UJ SeTAR CENTRE STANDARD OPERATING PROCEDURE

The *Heterogeneous* Testing Procedure For Thermal Performance and Trace Gas Emissions

SOP # 1.05
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1 GENERAL DISCUSSION

1.1 Purpose of Procedure

This standard operating procedure is intended to:

- Provide a basic understanding of the principles of stove testing.
- Describe routine operation of stove emissions performance and stove efficiency performance.
- To codify actions which are taken to determine the thermal and emissions performance of fuel/stove combinations.
- Detail quality control procedures for the reproduction of results in different tests under the same operating conditions.

This procedure is to be followed by all staff and analysts at the SeTAR Centre, University of Johannesburg.

1.2 Measurement Principle

Procedure uses mass loss and temperature gain for the determination of thermal efficiency.

TESTO® XL 350/454 uses electrochemical cells for gas measurements. CO_2 is determined using a non-dispersive infra red cell and is normally depicted as CO_2 IR. Oxygen balance is used for the calculation of excess air.

1.3 Measurements Interferences and their Minimisation

1.3.1 Water vapour interferences

Water vapour from the boiling pot will introduce a dilution effect on the flue gases hence compromising the results. Thus a pot should be used together with the lid it was designed for, and the lid should be equipped with a 10 mm diameter pipe protruding not more than 5 mm below the lower surface of the lid, which discharges steam outside any hood. In this way, steam from the pot will be removed from the gas stream being analysed. The pipe must always run upwards from the pot to prevent any pools of condensate from forming in the pipe. 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 the simmering phase (Ahuja *et al*., 1987).

1.3.2 Draft interferences

Any drafts across the test site are likely to interfere with measurements. 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 of shielded by wind impermeable screens.

1.4 Ranges and Typical Values of Measurements

For ranges and typical values of measurements for combustion trace gases, temperature and pressure refer to the section 1.4 of the SeTAR SOP # 2.05 Analysis of combustion trace gases using a TESTO® XL 350/454 analyser.

1.5 Typical Lower Quantifiable Limits, Precision and Accuracy

(Not applicable)

1.6 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 setting up for source sampling, the TESTO® XL 350/454, changing filters, un-installing equipment once testing is complete, cleaning, maintenance and calibration of instrumentation, and coding and analysing data on an EXCEL® spread sheet. 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.

1.7 Definitions

No terms used in this procedure require definitions

1.8 Related procedures

SOPs related to stove testing procedures which should be read and revised in conjunction with this document are:

- SeTAR SOP # 2.05 Analysis of combustion trace gases using a TESTO® XL 350/454 analyser
- SeTAR SOP # 3.0 Calibration of TESTO® XL 350/454.

2 APPARATUS, INSTRUMENTAITON, REAGENTS AND FORMS

2.1 Apparatus and Instrumentation

2.1.1 Description of the TESTO® XL 350/454 and its operational functions

The TESTO® XL 350/454 comprises of a control unit which is equipped with a probe socket and an integrated differential pressure probe. Up to six measuring channels can be shown simultaneously on the graphic display. Up to 250 000 readings are saved for the selected location and documentation can be made on site with the integrated printer. This measurement data can be transferred to a computer via the serial interface. Readings are acquired simultaneously at several locations by decentralized loggers and/or flue gas analyzer boxes. The data is transferred to the control unit through the TESTO® data bus.

The logger measures and stores the values even when not connected to the Control Unit. The logger is equipped with four probe sockets. The following probes can be operated with the logger: temperature probes, flow velocity probes, humidity probes, CO, CO_2 probes, current and voltage cables, rpm probes. The logger detects the probe connected to the probe socket every time the device is started.

The analyser contains the gas sensors, the measured gas and purging pumps, peltier gas preparation, gas paths, all filters, electronic evaluation and storage, the mains adapter and NIMH battery. The flue gas is drawn over the flue gas probe in the gas preparation when the gas pump is started manually or automatically. Here the measuring gas is suddenly cooled to 4-8 ºC. This precipitates the condensation with the lowest absorption of NO_2 and SO_2. The dry gas passes through a particle filter, which holds back the particles. The gases then pass through the pump to the gas sensors.

The analogue output box is used to issue the analogue signals of a selection of up to 6 measuring channels in complex measuring systems consisting of loggers and analyser boxes. For this, the different components must be connected by bus lines. A maximum of two analogue output boxes can be logged onto one TESTO® databus system. The analogue outputs are current outputs, 4 to 20 mA. A load of 500Ω per output is permissible.

