SeTAR CENTRE STANDARD OPERATING PROCEDURE

Analysis of combustion trace gases using a TESTO® XL 350/454 analyser

SOP #2.05
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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 using TESTO® XL 350/454.
- Describe routine operation of stove emissions performance using TESTO® XL 350/454 analyser.
- 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

The TESTO® XL 350/454 is a flue gas analyser. The smallest unit capable of making measurements is the Control Unit. Pressure measurements are also integrated. During routine operation 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. 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. The TESTO® uses the carbon balance to calculate 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 50 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

The typical ranges of gases collected with the TESTO® XL 350/454 are shown in the table below.

Table 1: Typical ranges of lowest gas concentrations for checking

Gas	Lowest gas concentration	TESTO® Adjustment	Lowest gas concentration for checking
CO	150ppm	1000ppm	10ppm
CO_{low}	50ppm	300ppm	5ppm
NO	80ppm	80/800ppm	10ppm
NO_{low}	40ppm	40/300ppm	5ppm
H_2S	40ppm	200ppm	10ppm
SO_2	100ppm	1000ppm	10ppm
NO_2	40ppm	100ppm	10ppm
HC	4000ppm	5000ppm	4000ppm

For detailed information on ranges and typical values of measurement refer to section 8 (technical data section) of the TESTO® manual.

1.5 Typical Lower Quantifiable Limits, Precision and Accuracy

(Not applicable)

1.6 Personal Responsibilities

Personnel carrying out this procedure are responsible for setting up for source sampling the TESTO® XL 350/454 for trace gas emissions performance of stoves, 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.

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 # 3.0 Calibration of TESTO® gas analyser.
- SeTAR SOP # 1.5 The heterogeneous testing procedure for thermal performance and trace gas emissions.

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 6 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 PC 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

The TESTO® flue gas analyser is program-driven and data is stored manually in xxxxx and an external spreadsheet via a compatible computer. The measurement cycle is set on

2.3 Maintenance

2.3.1 Filter change

If filters are visibly dirty, they need to be changed. Replace the filter if the pump performance drops (audibly). See TESTO® instruction manual for procedures in changing filters.

2.3.2 Changing the flue gas probe

If the flue gas is heavily laden with dust, it is possible that sections of the gas path preceding the hose filter will become contaminated or blocked. For the course filter, the surface filter is easily cleaned. Minor dirt can be removed by blowing out with compressed air. For thorough cleaning, an ultrasonic bath or use of a dental prosthesis cleaner is recommended. The filter must be replaced if encrusted or delayed. (Refer to the TESTO® instruction manual on how to change filters).

2.3.3 Recalibrating with test gases

The gas sensors are factory calibrated so that they can be used in the entire measuring range. Depending on the required accuracy, the sensors can be verified, recalibrated or calibrated to restricted measuring ranges with test gas. The calibration data is stored in the sensor's electronics, not in the instrument. Verification and recalibration as necessary is recommended every six months to retain the specific accuracy of NO_2, H_2S, HC, CO_{low} and CO_2i.

Ideally the test gas is applied directly to the tip of the probe to eliminate absorption in the gas path. The gas pressure must not exceed 30 hpa, ideally at zero pressure using a bypass.

2.3.4 Cleaning the pumps

Refer to the TESTO® instruction manual under section 4.1.8 on how best to clean the pumps.

Refer to the maintenance and trouble shooting guide for additional information.

2.4 Spare Parts

2.4.1 Hose set for conducting flue gas

Hoses for conducting flue gases are designed such that pressure does not develop on the measurement cell since this would lead to incorrect measurement readings. The hose is 5000 mm long and is intended to conduct flue gases away from the measuring instrument outside or to a safe place.

2.4.2 Wall bracket analyser

The wall bracket consists of a mounting bracket with a pipe, heat shield for analyzer box, and a lock. Under conditions of strong thermal radiation e.g. when attached directly to the flue, the heat shield is attached with clips to the handle and protects the analyser unit from excessive heating.

2.4.3 Hood

The hood is intended to protect the analyser box and the connected Control Unit against dirt and moisture. The hood can also be used in conjunction with wall bracket.

