Cooking Stove Test Methods

Sustainable Energy Technology and Research Centre

University of Johannesburg

Lab Manual, Aug 2013

SeTAR SOP # 33.03.01

Based on the

UJ SeTAR CENTRE STANDARD OPERATING PROCEDURE

*Heterogeneous* *Testing Protocol 20.x*

Included in this document:

Heat Flux Rate SOP # 21.01.03

Water Heater Test SOP # 22.03

Cooking Stove Test SOP # 22.04

C Pemberton-Pigott

2013

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# GENERAL DISCUSSION

## Purpose of this set of Standard Operating Procedures

### This set of standard operating procedures provides the test methods that will be used in the Indonesian Clean Stove Initiative product evaluation. Technologies proposed by manufacturers and market aggregators will be screen on the basis of these tests and checked for compliance with the performance targets provided in Table 1 of the Operational Manual for the CSI.

### This document will:

### Follow the conceptual grounds for determining stove performance outlined in SeTAR document “20.0 Heterogeneous Test Protocol”

### Describe the testing of stove emissions and efficiencies

### Determine the output values for the selected metrics

### Detail certain control procedures for the replication of tests

### Use definitions as per SeTAR SOP 0.01 *Definitions of terms* and SOP 0.02 *Variables used in the HTP*

## Determining the culturally relevant performance parameters

### The performance a cook sees while using a stove is the rate of fuel consumption, the attention required to make it operate properly, the rate of heating and the controllability. Other factors include safety, smoke, time to ignite and get up to working temperature, risk of burns, cost, durability and the accommodation of different pots or a number of pots. The first assessment of technologies will be to check whether or not it has enough cooking power to meet the expectations of the target consumer group.

### The cooking power of a stove is not the firepower but the amount of heat that gets into the pot and the time it takes to provide it. Based on field evaluations of cooking performance, it has been determined that in the target communities the rate at which heat enters pots, considered to deliver an ‘adequate cooking performance’ is about 2 Watts per square centimeter of heated surface. This is the *Heat Flux Rate* and is denoted by the symbol Q’’. It is the number of Joules of heat energy gained by the pot per second per square centimeter, considering all losses. That is the minimum acceptable performance of a stove operating at high power. A cooking session using a system with a heat flux rate of 2 W/cm2 will boil 5 litres of water in under 25 minutes. Using SeTAR SOP 21.01.03 this measurement can be made in the field or the laboratory.

### It is important to note that the nominal heated surface are of a pot (the underside) is the basis for this calculation. The diameter of the pot used will be the largest that will achieve the target heat flux rate and this information should be provided by the manufacturer. Thus a stove might be of any size, but will still be expected to meet the performance expectations of the consumers which of course vary with stove size. At this time the heat flux rate is not a pre-requisite for promotion, it is an advisory threshold determined by observations of current practise.

### The use in the home of multiple fuels is common with many preferring to use LPG for cooking tasks however heating washing and bath water with LPG is considered expensive so wood is preferred. Because this is a specialised task that requires little attention a category of appliance has been created with very limited demands in terms of controllability or flexibility. Performance will be measured using SeTAR SOP 22.03. A quantity of water up to 10 litres is placed into a container, the stove is fuelled and ignited. There is no requirement for fuel beyond bringing the water to a boil. There is no need for attention. Several stove designs are well suited to this type of task. Because of the specialised nature of the device, the system’s energy efficiency requirement is high. The heat flux rate is recommended to be at least 2 W/cm2 as a lower rate will be considered ‘too slow’ by the average user. The emissions of CO and PM will be quantified are divided by the number of MegaJoules that are delivered into the pot (net) during the test. There are target values for emission reductions which affect the overall assessment.

### Cooking requirements are more demanding with a requirement to show that the power level can be maintained on high, at half power and at one-quarter power. The purpose of this it to demonstrate that the cooking power can be controlled at particular levels. A stove with little or no controllability is very likely to be rejected by consumers. The energy efficiency of the system and the thermal performance will be assessed using SeTAR SOP 22.04. Again, the heat flux rate will be assessed and it is recommended that it be greater than 2 W/cm2 for the reasons given above. The emissions of CO and PM will be quantified are divided by the number of MegaJoules that are delivered into the pot (net) during the test. There are target values for emission reductions which affect the performance rating.

## Important note regarding the consumption of fuel

## It is intended that three replications of any test will be made so as to calculate average performance values. These three will be analysed as a group, preceded by an identical test to generate the ‘fuel remaining’ to be put into the stove on for the first measured test.

## The fuel consumption of a biomass burning stove is defined as the need to provide new fuel drawn from a supply that is sourced outside the system in order to conduct any one of a series of identical replications of a burn cycle, save the first[[1]](#footnote-1).

## Most stoves do not completely combust all the fuel placed in them during a burn cycle. There is always some ‘fuel remaining’. This term means fuel in the form of unburned sticks, dry or torrefied wood and the char that remains after the completion of a burn cycle. Leftover fuel is to be used in the subsequent fire when possible. This is the common behaviour of people who cook: they conserve and re-use leftover fuel.

## Some stoves cannot burn some or all of the remaining fuel. The unburnable portion of fuel remaining is to be considered ‘consumed’ as far as that stove is concerned. Thus when calculating the thermal efficiency of the system, no matter what its energy content, only the portion of the fuel remaining that can be used in the next replication is considered ‘unburned’.

## If all the remaining fuel can be burned by the same stove in the next replication, all of it must be fed into the fire at some point during the next replication. That subsequent replication shall be considered the first of the three replications which are evaluated. All valid tests will start with the fuel remaining from a previous identical replication.