2.2 Instrument Characterisation

Refer to SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454

2.3 Maintenance

Refer to SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454

2.4 Spare Parts

Refer to SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454

2.5 Equipment and apparatus

2.5.1 Digital scales

Depending on the size of the stove to be tested the size and accuracy of the digital scales will also vary. For liquid fuel/stove tests there is need to measure the fuel consumption accurately. Most paraffin stoves operating at full power use about 2g fuel per minute. Thus, one needs to measure the mass to at least 0.1g to determine the fuel consumption giving an accuracy of 73 watts. For all liquid fuel/stove tests use a 20kg digital scale with an accuracy of 0.1g. For solid fuel/stove tests 32kg digital scales with an accuracy of 1g are used giving an accuracy of 300 watts.

2.5.2 Digital thermometer

Digital thermometers with an accuracy of a $1/10^{th}$ of a degree with a thermocouple probe suitable for emissions in liquids should be used for carrying out the tests.

2.5.3 Pots

In order to optimise the comparability of the test across different types of stove we recommend that testers use two standard pots. The recommended pots are: a large pot (Hart 6.4 Litres capacity, 250 mm diameter, 125 mm height, 80% full of water) and a small pot (Hart 3.0 litres capacity, 200 mm diameter, 115 mm height, and 80% full of water). The testers should use both standard pot sizes to carry out the tests unless the stove requires a specific pot in order to function properly.

(A) 1 litre Casserole 150 mm with lid (B) 2 litre Casserole 175 mm with lid (C) 3 litre Casserole 200 mm with lid (D) 4.5 litre Casserole 225 mm with lid (E) 6 litre Casserole 250 mm with lid

Two pot sizes (**C** and **E**) are used in carrying out performance evaluation tests using the Heterogeneous stove Testing Protocols. The dimensions for pot C are as follows:

Diameter: 200 mm
Depth: 90 mm
Thickness of aluminium: 2 mm
Mass of empty pot: 435 g
Mass of lid: 101 g

The dimensions of pot **E** are as follows:

Diameter: 250 mm
Depth: 120 mm
Thickness of aluminium: 2 mm
Mass of empty pot: 680 g
Mass of lid: 192 g

2.5.4 Lids

The *heterogeneous test* should be performed with the lid on. However, there have been heated debates with regards to the use of pot lids during tests (see Annexure 1).

2.5.5 Water

Enough water should be available before carrying out the tests. There should be at least 15 litres of clean water present. In areas where water is scarce the water can be cooled and re-used in sub-sequent tests

2.5.6 Heat resistant pad

Always ensure the digital weighing scales are protected from excessive heat using resistant heat pads. If at all possible they should not be water-absorbent. To protect the digital weighing scales a heat resistant pad is placed on top of the scale and then the stove is placed upon it. The mass of the heat resistant pad should be checked before and after all tests to see if it has changed (usually indicating water loss).

2.5.7 Heat resistant gloves and gas masks

Ensure that heat resistant gloves are on hand before carrying out the tests. Use heat resistant gloves when tending the stoves during testing. Gas masks should be easily accessible in the event of carbon monoxide levels rising above recommended limits in the laboratory.

2.5.8 Lap top/ desk top for data logging

The minimum system requirements for TESTO® software include a PC with operating system Microsoft Windows 95® or higher, CD-Rom drive, Pentium 100 MHz, 32 MB Ram, 15 MB unused hard drive capacity, an available serial interface port (COM) or corresponding adapter for test 1, and USB port in a laptop or corresponding PC module for test 2. The computer is used for data logging and storage.

2.5.9 Tongs

Ensure that Tongs are present when carrying out tests involving solid fuels such as wood, charcoal and coal. Tongs are useful for handling char in solid fuel/stove tests.

2.5.10 Metal tray

A metal tray should be available for holding charcoal during fuel sorting and weighing.

2.6 Reagents

(Not applicable)

2.7 Gases

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

2.8 Forms and Paper Work

All fuel samples are logged into the *fuels data booklet* upon receipt at the laboratory. The laboratory Manager will create an inventory of the samples received and special instructions on handling of the samples prior to analysis. All stoves received at the Centre are recorded in the *stoves logbook* prior to analysis. The Laboratory Officer will create a *result logbook* to enter data during the experimental procedure. An example of the *result logbook* is given in the figure that follows:

