The Water Boiling Test for Solar Cookers – WBT SC

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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 patiency 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, mainly the latitude
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 (depending on the altitude of test site)

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.

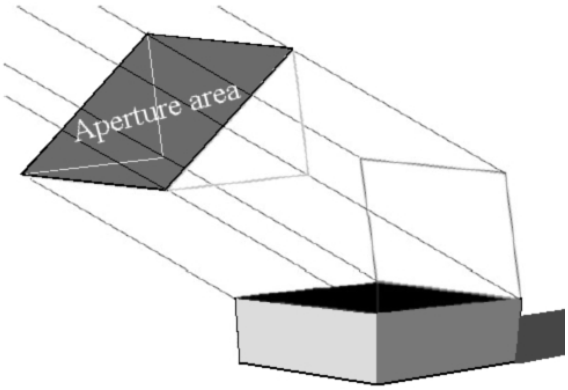
The protocol and sequential procedures

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.

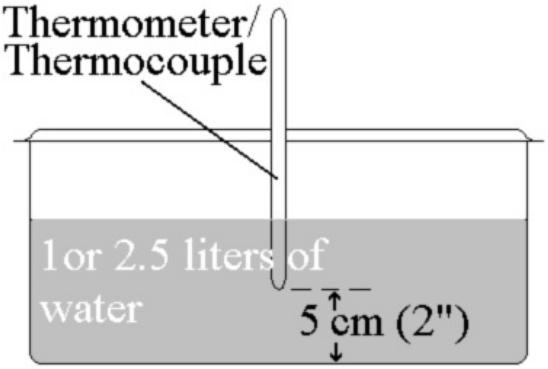
The test shall not be conducted earlier than two hours after sunrise and not later than two hours before sunset at clear sky. In contrary to the standard ASAE S-580 an insolation average of 500W/m^2 at clear sky has to be taken into consideration for calculation purposes, since the energy contents of 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.

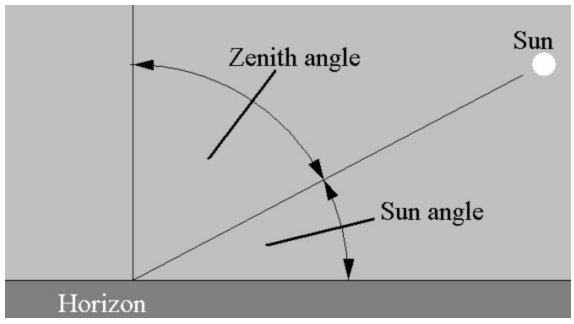
Further single explanations are extensively explained in Annex II of this paper. You will find a sample spreadsheet in Annex I.



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.



The WBT SC requires the knowledge of the sun angle.

Annex I: Form suggestion to conduct the WBT SC

WBT SC - Water Boiling Test for Solar Cookers

v. 1.0.3.

Amount of Water to be boiled (one or 2.5 liters)		Initial water temp. (°C)		Ambient temp. (°C)	

Type of cooker (box, panel, concentrator, hybrid, etc.)	

Position of the sun at the beginning of the test in degrees above horizon	
Position of the sun at the end of the test in degrees above horizon	

Test Location Name and Country	Altitude in meters	Location, coordinates Latitude	Longitude	Date dd/mm/yyyy

Reflector material (aluminum foil, glass mirror, etc.) *)		Aperture area
Insulation material (box cookers only) *)		
Heat trapping material (plastic oven bag, glass, etc.) *)		

*) if any

Local time	elapsed time (hrs., min.)	Temp. °C
	00:00	
	00:10	
	00:20	
	00:30	
	00:40	
	00:50	
	01:00	
	01:10	
	01:20	
	01:30	
	01:40	
	01:50	
	02:00	
	02:10	
	02:20	
	02:30	

Please enter the elapsed time to 65° water temperature	
	minutes

Optional	For more precise calculations, please enter the weight of pot and lid.

Optional	Check mark material of pot and lid	
		Aluminum or alloy
		Iron
		Copper
		Other

Observations

Test protocol designed by Bernhard S. Mueller and Faustine Odaba

Annex II

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, as 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 field "Observations".
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 a rolling boil. Depending on the altitude, this can be lower than 100°C (212°F). See point 1. as well.
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: 4th draft dated July 5th, 2010.

e) Chandak, A. G., Solar cookers other than concentrating cookers, test protocol dated July 5th, 2010.

f) Evaluation of Solar Cookers, VITA report no. 10, Office of technical services, US department of commerce, Washington, DC, USA.[1]

g) The Water Boiling Test (WBT) Version 4.2.2, Cookstove Emissions and Efficiency in a Controlled Laboratory Setting. US Environmental Protection Agency, Partnership for Clean Indoor Air (PCIA), Global Alliance for Clean Cookstoves (GACC), Aprovecho Research Center (ARC). http://www.aprovecho.org

[1] 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 your private purposes please apply the following formulas:

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), Δt is the temperature difference in °C. Please feel free to replace Δt by $(T_2 – T_1)$, where T_1 is the initial temperature and T_2 shows the final temperature.

If you want to be even more precise, please feel free to include the pot and lid in your own calculations and apply the above formula. For this purpose please note the following specific heat capacities:

Aluminum and aluminum alloys: 0.896
Iron: 0.452
Copper and copper alloys: 0.382

(again, just to remember; Water: 4.1868)

Intentionally, this WBT SC has an optional amount of 2.5 liters of water, to respond to the WBT 4.2.2 of PCIA/GACC/ARC. 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 presently a writer of books, brochures and articles on poverty-oriented energy solutions[2]. 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.

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.

[2] Mueller, B. S., Das Solarkocher-Handbuch, 240 pages, German, ISBN 978-3-8442-4471-7, epubli GmbH, Berlin