### There is an assumption here which is that the fuel remaining after each test will be about the same: in the same condition, the same sort of moisture level, the same total mass. The new fuel added to each replication is thus the only fuel that has to be assessed for heat and moisture content. Whatever new fuel has to be added to complete each replication is the raw fuel consumption for that burn cycle. The ‘As Received Heat Value’ (ARV) of that mass of new fuel is the energy consumption of the burn cycle. The heat received by the pot or pots divided by that raw fuel energy figure is the energy efficiency of the system as a whole and is the actual fuel consumption (if converted into a dry mass of fuel).

## Local practices regarding the fuel remaining vary so before making a comparative performance assessment, the practices that will prevail after the adoption of a new product should be assessed and reproduced during testing. It may be traditional to always let remaining coals burn out and dry tomorrow’s fuel. In that case a decision is required as to whether the stove should be evaluated on its own or in context. After sale, stoves are always used in a context.

## Metrics and their input values

### This Protocol uses pot mass, water mass and their specific heat capacities together with the change in temperature to calculate the *net heat gained*[[2]](#footnote-2), the *rate of* *heat gain[[3]](#footnote-3)* and the *heat flux rate[[4]](#footnote-4)* for a pot that does not boil, on a hot stove operating at high power.

### This Protocol uses the total heat content of the raw fuel consumed and the change in fuel mass to determine the g*ross energy consumption[[5]](#footnote-5)*, as well as the mechanical and chemical energy losses and the *net heat gained* by the pot to determine the *high power hot stove heat transfer efficiency*[[6]](#footnote-6)and the specific emissions of PM[[7]](#footnote-7) and CO[[8]](#footnote-8) per net MJ of energy delivered into a boiling a pot.

### This Protocol uses the total heat content of the raw fuel consumed and the change in fuel mass to determine the *gross energy consumption*, as well as the mechanical and chemical energy losses and the *net heat gained* by the pot to determine the *average* *heat transfer efficiency* and the *average system energy efficiency* when heating a potat different power levels.

## Measurements Interferences and their Minimisation

### Water vapour interferences.

### Water vapour from a boiling pot will dilute the flue gases thus compromising the results.[[9]](#footnote-9) If the emissions are being captured by a hood, any pot that will be brought to a boil should be used together with an appropriate lid that either seals well or which has sealant applied to the joint. This lid should be equipped with a vent pipe with an inside diameter not less than 10 mm. The inside portion should extend no more than 5 mm below the underside of the lid. This vent pipe can discharge steam outside any emissions capturing hood. By this means, steam and water vapour from the pot will be removed from the gas stream being analysed. Further, condensing water vapour creates droplets (fog) that is detected by light scattering particle detectors.

### The vent pipe must be bent in such a manner that condensate runs back to the pot or down into a condenser. In the latter case, the condenser can be placed on its own scale and the data captured to determine the evaporation of water in real time which is very useful. Measurements made while cooking tasks are performed with the lid off the pot will yield higher variability in the results and are biased toward under-reporting performance as removing the lid introduces heat losses that are difficult to measure or even estimate. In any case, the use of pot lids is an important part of efficient cooking practice and is practised by many different cultures. Without a lid low power is not really achieved during ‘simmering’. (Ahuja et al., 1987).

### Draft interferences

### Any drafts across the test site are likely to interfere with measurements though the effect varies from stove to stove. A draft may introduce excess air in the vicinity of the stove, and it may affect the thermal and emissions performance of the stove. Tests should be conducted either in an enclosed area shielded by wind impermeable screens. The use of an enclosed ventilation cabinet open on one side connected to an exhaust fan can unfortunately introduce significant errors because there a permanent cross-draft induced by the exhaust fan bringing air against one side of the stove. Unlidded pots further distort measurements made in such conditions. The exhaust fan connected to a hood or cabinet should not be run faster than is needed to capture the emissions.

### Scale resolution

### Because the HTP uses a mass based, chemically balance analysis method, the resolution of the scale can negatively affect the precision of the results if there is a combination of a low burn rate, a high calorific value fuel and a low precision scale. The issue is the detection of the number of Joules of heat released per reading period. If the read frequency is once per 60 seconds, the scale should have a precision of 1/10th of the change in mass per minute. For example:

### Power: 1000 Watts; Fuel: Kerosene, heat content 44,000 J/gram

### Burn rate = (60 seconds \* 1000 Watts)/ 44,000 Joules = 1.36 g/minute

### 1/10th x 1.36 = .136 so a 0.1 gram scale would be adequate and a 1 gram would not.

### Power: 10,000 Watts; Fuel: dame wood, heat content 14,500 J/gram

### Burn rate = (60 seconds \* 1000 Watts)/ 14,500 Joules = 41.38 g/minute

### 1/10th x 41.38 = 4.14 so a 2 gram resolution scale would be adequate and a 5 gram would not.

### 

### Ranges and Typical Values of Measurements

### Stoves vary in weight from 1 kg to more than 250 kg. It is wise to have scales to cover this range.

### For gas detection, a typical combustion analysis kit will cover 25% O2, 20% CO2, 2000 ppm NO and some level of NOx. It is important to get as high a range of CO as possible as values in excess of 30,000 ppm are attained with a poor stove.

### The temperature ranges to be covered are usually less than 1000°C so K-band thermocouples are adequate. The reading precision for water temperature thermocouples should be ±0.1°C.

### Typical Lower Quantifiable Limits, Precision and Accuracy

### (Not applicable)

### Personal Responsibilities

### All technicians in the laboratory carrying out this procedure are responsible for carefully reading and understanding the entire operating procedure before performing the tasks. They are also responsible for cleaning and adjusting the source sampling system, the gas analyser, changing filters, uninstalling equipment once testing is complete, cleaning, maintenance and the recalibration of instruments. The technicians are in addition responsible for retrieving, naming and archiving the data sets. The Laboratory manager is responsible for ensuring that the procedures are properly followed and to deliver the samples for shipping or for testing in the laboratory within the specified time period.

