# Emissions reductions from domestic coal burning: demonstration of an innovative bottom lit down draft stove

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# Background

- Despite decades of testing of low-smoke stoves and low smoke-fuels, particulate pollution (PM10) remains a stubborn air quality problem in the coal-burning low-income suburbs of South African.

## *Basa njenja Magogo* (BNM) as a medium term solution

- The Government has implemented a campaign to promote the use of ***top-lit, up-draft (TLUD)*** braziers (*imbaula*), as part of an integrated household energy strategy. The method, known colloquially as *Basa njenja Magogo* (BNM) (literally "*make fire like the old lady*").
- The BNM method can reduce PM10 emissions by up to 90%, mainly by combusting semi-volatile organics emitted during the initial volatilisation phase of the wood kindling and bituminous coal fuel.

# Imbawula (brazier) Right
# *Basa njenja Magogo* (BNM) Left

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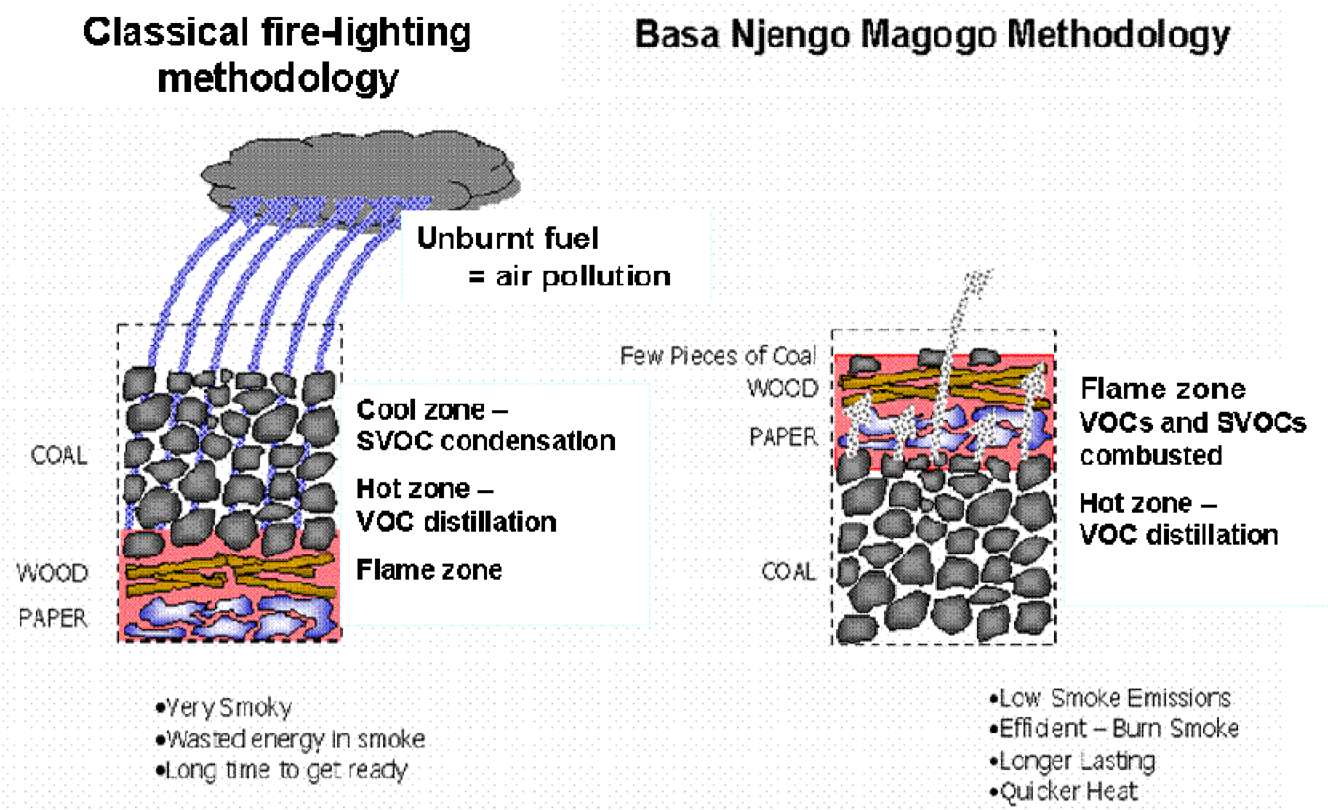
# The challenge

