Guidelines for Testing Charcoal Stoves with WBT 4.2.2
June 14, 2013

The following guidelines are intended to improve repeatability and reduce variability both from test to test and from site to site. The WBT 4.2.2 protocol, supplemented by these guidelines, should be followed for those tests where the results are intended to be consistent with what would be obtained at other testing centers around the world following this same protocol.

Alternatively, other local or regional protocols may be followed for those tests where the intention is to yield results consistent with historical or local custom.

I. PREPARING FOR TESTING

A. POT SELECTION:

- The following water volumes are recommended for the WBT: 2.5L, 5L, 7.5L, or 10L. Select the Test-Water-Volume according to instructions of the stove-producer (written instructions) or the intended use in target households (local custom of food volume to be prepared).
- Select pot for test according to the following criteria:
    - Pot size should be big enough to accommodate the selected Test-Water-Volume, but not so big that it would accommodate the next larger Test-Water-Volume (e.g. if 5L is selected, it should not accommodate 7.5L as well);
    - Cooking pots used for testing should be commonly used in practice with the stove (size, material etc.);
- For the same stove, larger pots will typically yield higher efficiency numbers and better ISO IWA emissions metrics, but at a cost of time to boil. It is recommended to use the largest pot possible that will still boil water in less than 40 min (from pot on to boiling).

B. FUEL SELECTION:

- Establish a consistent source of wood based lump charcoal, from one wood species and from one charcoal supplier, if possible.
- Fuel should be, as much as possible, homogenous and fully converted to charcoal (carbonized). Avoid any charcoal that still has a brown or woody appearance, compared with normal. Avoid using dirty charcoal, which may contain sand, grit, debris, etc.
- Use size recommended by the stove manufacturer. In absence of recommendation, screen the fuel, using a 2" square (5cm) screen and 1" square (2.5cm) screen as the upper and lower charcoal size limits.
- It is recommended to measure charcoal energy content and proximate analysis (fixed carbon, percent volatiles, ash content and moisture) using standard protocols [1] as often as

[1] Examples of protocols for fuel analysis include DIN EN 1860-2; Fuel moisture content: ASTM D4442-07 (for wood), ASTM D2961, D3302, D3173 (for coal); Fuel heat of combustion (energy content): ASTM D5865-10; Ash in coal: ASTM D3174; Proximate analysis of coal: ASTM D3172; Ultimate analysis of coal: ASTM D3176, D5373.

is practical for your organization. The fuel properties shall be noted in the documentation of the test.

II. CHARCOAL STOVE TEST PROTOCOL

A. LOADING THE STOVE:

- If available, load charcoal to the volume specified in the manufacturer's instructions which are distributed with the stove.
- If no instructions are available, then fill to the volume of the combustion chamber,
- OR, for stoves which are not normally filled completely, load charcoal per the local custom.
- If local custom is followed for loading the stove, the procedures should be researched and clearly documented by the local or regional testing center.

B. LIGHTING PROCEDURE:

- It is recommended to top light using kerosene as starter or lighting fuel, to have consistent lighting procedures within the testing center.
    - The amount of starter may be up to 5% by weight of the weight of charcoal used in the test charge. The density of kerosene at 20°C is 0.81 g/mL, which can be used to calculate the volume, if measuring kerosene by volume.
    - Add the kerosene slowly & evenly to allow time for the liquid to soak into charcoal.
- Light time may be determined by flame out, or by 5% loss of charcoal weight.
- The lighting time is normally 4 – 6 minutes.
- At the (declared) end of the lighting phase (with pot off), the weight of the stove (including fuel) is measured before the cooking pot is placed on the stove.
- Solid lighting fuel and/or lighting from the bottom may be used if recommended by stove manufacturer or depending on local customs. If solid lighting fuel or lighting from the bottom is used, the lighting procedure has to be documented, including the weight of the lighting fuel. It is desirable to know the energy content of the starting fuel.
- Fanning, or the use of accessories (for example, draft-inducing chimneys), during the lighting time is permissible if
    - it is part of the manufacturer's established and written instructions which are distributed with the stove

    OR
    - is the normal custom for the stove (for example, if fanning is used to increase the speed of lighting),

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See also Jenkins BM, Baxter LL, Miles TR Jr., Miles TR. (1998). Combustion properties of biomass. *Fuel Processing Technology*, 54, 17-46.

C. ADDITIONAL FACTORS:

LID:

- A conventional and well-fitting lid (preferably the one which is sold with the pot) OR a floating closed cell foam insulator should be used to reduce the variability associated with operating with no lid on the pot.
- For the monitoring of water temperature in the pot, the lid should have a hole to accommodate the sensor.

DOOR OR DAMPER OPERATION:

- Operate the door or damper per manufacturer's instruction (if available).
- If manufacturer's instructions are not available, position the door or damper wide open during lighting and high power phase and close the door as soon as boiling is reached.
- Keep the door or damper closed during low fire / simmer, unless simmer cannot be maintained with the door closed, in which case, open the door just enough to maintain temperature through the simmer phase.
- Note that stoves without doors (e.g. many traditional charcoal stoves) may be operated as in the high power phase (unchanged), if that is the local practice. Regulating firepower by removal of charcoal is permissible if it is well-documented.