### Definitions

### No terms used in this procedure require definitions that are not covered in the document

### SeTAR 0.01 Definitions of terms

## Normative References used in this SOP 33.03

## SOPs relevant to these stove testing protocols are:

* + SeTAR 0.01 Definitions of terms
  + SeTAR 0.02 Variables used in the HTP
  + SeTAR 1.01 Mass measurements made using an electronic balance
  + SeTAR 2.01 Gas measurements made using a gas analyser
  + SeTAR 3.01 Temperature measurements made using a thermocouple
  + SeTAR 4.01 PM measurements made using a light scattering instrument
  + SeTAR 20.0 Test philosophy
  + SeTAR 21.01.03 Heat flux rate
  + SeTAR 22.03 Water Heater Test, high power, boiling
  + SeTAR 22.04 Cooking Stove Test, multi-power, non-boiling
  + SeTAR 23.01 Data archiving
  + SeTAR 23.02 HTP spreadsheet entry
  + SeTAR 29.01 Test report structure

## Apparatus, Instrumentation, Reagents And Forms

### Apparatus and Instrumentation

### For a detailed list of all equipment please refer to SeTAR 22.02.1 *Laboratory Equipment List*

### The set of procedures in this Protocol requires the following equipment

* A scale for the stove with serial port reading capability and suitable resolution with a heat resistant pad to protect it from the fire.
* A scale for weighing fuel, pots, water, insulating materials etc.
* A gas collection hood with chimney, optionally fitted with a controllable exhaust fan
* A diluter connected to the hood (or chimneys) for smoke sampling that uses dried air as a dilutant
* A compressor to supply dilution air
* Two gas cooling (conditioning) devices for dehydrating the gas samples
* Two gas sample pumps rated at 90 litres per hour
* A control panel capable of monitoring the volume of dry air entering the diluter, monitoring the temperature
* A computer with which to collect, store and analyse test data
* A thermocouple logger adequate to record the temperature of: the ambient air, the exhaust gas where they leave the room, the water in each pot, and other place of interest
* A gas analyser for measuring O2, CO and CO2 plus any other gas of interest
* A gas analyser or a separate channel in the first analyser for measuring, in the dilution tunnel, a CO2 concentration of at least 5%
* A particle counter capable of measuring not less than 150 milligrams per cubic metre
* At least two standard pots, large and small, a 2:1 ratio of the area of the bottom surface. Some stoves requires a specific pot in order to function properly. A stove may have a recommended maximum size for its rated performance level in which case that size should be used, plus small ones if a multi-pot-size test has been requested. Some stoves can cook, or require, more than one pot to function properly.
* Heat resistant gloves, tongs, gas mask for smoky stoves

## Instrument Characterisation

Not required.

## Maintenance

Refer to the instruction manual for each device for the relevant information.

## Spare Parts

Not required during the test.

## Water

Enough water should be available before carrying out the tests. There should be at least 15 litres of clean water present. A typical efficiency test at multiple power levels may require 50 litres of cool water. In areas where water is scarce the water can be cooled and re-used in sub-sequent tests.

## Reagents

Not applicable

## Calibration Gases

Gases used for calibration and the calibration protocols are not covered in this document.

## Forms and Paper Work

### Fuels

All fuel samples are logged into the FUEL DATA booklet upon receipt at the laboratory. Select a suitable quantity of fuel for the test and keep a representative sample aside. Weigh the sample(s) to 0.1 g precision and mark them. Send them to be tested for moisture content. Prepare the rest appropriately if necessary.

### Stoves

All stoves received at the Centre are recorded in the stoves logbook and should be fired at least once before testing to evaporate any moisture retained by ceramic components.

### Test Information

### The data to be noted about each test is shown on the table below. Sample data is entered.

|  |  |  |  |
| --- | --- | --- | --- |
| General | | | |
| Physical location where the test was conducted | SeTAR Centre UJ | | |
| Test Number | SeTAR\_541 | | |
| Test date | 30-Jul-13 | | |
| Test Time | 12:01:00 PM | | |
| Pot On | Yes | | |
| Test Administrator | Taffy, Thoko | | |
| Test Description | Batch Burn, Emissions, Particulates and Efficiency | | |
| Test Analysis performed by | C Pemberton-Pigott | | |
|  |  | | |
| Testing Environment | | | |
| Ambient Temp in the testing room | 13 | | |
| Local water boiling point, Deg | 94.60 | | |
| Oxygen % | 20.94 | | |
| CO2 % | 0.039 | | |
| CO ppm | 1 | | |
| Relative Humidity | 51% | | |
| Stack Rel. Humidity | 56% | | |
| Ambient PM 2.5 reading at the start of testing | 8 µg/m3 | | |
| Ambient PM 2.5 reading at the end of testing | 9 µg/m3 | | |
|  | | | |
| Stove Description | | | |
| Stove Manufacturer: | Local | | |
| Model: | Stove 1 | | |
| Stove Type (Cooking, Space Heating etc.) | Cooking | | |
| Chimney (Yes/No) | Yes | | |
| Description | Stick-fed wood all-metal stove | | |
| Dimensions, L, W, H | 350 | | |
| Vertical height from base to the flat top surface | 360 | | |
| Chimney Description |  | | |
| Description | Ungalvanised steel tube | | |
| Total vertical height | 3.1 M | | |
| Total length of the gas path | 3.72 M | | |
| Length from stove to roofline at 7~ | 1.95 M | | |
| Length from roofline to top | 1.15 M | | |
| Diameter, mm | 90 mm | | |
|  | | | |
| Fuel | | | |
| Type of Fuel | Wattle | | |
| Average moisture content | 11.50 | | |
| As Received (AR) heat content of fuel | 15.08 | | |
| Average diameter mm | 25 | | |
| Average length mm | 220 | | |
| Fuel added during the initial burn, g | 1100 | | |
| Fuel added during refuelling, g | 0 | | |
| Percentage of fuel that should be burned during the test | 90 | | |
| Char Remaining at the end (wood fires) | 90 | | |
|  | | | |
| Cooking Performance Test | Pot 1 | Pot 2 | Pot 3 | Pot 4 |
| Pot used: Maker | Hart | Hart | Hart | Hart |
| Pot material (ignore handle material if it differs) | Aluminum | Aluminum | Aluminum | Aluminum |
| Name given in the Laboratory | Large | Large | Large | Large |
| Diameter | 254 | 254 | 254 | 155 |
| Depth | 145 | 145 | 145 | 90 |
| Pot Mass, empty without lid | 684 | 684 | 684 | 170 |
| Lid mass | 192 | 192 | 192 | 65 |
| Water Mass | 5000 | 5000 | 5000 | 800 |
| Water Heating Function (Low Pressure Boilers etc) | Material | Specific Heat, Cp | Mass |  |
| Working Fluid | Water | 4.186 |  |  |
| Cooking Deck 1 | Aluminum | 0.897 |  |  |
| Cooking Deck 2 | Aluminum | 0.897 |  |  |
| Cooking Deck 3 | Aluminum | 0.897 |  |  |