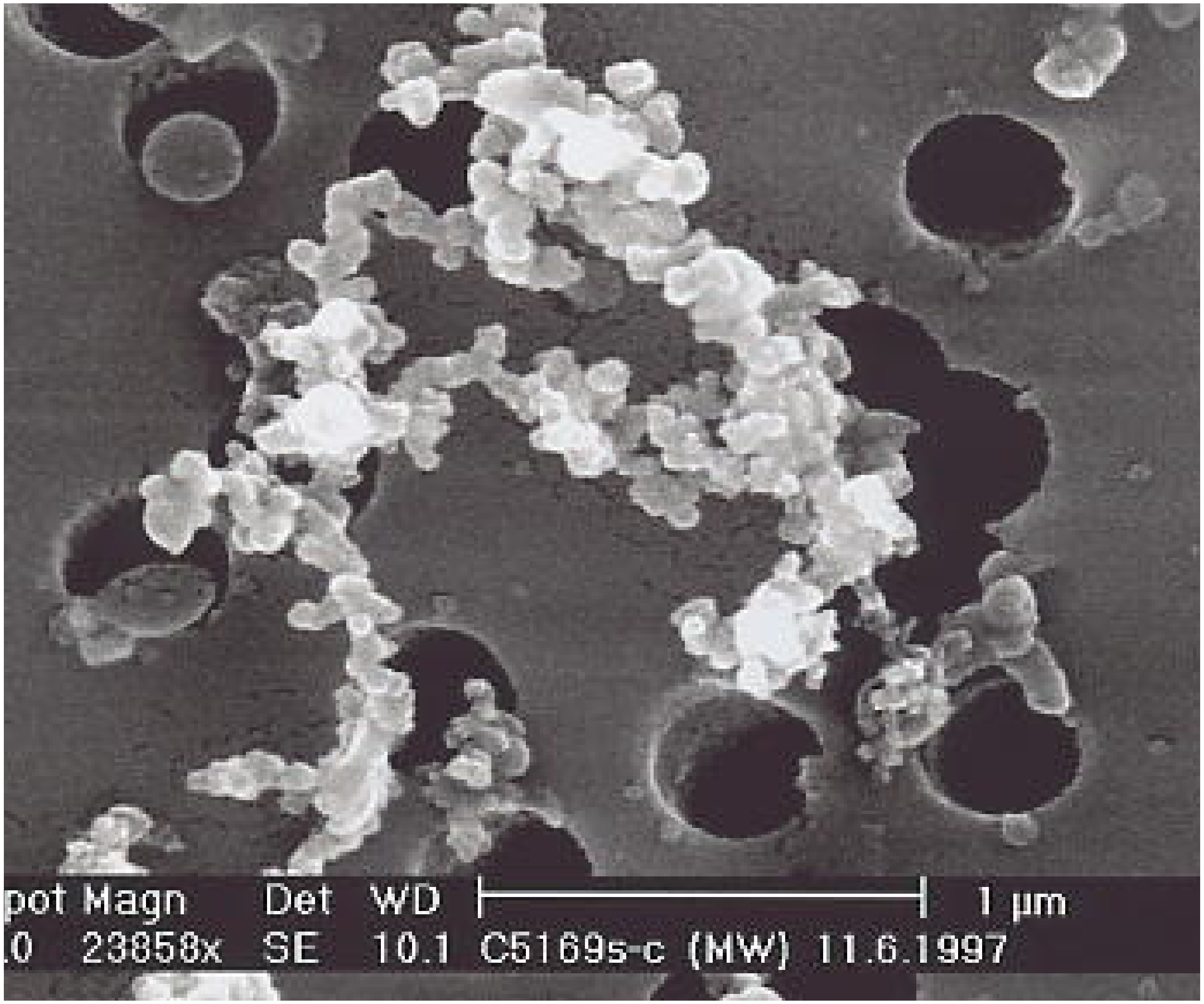
- However, the principles underlying the BNM have not been scientifically studied, optimised or adapted to the design of fuel-efficient, low-emission, affordable stove for the bottom end of the market.