SeTAR Centre's Result Log Book				
Time	**Weight**	**Fuel loss**	**Water Temperature**	**Comments**
13:01:10	2572.3	0	23.6	Pot on START TESTO
13:02:10	2569.7	2.3	24.8	
13:03:10	2567.3	5.2	26.2	
13:04:10	2563.6	9.0	30.3	
13:05:10	2558.4	12.3	33.4	
13:06:10	2556.5	13.8	35.9	
13:07:10	2550.2	15.9	38.0	
13:08:10			41.6	
13:09:10			44.5	
13:10:10			47.8	
13:11:10			50.2	
13:12:10			53.6	
13:13:10			56.4	
13:14:10			59.3	
13:15:10			61.6	
13:16:10			64.5	
13:17:10			67.3	
13:18:10			70.2	
13:19:10			73.9	
13:20:10			76.0	

Figure 1: Example of the result logbook during emissions and performance evaluation of stoves

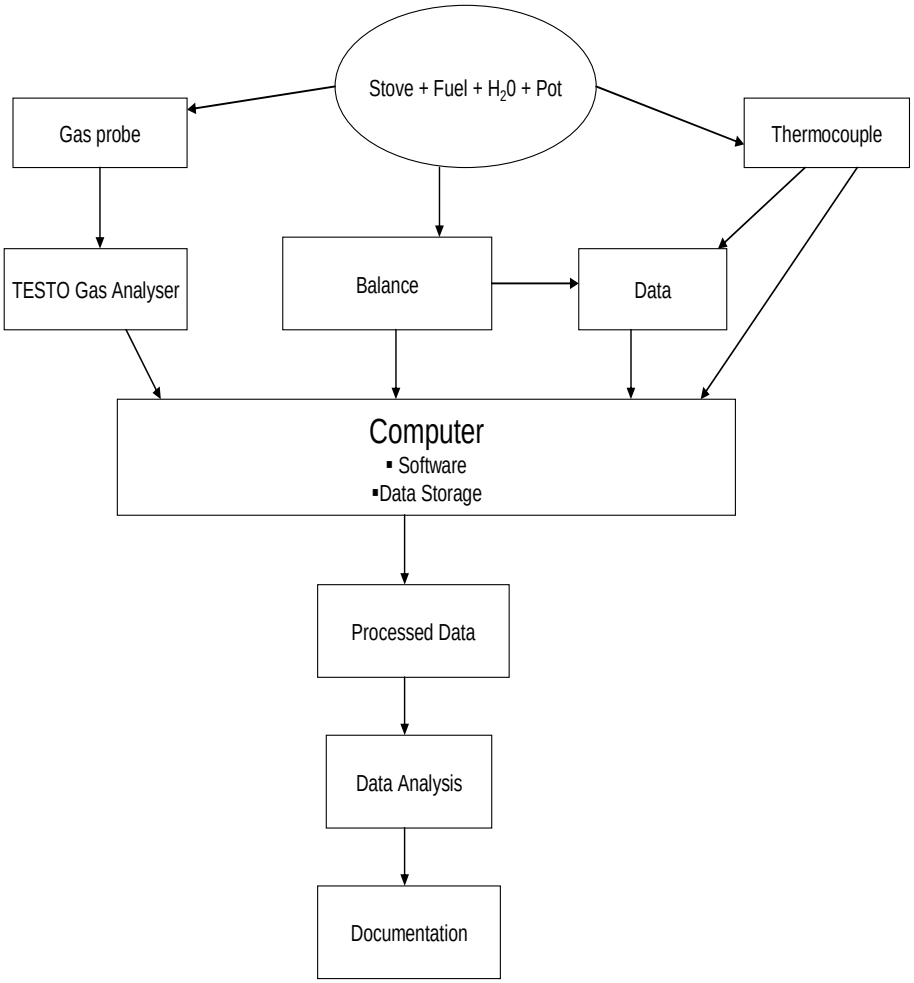
3 CALIBRATION STANDARDS

Refer to SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454 for the calibration of the TESTO®

Mass balance calibration procedures are contained in their instruction manuals.

4 PROCEDURES

4.1 General Flow Diagram



4.2 Experimental procedure

4.2.1 Weigh the insulation material between the scale and the stove.

4.2.2 Weigh the empty pot and lid and record the masses on the data sheet.

4.2.3 Put 5.000 Litres or 2.000 litres of water into the pot, weigh everything (Pot + Lid + water). Alternatively fill the pot to 80% of capacity and weigh the combination and record all.

4.2.4 Measure the temperature of the water by placing the plastic frame holding the thermocouple into the water, 50 mm above the bottom of the pot in the centre of its diameter.

4.2.5 Weigh the stove without the fuel and record the mass on the data sheet.

4.2.6 Weigh the fuel that will be used during the test and place it on the scale next to the stove. If it is a liquid fuel stove skip this step.

4.2.7 Fill the stove with the fuel. For liquid fuels, measure and record the initial temperature of the fuel before lighting it up. Weigh the stove and the fuel and record the mass in the data sheet. There should be no spilled fuel on the stove that will evaporate and affect the total weight.