# Heat Flux Rate, a cooking power test with procedures for determining the *net heat gained Q*, the *rate of* *heat gain Q’* and the *heat flux rate Q’’* for a pot that does not boil, on a hot stove operating at high power.

## This procedure can, if desired, be conducted at the same time as some other procedures such as those which determine the *Net Firepower* and *System Energy Efficiency*.

## General Flow Diagram

## Experimental procedure

### It is incumbent on the laboratory technicians to create their own check list for the equipment they have available.

### Weigh two identical empty pots and lids and record their masses on the data sheet.

### Determine the material from which the pots are made and their specific heat capacity *Cp*. Calculate a mass of water equivalent to the total heat capacity of each as follows:

### (Pot *Cp* x Pot mass + Lid *Cp* x Lid Mass) = *grams of water equivalent* [1]

### *Cp* of Water

### Fill each pot to 80% capacity and record the mass of water added. The mass added to each pot should be the same. The water temperature should be below 30°C.

### Add the *grams of water equivalent[[10]](#footnote-10)* of the pot and lid material to the mass of water in the pot to get the initial water mass equivalent of the pot, lid and contents.

### Water mass + *grams of water equivalent* of the pot and lid

### = Initial water mass equivalent *MWi* [2]

### Prepare to measure the temperature of the water by placing a plastic frame holding a thermocouple 50 mm above the bottom of the pot approximately 1/6th of its diameter away from the pot centre.

### If the temperature is being automatically recorded, start the logger. If recording manually write the time and temperature in the logbook at regular intervals such as once per minute. Automatic recording is typically done once per 10 seconds.

### Heat the pot by any means, for example using a cooking stove. Continue to record the temperature of the water in the pot.

### When the temperature reaches 70°C it can be reasonable expected that no water will have evaporated from the pot at this temperature. The data collected to this point is useful but is not the first interest in this experiment.

### Remove the first pot and place the second pot on the stove and immediately begin recording the temperature. By this time the stove should be at operating temperature and the firepower at its steady maximum level. The *net heat gained*, *rate of heat gain* and *heat flux rate* will be determined using this second pot.

### Continue heating and recording. When the temperature in the second pot reaches 70°C the experiment is over.

### Locate the data sets that were recorded after the time when the water temperature reached 30°C. Calculate for each time interval thereafter the *net heat gained.*

### Calculate the *net heat gained* per measurement interval by applying the formula:

### (Final temperature *Tf* – Initial temperature *Ti*) x Initial water mass equivalent *MWi* x the *Cp* of water *CpH2O* = net heat gained (Joules)

### *CpH2O* = 4.186

### (*Tf* –*Ti*) x *MWi* x 4.186 = Joules (a negative answer means it lost heat) [3]

### The answer is the net heat gained by the pot during the interval from time the time of recording *Ti* to the time of recording *Tf*.[[11]](#footnote-11)

### Create a scatter chart of the running total of all calculated values, plotting the *net heat gained* points on the Y-axis and Time on the X-axis. This chart is part of the final report.

### Calculate average the *rate of heat gain* (power) as above but using the temperature nearest 30 as the value of *T*i and nearest 70 for the value of *Tf*. and the respective recording times as follows:

### Heat gained in the interval (Joules) = Watts (power) [4]

### Time Interval expressed in seconds

### Calculate the *heat gain rate* for each time interval and create a scatter chart plotting the values with Watts on the Y-axis and Time plotted on the X-axis.

### Determine the *heat flux rate* by dividing the rate of heat gain by the *nominal heated surface area[[12]](#footnote-12)* of the pot used during the test. Express the answer in Watts/cm2.

### Watts . = Watts/cm2 [5]

### Nominal heated surface area, cm2

### If the mass of the insulator on the scale or the mass of the stove have change more than 0.5% the test result should not be accepted if it involves a calculation of the heat developed by the fire. These mass differences usually arises because the object has been moistened prior to the test and the moisture has evaporated during the test at an unknown time. If a mass variation is accepted which exceeds this amount, the report should highlight this and indicate that the [Standard Error](http://en.wikipedia.org/wiki/Standard_error_(statistics)) will be larger than usual.

# Water Heater Test: These procedures determine the *gross energy consumption rate[[13]](#footnote-13),* the *average* *net firepower*, the *net heat gained* by the pot and the *average heat transfer efficiency*[[14]](#footnote-14), the *system efficiency[[15]](#footnote-15)* and the specific emissions of *PM*[[16]](#footnote-16) and *CO*[[17]](#footnote-17) per net MJ of energy delivered into a heated a pot.