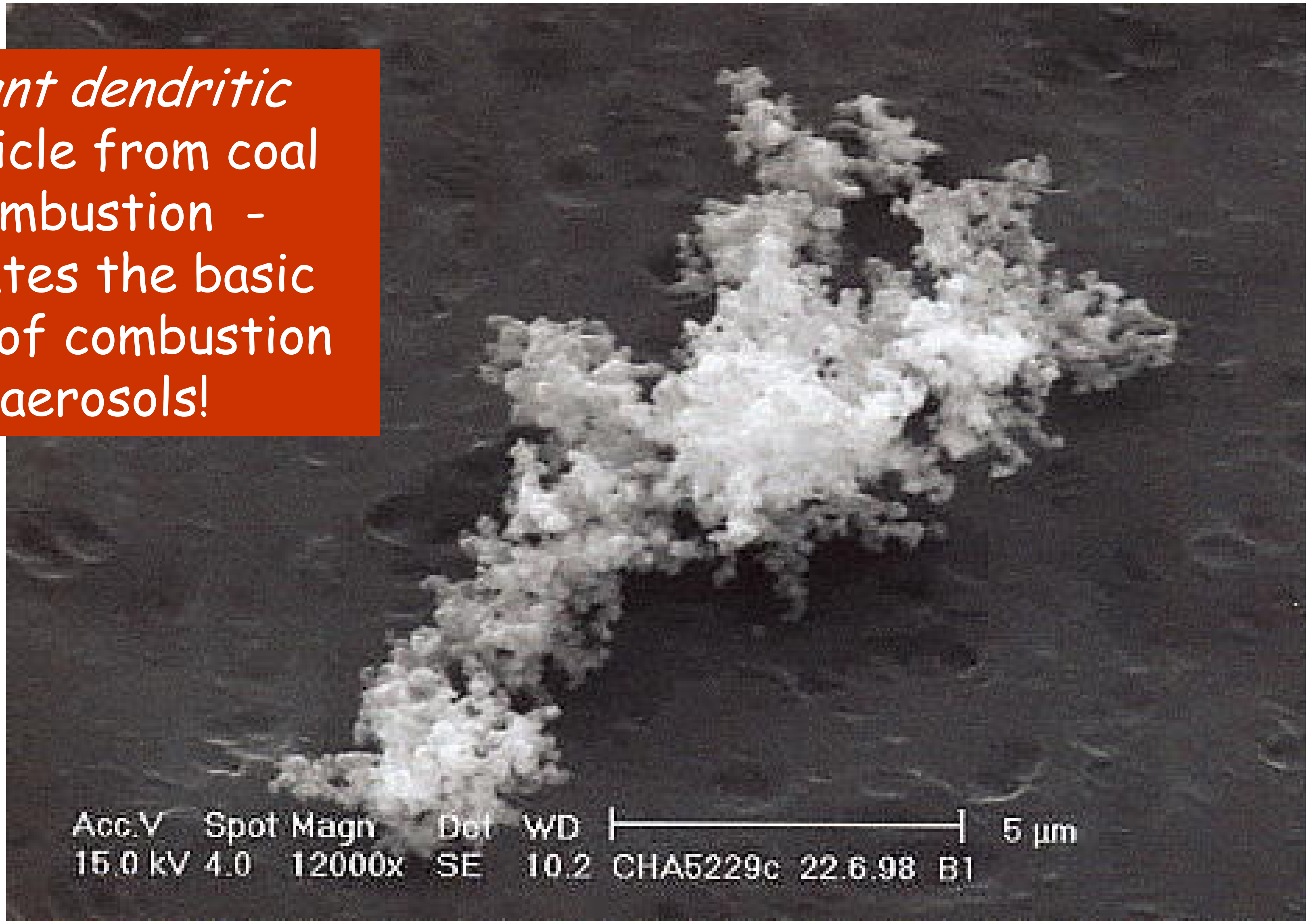
# Power Demand

- The design specification of a stove for this market segment requires a two-plate, 4 to 6 kW stove, burning bituminous coal, a 90% PM10 emission reduction, and low CO specific-emission factor (<2% avg. CO/CO2 ratio).
- We discuss the scientific principles of an innovative design of a ***bottom-lit, down-draft (BLDD) stove*** to meet these specifications.
- We report on emissions test results of a prototype device, using the SeTAR Centre ***heterogeneous stove testing protocols.***

# Properties of Soweto coal smoke aerosol: Tarry condensation particles from coal combustion in respirable size range



*Giant dendritic* particle from coal combustion - violates the basic laws of combustion aerosols!




**M Wentzel, HJ Annegarn, G Helas, S Weinbruch, AG Balogh, JS Sithole, Giant dendritic carbonaceous particles in Soweto aerosols.** ***South African Journal of Science*** 95 **(1999) 141-146.**

# Properties of Soweto coal smoke aerosol: Black carbon - small fraction of total aerosol mass (measured with a Magee aethalometer)

