmbH, Berlin