## Experimental procedure

### It is incumbent on the laboratory technicians to create their own check list for the equipment they have available. This procedure requires the use of a condenser to collect water evaporated from the pot and a scale to determine the changing mass of the condensate.

### Select and weigh the largest pot or specialised empty water container rated by the manufacturer for the appliance and its accompanying lid, if applicable, and record their masses on the data sheet.

### Determine the material from which the pot and lid are made and the specific heat capacity *Cp* of each. Calculate the mass of water that has the same total heat capacity per degree C as follows:

### (Pot *Cp* x Pot mass + Lid *Cp* x Lid Mass) = *grams of water equivalent* [1]

### *Cp* of Water

### Fill the container (pot) with water to 80% of the maximum volume and record the mass of water added. The water should initially be below 30°C.

### Add the *grams of water equivalent* of the pot to the mass of water in the pot to get the *initial water mass equivalent[[18]](#footnote-18)* of the pot, lid and contents.

### Water mass + *grams of water equivalent* of the pot and lid

### = Initial water mass equivalent MWi [2]

### Prepare to measure the temperature of the water by placing a plastic frame holding a thermocouple 50 mm above the bottom of the pot approximately 1/6th of its diameter away from the pot centre.

### Press ZERO on the stove scale. Place the insulation material on the scale and record the mass. Press TARE to zero the scale and put on the stove. Record the indicated mass of the stove. Press TARE again.

### The fuel loaded into the stove should include the burnable fuel remaining from a previous identical replication of this procedure. Record the mass of re-used fuel *MFR* and the mass of the new fuel added *MFN* to be able to complete the test. In the case of TLUD pyrolysers[[19]](#footnote-19) the reuse of such fuel may not apply because they may require new fuel for each burn. Separately record the mass of new fuel added. If a stove cannot burn the fuel remaining from a previous test, that remaining fuel from the previous replication counted as ‘consumed’ and only new fuel will be used.

### If recording the temperature automatically, start the logger. If recording manually write the time and temperature in the logbook at regular intervals such as once per minute. Automatic recording is typically once per 10 seconds.

### Connect the water container to the condenser and start the DSC program to collect the condensate mass data. Start the Particle counter and the gas analyser following the appropriate procedures for calibration. See the Normative references for detailed procedures.

### Ignite the fire and place all fittings or covers that may be needed. Adjust the fire to its maximum setting. Continue to record the temperature of the water in the pot. The test continues in this manner until the water has reached the boiling point and sustained a stable boiling point temperature for at least 2 minutes. Note the time of completion.

### Remove the pot from the stove and determine its total mass.

### Turn off the water heater using the mechanism or method provided by the manufacturer. If the product is designed to have the fire burn out on its own, allow that process to continue while recording all data. Otherwise, note the time and extinguish the burning fuel using a method that does not add moisture to it and stop all data logging.

### Evaluate the fuel remaining and determine its mass. If it is substantially similar to the mass of the fuel used from the previous burn cycle, note the comparison as favourable and save it for the next replication. If there is no fuel remaining or it is not useable in the next replication, it is considered for fuel consumption calculations to have been ‘consumed’.

### Where the fuel is not re-useable and where practical, assign a heat value to the fuel remaining by using a burn-out method[[20]](#footnote-20) or bomb calorimetry[[21]](#footnote-21).

### The pot mass will not have changed so any difference between the initial and final mass of the pot is due to the evaporation of water. Calculate the heat gained by the pot per measurement interval by applying the formula for the time interval from ignition to the end of the test:

### [(Final water temperature *Tf* – Initial water temperature *Ti*) x Initial total mass *MTi* x the *Cp* of water *CpH2O*) + (Initial pot mass *MTi* – Final pot mass *MTf*) x the Latent heat of evaporation of water: 2257 Joules per gram] = Joules gained

### [(*Tf* – *Ti*) x *MTi* x 4.186 + (*MTi* – *MTf*) x 2257] = Net Heat Gained (Joules) [5]

### The answer is the total heat (Joules) gained by the pot (net)[[22]](#footnote-22) during the test period.

### Calculate the *gross energy consumption* as follows:

### Mass of new fuel added *MFN* to the fire per burn cycle (per replication) x AR Heat value

### *MFN* x AR heat value (MJ/kg) = Gross energy consumed during the test (Joules) [6]

### Calculate the system efficiency as follows

### Net heat gained . x 100 = System Efficiency (%) [7]

### Gross energy consumed

### Calculate the gross energy consumption rate as follows:

### Gross energy consumed (Joules) = Gross energy consumption rate (Watts) [8]

### Duration of test (seconds)

### Enter the data collected during the test into the HTP Spreadsheet.[[23]](#footnote-23) Select the starting and finishing times for the test by entering the corresponding data line numbers in the Green section of the PERFORMANCE page. It will automatically calculate the average *heat transfer efficiency*.

### The gross energy consumed number is reduced by the combustion inefficiencies. The CO mass is assigned a heat value of 10.1 MJ/kg and Hydrogen a value of 120 MJ/kg. In most cases there is no need to assess the heat content of the fuel remaining as it will be used in the next replication.[[24]](#footnote-24) In the case of TLUD char-making stoves with interrupted burn cycles the charcoal mass equivalent[[25]](#footnote-25) of all fuel remaining should be entered on the Test Info page.

### Having selected the correct data set for the test interval the PM2.5 mass per Net MJ will appear on the Green section below dedicated to PM/MJNET. The same follows for the CO mass per net MJ in the CO section.

### If the mass of the insulator on the scale or the mass of the stove have change more than 0.5% the test result should not be accepted if it involves a calculation of the heat developed by the fire. These mass differences usually arises because the object has been moistened and the moisture has evaporated during the test at an unknown time. If a variation is accepted which exceeds this amount, the report should point this out and indicate that the [Standard Error](http://en.wikipedia.org/wiki/Standard_error_(statistics)) is larger than the usually accepted value.