NOTE ABOUT POSSIBLE CHANGES IN WEIGHT OF STOVE:

- The stove and fuel may be weighed together to obtain a measurement of remaining fuel between test phases, but caution is advised, because the weight of the stove may change during operation due to moisture being driven off by heat. The change in weight can be significant, particularly for some ceramic materials and for mud. If the combined weight of the stove and fuel is measured, the "empty" weight of the stove must be carefully determined. The stove may be operated before testing to drive off moisture, and the weight without moisture can be obtained, but the stove may reabsorb moisture before the test begins.
- If there is a significant change in stove weight between the start and end of the test (more than 5 g), use the measured weight of the empty stove at the end of the test. It is also important to account for the ash remaining in the stove, because charcoal tends to have higher ash content than wood fuel.

D. CALCULATIONS:

- CO and Particulate emissions from the lighting phase are included as part of the high power test results.
- Charcoal consumed during the lighting phase is included in the total charcoal used for determining high power efficiency.
- The lighting fuel (kerosene) is not included in the energy efficiency calculation.

III. OPTIONAL TEST PROCEDURES:

A. OPTIONAL OVERLOAD TEST(S):

- Reload the stove with 25% more fuel by average weight of the batch used for the standard test (see section "Loading the stove").
- If the stove cannot physically accept 25% additional fuel without lifting the pot above the pot supports, reduce the loading to the maximum that will physically fit into the stove with the pot still resting on the pot supports.
- Conduct 3 or more tests at this condition and record performance separately.

B. OPTIONAL MINIMUM LOAD TEST(S):

- Load the stove with the minimum amount of charcoal to complete the cooking task. This amount will need to be determined before these optional tests are conducted.
- Conduct 3 or more tests at this condition and record performance separately.

C. OPTIONAL HOT START:

- There is value in determining the impact of adding charcoal to hot coals on emissions and efficiency. For this reason, a hot start or other regulated addition of charcoal may be included in later guidelines. Following is a suggested procedure.
  - At the end of the cold-start phase of the WBT, remove the pot and weigh the stove and fuel together (without disturbing the hot charcoal).
  - Add additional charcoal to the stove so the total mass of charcoal is similar to the mass used at the beginning of the cold-start phase.
  - Weigh the stove and fuel together just before beginning the hot-start phase.
  - Place the pot (with water at ambient temperature) on the stove, and complete the hot-start phase.

IV. Areas For Future Study

It is recommended that parametric tests and research be conducted in order to better understand the effect of the following on stove performance during the WBT:

- Selection of pot material, standardized or based on local practices
- Height/diameter ratio of pot
- Amount of water used, particularly during simmering phase
- Fanning and other draft enhancing practices/technologies (e.g. chimneys placed on the char) during starting
- Amount of fire starter, including limits or as a fraction of amount of charcoal
- Type of fire starter, including solid starting materials or a combination of liquid and solid fuels (e.g. solid fuels oaked in kerosene)
- Emissions during the lighting phase, hot start, and cold start phases
- Emissions after the simmer phase is completed (run down of stove)
- More appropriate "drive" or "burn" cycles
- Loading and removal of char within a cooking process as part of the heat management of a charcoal stove. What is the impact on fuel consumption, emissions, and variability of results? How relevant/widespread is this practice? If relevant: How can it be simulated in the test? If charcoal loading and removal is common local practice to control fire power, investigate and document this practice in more depth and provide more specification in these guidelines. Lighting procedure, including top lighting, and evaluating different procedures for bottom lighting
- Impact of the use of floating closed cell foam on the results compared with the use of a well-fitting lid

The following supportive work is also recommended:

- Develop a standard reporting sheet, comparable to the WBT 4.2.2 spreadsheet, which includes starting phase, heating phase and simmering phase separately. For some values, starting and heating phase are summarized.
- Investigate feasible options for measuring emissions from lighting phase separately from heating phase, including the need to change filters or to have two sets of filter sampling equipment
- Addition of starter energy in the energy efficiency calculation
- Determine the lab equipment required and the difficulties associated with testing for proximate analysis and ultimate analysis
- Research how to most easily and reliably determine the extent of carbonization of the charcoal (specific density, etc)
- Characterize by proximate, ultimate and heating value analysis, the residual charcoal left over after the WBT
- Energy efficiency (useful energy over total energy provided, including lighting) is distinct from heat transfer efficiency (useful energy over energy provided when the pot is on). Given that most results include data needed for both calculation, investigate differences in

energy efficiency and heat transfer efficiency, how to incorporate improve procedures. Also consider discarded charcoal

- Calculation of the heat transfer efficiency during high power phase (not including energy used during lighting phase)
- Develop a standard “reference fuel”

All who attended the last review at the GACC 2013 Forum in Phnom Penh, Cambodia on Friday March 22, 2013 were in agreement with the Draft upon which these Final guidelines are based. Participants were:

Name	**Affiliation**
Christian L'Orange	Colorado State University
Christa Roth	Food & Fuel - Malawi
Christoph Messinger	GIZ - Benin
Wim Getkate	CREEC
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Others who participated in the development of these guidelines at Phnom Penh but who were not at the meeting on Friday March 22nd included:

Name	**Affiliation**
Dean Still	Aprovecho
Sanya Detweiler	Aprovecho
Elisha Moore-Delate	Improved Cooking Technology Program
Peter Scott	Burn Manufacturing

After the Forum in Phnom Penh, written comments were received from:

Name	**Affiliation**
Aprovecho Research Center	
Centre for Research in Energy and Energy Conservation	
Jim Jetter	US EPA
Crispin Pemberton-Pigott	New Dawn Engineering
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Final review panel:

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