4.2.8 Choose an appropriately sized scale. Press ZERO to set the mass reading to 0.000 kg or 0 grammes.

4.2.9 Place the stove on the scale. It should show the mass of the stove + fuel (M0~0)

4.2.10 Start the calibrated gas analysis equipment, data logger (START TESTO®)

4.2.11 The stove should be at room temperature. Light the stove with the pot off according to the manufacturer's instructions, noting the time of ignition using a match, match extension, or using a lighting fluid such as methylated spirit as appropriate. The fire should be started in a reproducible manner according to local practices or the manufacturer's instructions.

4.2.12 Operate the stove until the fuel consumption stabilises at the highest possible power setting available. Every 60 seconds, record the mass of the stove + the fuel. When the fuel consumption rate is stable, note the time and mass reading (M0~0) and record it in the data sheet.

4.2.13 TARE the scale and place POT1 + Water1 (M1~0) noting the time, Mass (M1~0), Time (T~11).

4.2.14 Each 60 seconds, note the temperature T~11, mass (M1~0), lift POT1 and record M2~0. (M2~0) is the mass of the fuel burned.

4.2.15 Continue with this process until the temperature of the water reaches 80 °C. If you wish, you may continue noting T~11, M1~0, and M2~0 till the water boils vigorously.

4.2.16 Turn the power down to the midpoint between the highest and lowest power level and allow the fuel consumption to stabilise.

4.2.17 Replace POT1 with POT2 filled with cold Water2 (M1~0) noting the time, Mass (M1~0), Time (T~11).

4.2.18 Continue noting after every 60 seconds the temperature (T~11), pot mass (M1~0) and fuel loss mass (M2~0) until the temperature of the water reaches 80 °C.

4.2.19 Replace POT2 with POT3 filled with cold water, prepared as before. Turn down the power to the lowest sustainable level and allow fuel consumption to stabilise.

4.2.20 Continue noting after every 60 seconds T~11, M1~0 and M2~0 until the temperature of the water reaches 80 °C.

4.2.21 At the end of the low power readings, stop the TESTO® and measure the fuel remaining at the end of the test.

4.2.22 Save the data from the TESTO® and the scales immediately and export it all to EXCEL® data sheets for archiving and analysis.

4.2.23 Note the fuel temperature of the fuel and record it on the data sheet.

4.3 Analyser Start-up

Refer to SeTAR SO P# 2.05 Analysis of combustion trace gases using TESTO® XL 350/454.

4.4 Routine Operation

Refer to SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454.

4.5 Analyser Shut Down

Refer to SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454.

4.6 Abbreviated Operational Check List

4.6.1 Starting Up

- Assemble the apparatus according to the existing SOPs.
- Zero the sensors of the gas analyser.
- Perform a fresh air rinse of the instrument. The probes are cleaned by blowing compressed air through their nozzles.
- Connect the analyser to a computer.
- Choose the measuring cycle.
- The ignition method should always be the same.
- Check to see if there are any fuel or water spills on the stove or the scales before lighting the stove.
- The stove should be placed perfectly flat on the scale and the scale should be level, as indicated on its bubble indicator.

4.6.2 Routine Operation

- Constantly check on pump flow during the experimental analysis. If it drops below 0.5 $Lmin^{-1}$, the tests has to be stopped, the machine checked and re-runs performed.
- The power setting (high, medium, and low) is always at the same level in different tests using the same fuel/stove combination.
- Check to see that the scales are functioning properly.
- The stove/pot system should be at the centre of the extraction hood during tests.
- The masses and temperatures are recorded every minute if done manually, or every 10 seconds if done automatically.

4.6.3 End Test and Analyser Shut Down

- Use Microsoft EXCEL® to store electronic data from real time measurements.
- Zero the sensors and perform a fresh air rinse of the analyser.
- Make sure all equipment has been retrieved and stored properly according to specific SOPs.
- Do not leave the site without acquiring data from any real-time monitors that may be operating at the facility (Fuel temperatures, fuel consumption, start time and end time etc).
- Clean the operational area.

5 QUANTIFICATION

(Not applicable)

6 QUALITY CONTROL

6.1 Reproducibility 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.

6.2 Daily Validation

Validation is done manually by checking the pumps before and after the analysis is performed. See SeTAR SOP # 2.05 Analysis of combustion trace gases using TESTO® XL 350/454.

6.3 Validation of Final Data File

The data is exported to an EXCEL® spread sheet for archiving and analysis. 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.

7 REFERENCES

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8 DOCUMENTARY CHANGES

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

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.