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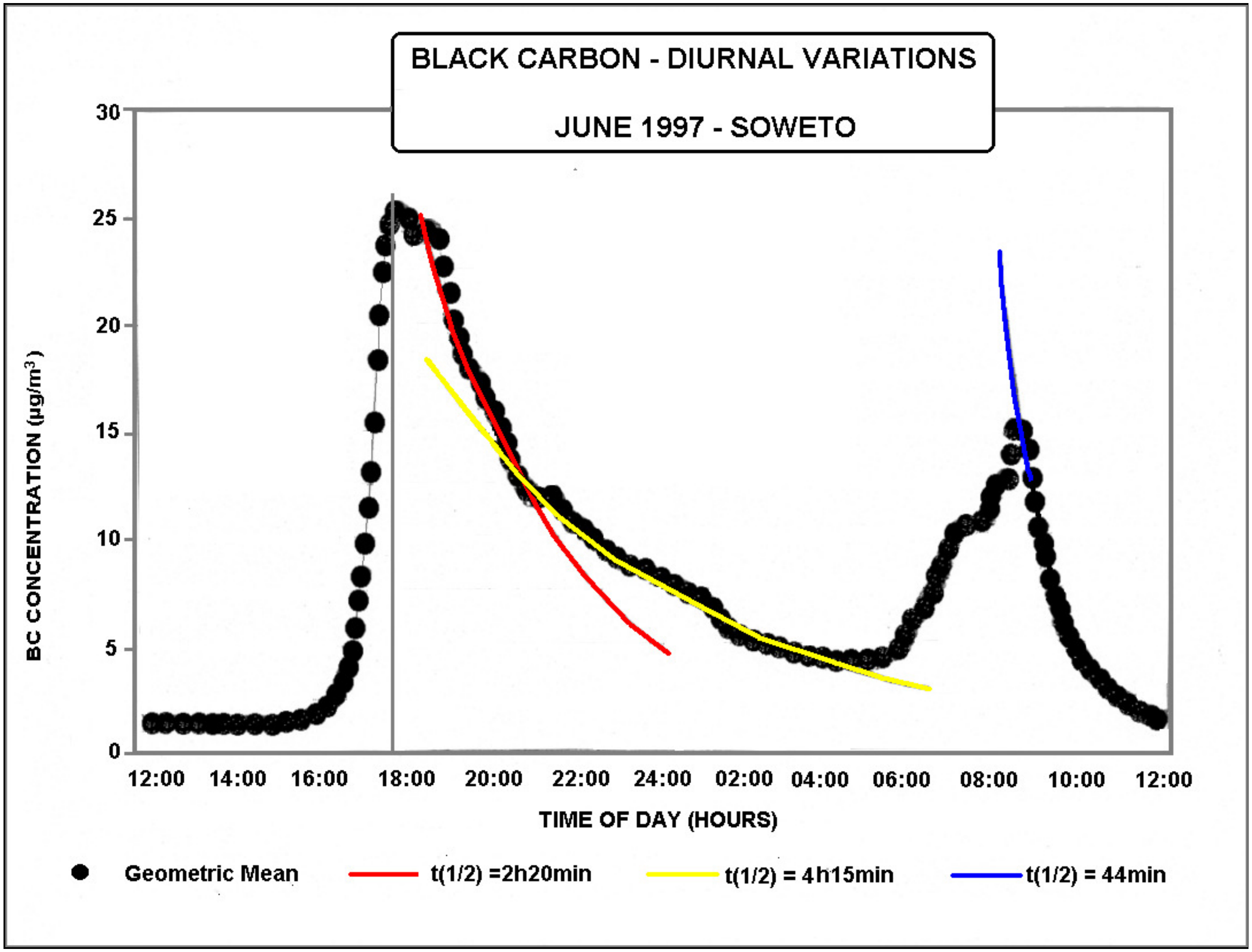

# Design principles of a Bottom-lit Down Draft (BLDD) stove

- Kindling is placed on the grate, with coal loaded above (As per traditional boy-scout fire lighting method)
- However, air is passed through the fire zone from the top downwards (*in apparent violation of the laws of physics that tells us that hot air rises!)*
- A bed of red hot coke lies on the grate, through which all volatiles and combustible gases must pass to get to a combustion chamber, which lies **below** the grate.
- A controlled quantity of pre-heated secondary is injected into the combustion chamber to produce a turbulent, high temperature flame with low excess air.
- The downward draft through the coal bed is sustained through the thermal draft induced by an appropriately designed chimney.

# CCP Mark IV 5 kW experimental downdraft stove

# Smoke extraction and test rig

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# SeTAR Heterogeneous Testing Protocols

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- Heterogeneous - '*diverse in character or content*'
- Standardised
- Operate the appliance at different power levels
- Use different pot sizes and volumes of water
- Use different loading and operating parameters
- Ultimately this gives a profile of the stove performance identifying optimal conditions and loadings.
- Differs from ***homogeneous testing*** where almost all parameters are fixed to arbitrary values.
- ***Heterogeneous testing*** covers most realistic operating scenarios, discovers hidden good and bad features.