# Cooking stove test: This Protocol determines the *gross energy consumption rate*, the *average* *net firepower*, the *net heat gained* by the pot, the *heat flux rate*, the *average* *heat transfer efficiency,* the *average system efficiency* and the specific emissions of *PM* and *CO per net MJ* of energy delivered into a series of pots at different power levels.

# It is a task-based test requiring a demonstration that the product can effectively control the firepower and has sufficient cooking power to meet the minimum performance requirements of the users (whose needs have been previously characterised).

### This procedure can be conducted at the same time as some other procedures.

### General Flow Diagram

## Experimental procedure

### It is incumbent on the laboratory technicians to create their own check list for the equipment they have available

### Press ZERO on the stove scale. Place the insulation material on the scale and record the mass. Press TARE to zero the scale and put on the stove. It will indicate the mass of the stove. Record it.

### Press TARE again. Load enough fuel into the stove to complete the test and when finished, record the indicated mass which will be the mass of fuel loaded. The fuel loaded should include the burnable fuel remaining from a previous identical replication of this procedure. The total mass of this old fuel should be recorded, and separately, the mass of new fuel added to this. If the stove cannot burn the fuel remaining from a previous test it is discarded or sent to some other purpose and only new fuel will be used.

### In the case of stoves that will be refueled during the test, place additional fuel next to the stove also on the scale if some will be added during the test. If it is a liquid fuel stove skip this step. If it is a gas or liquid fuel stove connected to a tank of fuel by a flexible pipe, place the fuel container on a separate scale and record the mass separately throughout the test.

### These procedures will test the claim by the manufacturer that the stove can deliver energy to the pot at the required *heat flux rate*. The test should be conducted using the largest pot for which the manufacturer claims the stove can meet the *heat flux rate* requirement. Select two or more such pots with lids, each having the same empty mass and fill them 80% full of water so they each have the same total mass. The water temperature should be below 30°C. The water mass may alternatively be another culturally relevant quantity. Weigh and record the total mass of each (Pot+Lid+water).

### Determine the material from which the pot and lid are made and the specific heat capacity *Cp* of each. Calculate the mass of water that has the same total heat capacity per degree C as follows:

### (Pot *Cp* x Pot mass + Lid *Cp* x Lid Mass) = *grams of water equivalent* [1]

### *Cp* of Water

### Add the *grams of water equivalent* of the pot to the mass of water in the pot to get the *initial water mass equivalent[[26]](#footnote-26)* of the pot, lid and contents.

### Water mass + *grams of water equivalent* of the pot and lid

### = Initial water mass equivalent MWi [2]

### Prepare to measure the temperature of the water by placing a plastic frame holding a thermocouple 50 mm above the bottom of the pot approximately 1/6th of its diameter away from the pot centre.

### Start the particle counter and record the ambient PM2.5 level. Start the gas analyser and check that the background readings are within tolerance. Start the temperature logger and check that all thermocouples are recording. Start as many copies of the Digital Scale Capture (DSC) as are necessary. Enter the test number on the CONFIG tab of each copy. Set the diluter air flow to the anticipated requirement. Check that the instruments and the computer have their time clocks synchronized.

### For liquid fuels, measure and record the initial temperature of the fuel before ignition and repeat the measurement after at least one hour of high power operation (which may be after these procedures are completed). There should be no spilled fuel on the stove that will evaporate and affect the total weight.

### With the fuel loaded and the pot off the stove, press TARE on the stove scale to set the stove scale mass reading to Zero. This step is optional for automatic recording but advisable for manual recording of scale data. The point is to record the mass of the entire system without the pot in place, before the fire is ignited.

### Ignite the stove with the pot on or off according to the manufacturer’s instructions using a match, match extension, or using lighting material such as traditional substances, methylated spirits, paraffin or diesel as appropriate. Record the time of ignition. The fire should be started in a reproducible manner according to local practices or the manufacturer’s instructions. If a lighting cone is used, the pot will probably have to be removed during the early fire.

### Following culturally relevant practice, place the pot on the stove either immediately or after some minutes and record the ‘Pot On’ time in the Logbook. The time interval between ignition and Pot On must be consistent from test to test. Emissions from the fire during this time are counted in the *average emissions* values.

### Operate the stove until the fire stabilizes at the highest power setting available. The mass, gas, temperature and PM readings should be recording automatically every 10 seconds at all times. Continuously monitor the PM reading on the particle counter and adjust the dilution as necessary to keep the reading within the limits of the particle counter. Change the dilution gradually. The PM reading does not respond immediately. For the Dusttrak DRX and DataRAM 4 try to keep the reading below 120 mg/m3. Do not reduce the dilution below 4:1. The ratio of the two CO2 readings indicates the dilution.

### Continue with recording while maintaining a constant firepower until the temperature of the water reaches 70°C. During this time the stove body temperature should stabilise. “Constant” means within 20% of the average value from when the pot was put on.

### Upon reaching 70°C exchange the pots, taking off Pot 1 and placing Pot 2 on the stove with its thermocouple in place. Continue all data logging. In the meantime fill the first pot with fresh, cold water attaining the same total mass as before. The high power level must be maintained for not less than 20 minutes to collect enough data but not more than 30 minutes. If enough data has been collected (>20 minutes), not the time and reduce the firepower until it reaches ½ the full power level, which is t say, at ½ the rate of burning fuel. The fuel burn rate is displayed at the top of the right hand panel of the DSC Programme that reads the stove scale. When the temperature of water in the pot reaches 70°C it should again be changed to the other pot with fresh water. When the ½ power level is stable, exchange the pots whether or not the water has reached 70°C.

### Continue holding the firepower at ½ the full power rate for at least 20 minutes but not more than 30. Exchange the pots when necessary.