2.4.4 Carrying strap set

The carrying strap set consists of a carrying strap with two carbine hooks, two plastic clips, and a metal plate. The carrying strap can be used either for the analyser box or for individual control units.

2.4.5 Carrying case

The case is designed to allow the instrument to be operated whilst still in the case. However, ensure the gases can pass unobstructed from the exhaust opening. Do not close the case during measurements to allow the flue gas to dissipate.

2.4.6 Service case

The analyser is attached in the case by the handle. The accessory box can be clipped beneath the service case to hold further accessories.

2.5 Reagents

(Not applicable)

2.6 Gases

Recommended test gases by parameters from factory calibration of the TESTO® are presented in Table 2.

Table 2. Recommended test gases by parameters (TESTO® factory calibration)

Parameter	Test gas concentration
CO_{low}	300 ppm CO, 1.4% O_2, Rem. N_2
CO	1000 ppm CO, 1.4% O_2, Rem. N_2
$CO + CO_{low}$	400 ppm CO, 300ppm H_2, 5% O_2, Rem. N_2
NO_{low}	400 ppm, Rem. N_2 and 300ppm NO, Rem. N_2
NO	80 ppm NO, Rem. N_2 and 800ppm NO, Rem. N_2
NO_2	100 ppm NO_2, Rem. Synthetic air (SA)
SO_2	1000 ppm SO_2, Rem. N_2 or SA
H2S	200 ppm H_2S, Rem. N_2 or SA
HC	5000 ppm CH_4, Rem. SA
CO_2-IR	17% CO_2, Rem. N_2 and 40% CO_2, Rem. N_2

2.7 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.

3 CALIBRATION STANDARDS

The gases sensors are factory calibrated so that they can be used in the entire measuring range. Depending on the required accuracy, the sensors can be verified, recalibrated or calibrated to restricted measuring ranges with test gas.

4 PROCEDURES

4.1 General Flow Diagram

4.1.1 Operational procedure

1. Connect flue gas probe
2. Insert flue gas probe in the flue gas stream.
3. Switch on the TESTO® XL 540 flue gas analyser.
4. Zero all cells (zeroing phase): temperature measurement is conducted during the zeroing phase and is interpreted by the TESTO® as the combustion air temperature and is stored as the combustion air temperature value after the zeroing phase.
5. Set fuel if necessary.
6. Perform a fresh air rinse of the instrument. The probes are cleaned by blowing compressed air through their nozzles.
7. Start the calibrated gas analysis equipment and data logger (START TESTO®)
8. Constantly check for deviations in the operation of the machine (e.g. constantly check the pump flow rate. If it drops below 0.5 L/min, the tests has to be stopped)

9. At the end of the low power readings, STOP TESTO®
10. Save the data on the TESTO® and immediately export it to an Excel® data sheet for analysis.

4.2 Analyser Start-up

The following steps outline analyser start-up:

1. Connect the probe, Control unit and logger: the triple-function probe is connected to the probe socket of the Control Unit by the plug-in cable.
2. Position the flue gas probe in the flue gas stream.
3. Switch on the Control Unit: after the Control Unit has been switched on and a brief initialisation phase has elapsed, the readings of the connected probe and of the pressure sensor installed in the Control Unit are displayed.

4.3 Routine Operation

1. **P START** starts the measurement

4.4 Analyser Shut Down

1. **P STOP** stops the measurement

4.5 Abbreviated Operational Check List

4.5.1 Start 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.

4.5.2 Routine operation

- Constantly check on pump flow during the experimental analysis. If it drops below 0.5 L/min, the tests has to be stopped, the machine checked and re-runs performed.

4.5.3 End test and analyser shut down

- Store data if necessary under selected **Mem.** - manual storing of individual measurements.
- Export data to an Excel® file.
- Zero the sensors and perform a fresh air rinse of the analyser.
- Do not leave the site without acquiring data from any real-time monitors that may be operating at the facility.