### Reduce the firepower to ¼ of full power and then stable, exchange the pots again. Hold the power level for at least 20 minutes but not more than 30. Exchange the pots when necessary as then reach 70°C.

### Excluding the ignition and power ramping following the ignition period, the tester duration will be a maximum of 90 minutes.

### If it possible to run this test using stove with multiple pots provided that the pot temperatures are recorded. Only one cooking position has to meet the *heat flux rate* benchmark.

### This test procedure can be used with pots that are brought to a boil and simmered, however it must be noted in the test report that the heat transfer and system efficiency numbers will not be valid because the unmeasured proportion of the heat losses from the pot at low power mean the such efficiency numbers are without scientific merit.

### During a test that involves boiling pots, the loss of water mass from evaporation must be known in real time. The pot or pots should be connected to a condenser in such a manner that the mass of water condensed from Pot 1 *MP1CON* can be recorded on a scale in real time. This can also be done with multiple pots: *MP2CON**MP3CON*… When the experiment has ended, stop recording and measure the total mass of the pot, lid and water remaining in it and apply the formulas in the Water Heater Test to the correct figure for *net heat gained*.

### Ending the test

### There are two distinct procedures available for ending tests and the one selected depends on the stove type.

|  |  |
| --- | --- |
| **Stick burning stoves** that can burn the leftover fuel in the subsequent fire | **Batch-loaded stoves and pyrolysers** that cannot re-use leftover fuel. |
| Note the time. Remove the pot from the stove, remove all fuel and extinguish as quickly as possible. | Remove the pot and extinguish the fuel. Weigh the char and partially burned wood, and if possible, determine its calorific heat content using a bomb calorimeter. |
| Separate that portion (or all) of the fuel that can be burned in a subsequent test. Record the mass. | Weigh and record the total mass of char remaining. This is used to calculate the net firepower and the heat transfer efficiency. |

## Data Entry

### Enter the data collected during the test into the HTP Spreadsheet. Enter the starting and finishing times for the whole test by entering the corresponding data line numbers in the Green section of the PERFORMANCE page. The **Green** reporting sections will show the average PM and CO mass/MJNET. The last line number should be the same as the finish line in the **Blue** section.

### Enter the starting and finishing times for the selected 20 minute section of the high power portion of the test by entering the corresponding data line numbers in the **Red** section. It will automatically calculate the average *Gross energy consumption rate*, the *net firepower,* the *system efficiency*, the *heat transfer efficiency* and the *heat flux rate* at high power.

### Enter the starting and finishing times for the selected 20 minute section of the half-power portion of the test by entering the corresponding data line numbers in the **Orange** section. It will automatically calculate the average *Gross energy consumption rate*, the *net firepower,* the *system efficiency*, the *heat transfer efficiency* and the *heat flux rate* at ½ power.

### Enter the starting and finishing times for the 20 minute quarter-power portion of the test by entering the corresponding data line numbers in the **Blue** section. It will automatically calculate the average *Gross energy consumption rate*, the *net firepower,* the *system efficiency*, the *heat transfer efficiency* and the *heat flux rate* at ¼ power.

### The gross energy consumed number is reduced by the combustion inefficiencies. The CO mass is assigned a heat value of 10.1 MJ/kg and Hydrogen a value of 120 MJ/kg. In most cases there is no need to assess the heat content of the fuel remaining as it will be used in the next replication. In the case of TLUD char-making stoves with interrupted burn cycles the charcoal mass equivalent of all fuel remaining should be entered on the Test Info page. Unlike some other test protocols, this correction does not always require an assessment of the heat value of fuel remaining unless the stove cannot burn the fuel remaining at the point at which the test was stopped. When it is required, then an equivalent char mass can be entered on the Test Info page (Charcoal remaining) which will correct for the energy made available to the pot. The energy value should be converted to a char equivalent mass at 29.5 MJ/kg LHV.

### Having selected the correct data set for the test interval the PM2.5/MJNET will appear on the Green section below dedicated to PM/MJNET. The same follows for the CO mass per net MJ in the CO section.

### If the mass of the insulator on the scale or the mass of the stove have change more than 0.5% the test result should not be accepted if it involves a calculation of the heat developed by the fire. These mass differences usually arises because the object has been moistened and the moisture has evaporated during the test at an unknown time. If a variation is accepted which exceeds this amount, the report should point this out and indicate that the [Standard Error](http://en.wikipedia.org/wiki/Standard_error_(statistics)) is larger than the usually accepted value.

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# QUANTIFICATION

(Not applicable)

# QUALITY CONTROL

## Reproducibility of Testing

Tests are run several times to determine a uniform lighting method and burn cycle that’s reproducible before the three definitive tests. Test runs that do not fall within the standardised cycle are rejected due to lack of Uniformity. Inconsistent results for which a reason cannot be found entails the tests to be re-run.

## Daily Validation

Validation of gas readings is done by checking that the pump flow rate and the internal pressure are consistent. In the case of a Testo gas analyser being used, see SeTAR SOP # 2.05 *Analysis of combustion trace gases using TESTO® XL 350/454*.

## Validation of Final Data File

The data files and the analysis file which is an EXCEL® spreadsheet are to be archived in at least two locations. During the analysis quality control checks can be made on the data. If the data falls within the specified limits and ranges it is accepted and processed, and if the data falls outside the specified limits and range it is discarded.

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# Documentary changes

15 December, 2010: Added signatures to the title page and adjusted page numbering.  
16 February, 2012: Modified the testing procedures.

20 August 2013: Updated for the WB CSI Pilot, Indonesia with three separate protocols for heat flux, water heaters and cooking stoves which is published separately as SOP 33.03.03.