5 QUANTIFICATION

5.1 Calibration Procedures

The gases sensors are factory calibrated so that they can be used in the entire measuring range. Depending on the required accuracy, the sensors can be verified, recalibrated or calibrated to restricted measuring ranges with test gas. The calibration data is stored in the sensor's electronics not in the instrument.

Verification and recalibration as necessary is recommended every six months to retain the specific accuracy of NO_2, H_2S, HC, CO_{low} and CO_2i. Recalibration in the < 500ppm (with CO_2-IR < 25 Vol. %) can lead to inaccuracies in the upper measuring range.

The high quality standards of the machine are confirmed by the ISO 9001 certificate.

5.2 Calculations

Principles of calculation are presented in the TESTO® 350/454 XL manual in section 6.1.

6 QUALITY CONTROL

6.1 Performance Testing

6.2 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. Analyser anomalies include high ambient O2 measurements, under estimation of total Carbon, and under estimation of gases in the sample. Inconsistent results for which a reason cannot be found must be rerun again.

6.3 Control Charts

If the process is in control, almost all points will plot within the control limits. Any observations outside the limits, or systematic patterns within, suggest the introduction of a new (and likely unanticipated) source of variation, known as a *special-cause* variation. Since increased variation means increased *quality costs*, a control chart *signalling* the presence of a special-cause requires immediate investigation. Control charts limit *specification limits* or targets because of the tendency of those involved with the process (e.g., machine operators) to focus on performing to specification when in fact the least-cost course of action is to keep process variation as low as possible. This makes the control limits very

important decision aids. The control limits tell you about process behaviour and have no intrinsic relationship to any specification targets or *engineering tolerance*.

The purpose of control charts is to allow simple detection of events that are indicative of actual process change. This simple decision can be difficult where the process characteristic is continuously varying; the control chart provides statistically objective criteria of change. When change is detected and considered good its cause should be identified and possibly become the new way of working, where the change is bad then its cause should be identified and eliminated.

Examples of control charts are presented below:

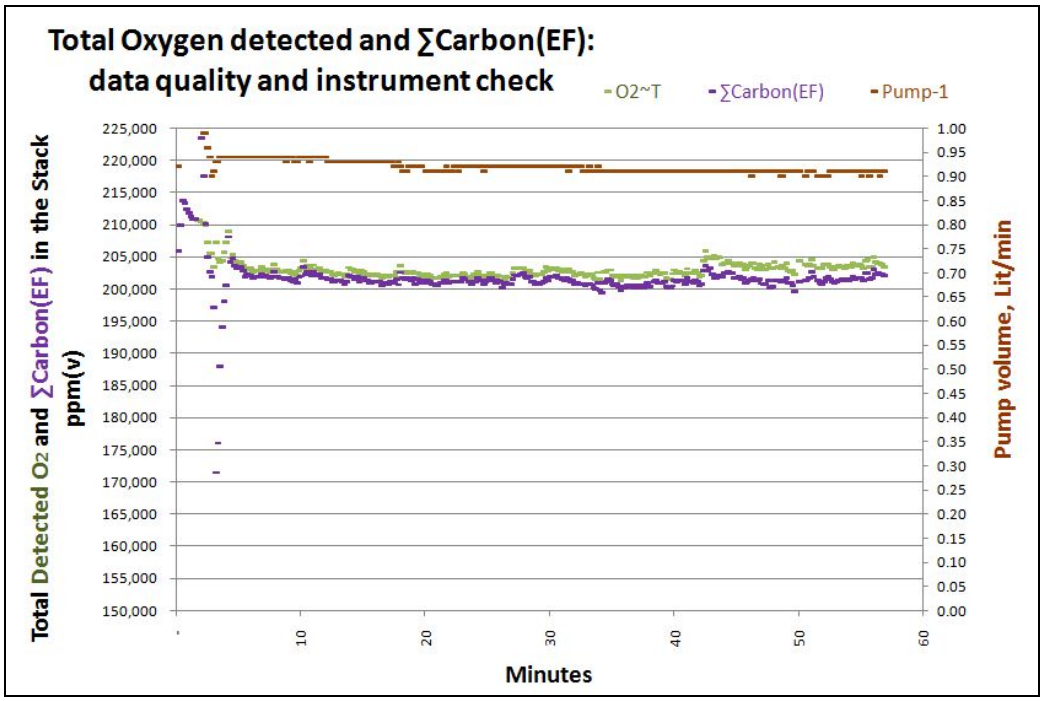

Figure 1: Example of good quality data on a control chart

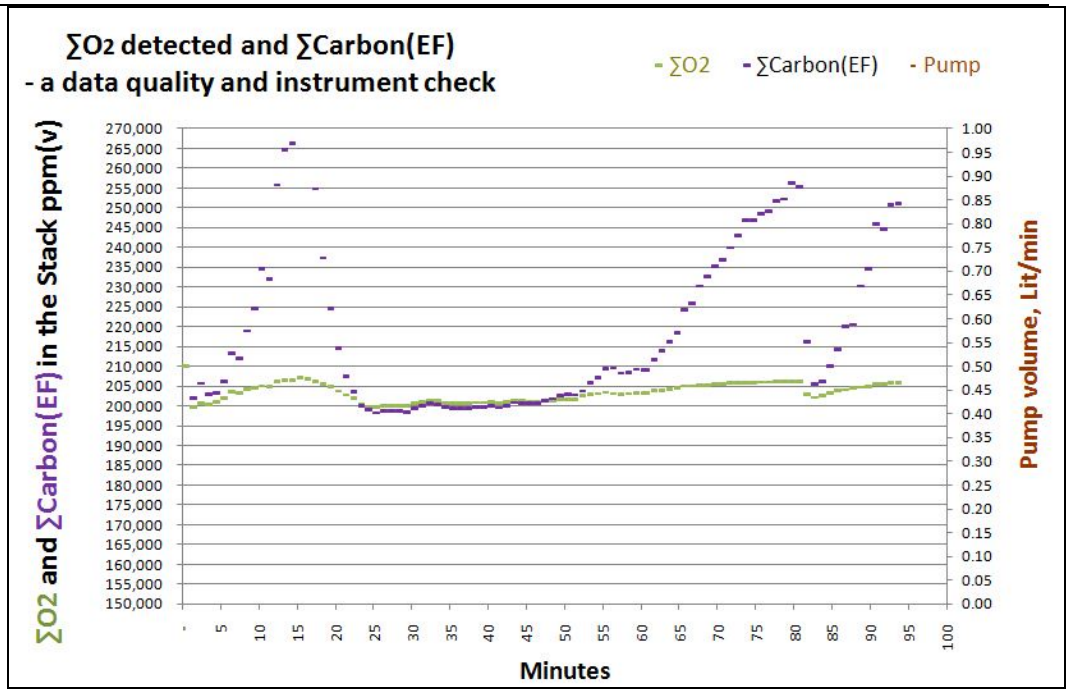

Figure 2: Example of bad quality data as shown on control charts

6.4 Daily Validation

Validation is done manually by checking the pumps before and after the analysis is performed. The following items are checked before the analysis:

6.5 Validation of Final Data File

The data from the TESTO® is exported to an Excel sheet for final data validation. Data are checked for consistency, and limits and ranges are verified for quality control purposes.

7 REFERENCES

Ahuja, D.R., V. Joshi, K.R. Smith, C. Venkataraman (1987), Thermal performance and emission characteristics of unvented biomass-burning cook stoves, *Biomass* ***12***, 247–270.

DRI SOP # 2-114r7: *PM2.5 FRM Gravimetric Analysis*, Revision No. 7, Desert Research Institute, Nevada, 2010.

DRI SOP 2-208.1: *Filter Pack Assembly, Disassembly, and Cleaning Procedure*, Revision No. 1, Desert Research Institute, Nevada, 1989.

Instruction manual for TESTO® 350M/XL, Testo AG, Germany. www.testo.de

SeTAR SOP # *The heterogeneous Testing Procedure for Thermal Performance and Trace Gas Emissions*, SeTAR Internal Report No. 01-10, University of Johannesburg, 2010.

8 DOCUMENT CHANGES

15 December, 2011: added signatures to the title page and adjusted page numbering.