**Annexure 1**

1. Pots: The capacity, dimensions and material of the pot have a significant influence on stove performance (Bailis *et al*., 2007). If testers use a non-standard pot, they should record the capacity, dimensions, weight, and material. However, use of non-standard pots may lead to a bias in the results and make them difficult to compare to other tests.
2. Lids: It is argued that the lids generally improve the performance of the stove yet the main purpose of the WBT is to quantify the way that heat is transferred from the stove to the cooking pot (Bailis et al., 2007). The approach is based on the premise that the fuel, stove and the pot (including the lid) and the operator represent the cooking system. All these factors should be optimised to improve the thermal and emissions performance of the stove. Since the lid is used for the actual cooking task, it is imperative that testers also use lids when conducting the test to simulate the actual cooking task. Open pots can complicate the test by increasing the variability of the emissions performance outcome and making it harder to compare from different tests. “*By not using a lid, evaporation rates are higher and the stove must be run at a somewhat higher power to maintain the temperature than is the case with a lid*.” (Baldwin, 1986:263). Many stoves optimised for fuel efficiency will not boil a pot of water with the lid removed. We therefore recommend that the test be carried out with the lid on.

1. From SeTAR 0.10 *Stove Testing Definitions* Para 1.1 [↑](#footnote-ref-1)
2. *Net heat gained* by the pot is the sensible heat gain of the lid, pot and its contents as detected by a change in the water temperature expressed in Joules. [↑](#footnote-ref-2)
3. *Rate of heat gain* is the heat gained with respect to time, which is power, expressed in Watts. It can also be termed the *Cooking Power*. [↑](#footnote-ref-3)
4. *Heat flux rate* is denoted by \overrightarrow{\phi_q} or Q” and is the rate at which heat is transferred into a pot per unit area of heated surface (typically the area of the bottom surface of the pot) expressed in Joules per second per square metre (= Watts/m2). Because number in *MKS* units would be large, the *heat flux* is instead reported in Watts/cm2 which is a [*CGS*](http://www.unc.edu/~rowlett/units/cgsmks.html) unit and is the power per unit area, expressed in Watts/cm2. [↑](#footnote-ref-4)
5. *Gross energy consumption* is the energy equivalent of the fuel consumed by the stove per replication of the burn cycle inclusive of mechanical losses, expressed in MegaJoules. It can also be re-expressed as an equivalent dry fuel mass consumed. It is conducted as one in a series of identical replications. See Para 1.2. [↑](#footnote-ref-5)
6. *System Energy Efficiency* is the ratio of the heat energy gained by the pot expressed in Joules to the heat energy that was potentially available from the fuel that was consumed, based on its As Received energy value. [↑](#footnote-ref-6)
7. Milligrammes emitted per MJNET delivered into the pot [↑](#footnote-ref-7)
8. Carbon dioxide emitted per MJNET delivered into the pot [↑](#footnote-ref-8)
9. This dilution effect can be removed by calculation using the data, additional equipment and a chemically balanced method of analysis. [↑](#footnote-ref-9)
10. The *mass of water equivalent* will be used to calculate the quantity of heat gained when the water temperature rises. An added water mass is a mathematical proxy equalling the heat gained by the pot and lid. [↑](#footnote-ref-10)
11. Technically it is the ‘accumulated heat’, other heat having entered and left again, hence the term ‘net heat gained’. [↑](#footnote-ref-11)
12. The nominal heated surface area of the pot is the area of a circle equal to the base diameter of the pot ignoring lips and ridges. For rectangular pots the same principles apply. For a wok the outside diameter is used. [↑](#footnote-ref-12)
13. *Gross energy consumption rate* is the energy equivalent of the fuel consumption rate averaged over the burn cycle, inclusive of mechanical losses, expressed in kW. It can also be re-expressed as an equivalent dry fuel mass consumption rate. It is conducted as one in a series of identical replications. See Para 1.2. [↑](#footnote-ref-13)
14. *Average heat transfer efficiency* is the ratio of the net heat energy gained by the pot to the net heat energy that was available from the fire. [↑](#footnote-ref-14)
15. *System efficiency* is the ratio of the net heat energy gained by the pot to the potential heat energy that was available from the fuel consumed. [↑](#footnote-ref-15)
16. Milligrammes emitted per MJNET delivered into the pot [↑](#footnote-ref-16)
17. Carbon dioxide emitted per MJNET delivered into the pot [↑](#footnote-ref-17)
18. See foot note 10. [↑](#footnote-ref-18)
19. These top-lit updraft combustors create charcoal while producing a combustible gas. Normally they cannot burn, in a subsequent fire, the char they create. [↑](#footnote-ref-19)
20. A burn-out method uses a standard combustor and standard pot with a known heat transfer efficiency and establishes the heat value of the fuel by determining the total heat gained by the pot and dividing it by the heat transfer efficiency. [↑](#footnote-ref-20)
21. The fuel is homogenised and a representative sample is analysed in a bomb calorimeter to establish its HHV. [↑](#footnote-ref-21)
22. There are a few tens of Watts more heat which enters the pot and leaves by conduction, convection and radiation all of which are difficult to quantify. The exact total amount of heat entering the pot is not known precisely. Removing the lid from a 270 mm diameter boiling pot introduces a significant ≈210 Watt radiant heat loss that is also not measured. Tests should be performed with a lid on pot to minimise such errors. [↑](#footnote-ref-22)
23. For detailed instructions on the collection, naming and processing of test data please see the SeTAR Lab Manual v1.01. [↑](#footnote-ref-23)
24. Unlike other test protocols, this correction does not require an assessment of the heat value of fuel remaining unless the stove cannot burn the fuel remaining at the point at which the test was stopped. If this is the case, then a char mass can be entered on the Test Info page which will correct for the energy made available to the pot. [↑](#footnote-ref-24)
25. For this purpose charcoal heat value is to be standardized at 29.5 MJ/kg. [↑](#footnote-ref-25)
26. See foot note 10. [↑](#footnote-ref-26)