# DustTrak DRX Aerosol monitor (Max 150 mg/m$^3$ & TESTO flue gas analyser

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# Setting the fire: 100g kindling;
# Fuel load: 1.1 kg bituminous coal (22 MJ/kg)

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# The fuel load is ignited

# Down draft is self-induced
# There is no smoke into the living space

# Pyrolization under way. All gases and smoke to down in the coal.

# Two plate cooking on a 6 kW BLDD stove
# The fire is under the pot on the right.

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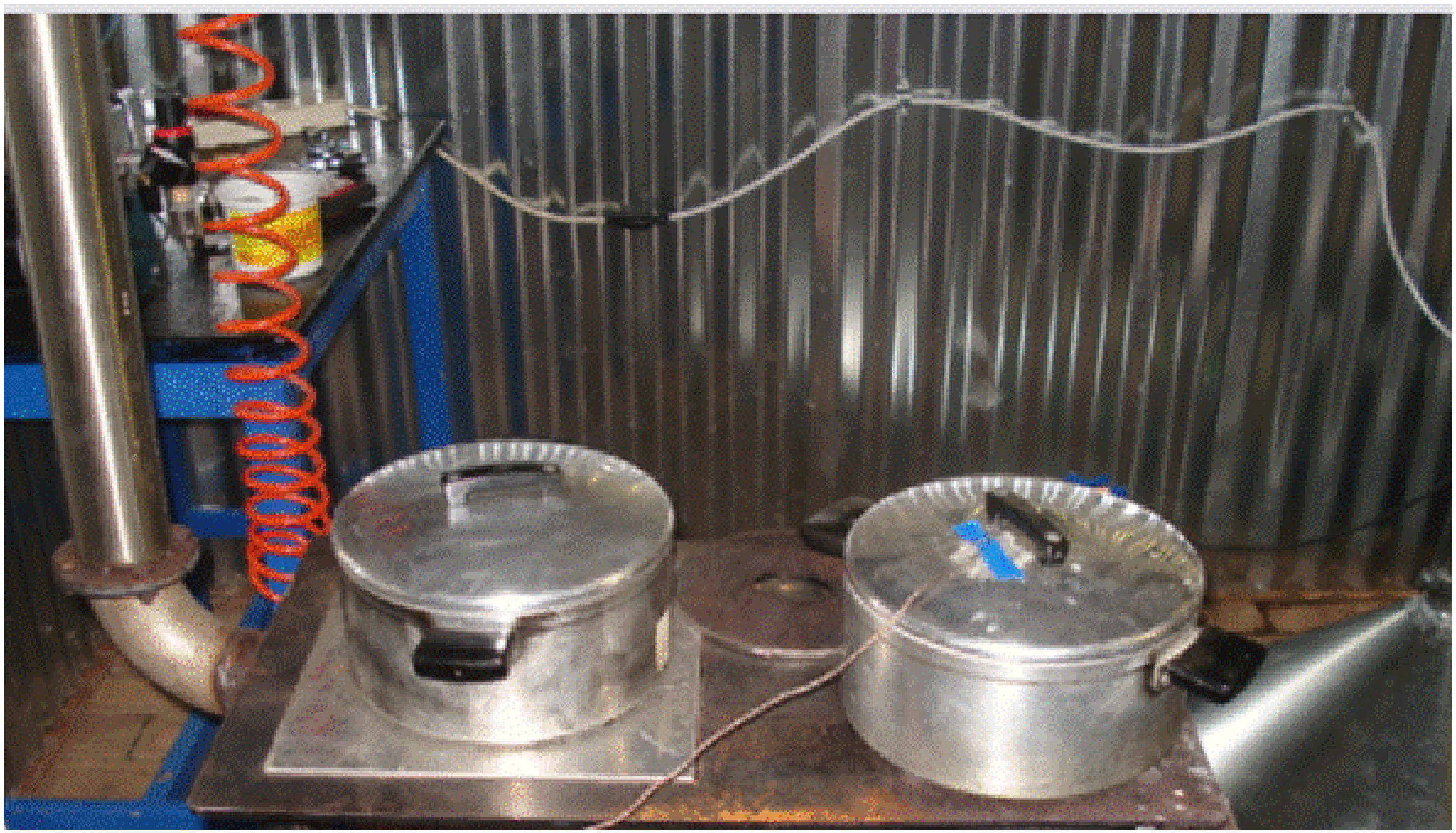
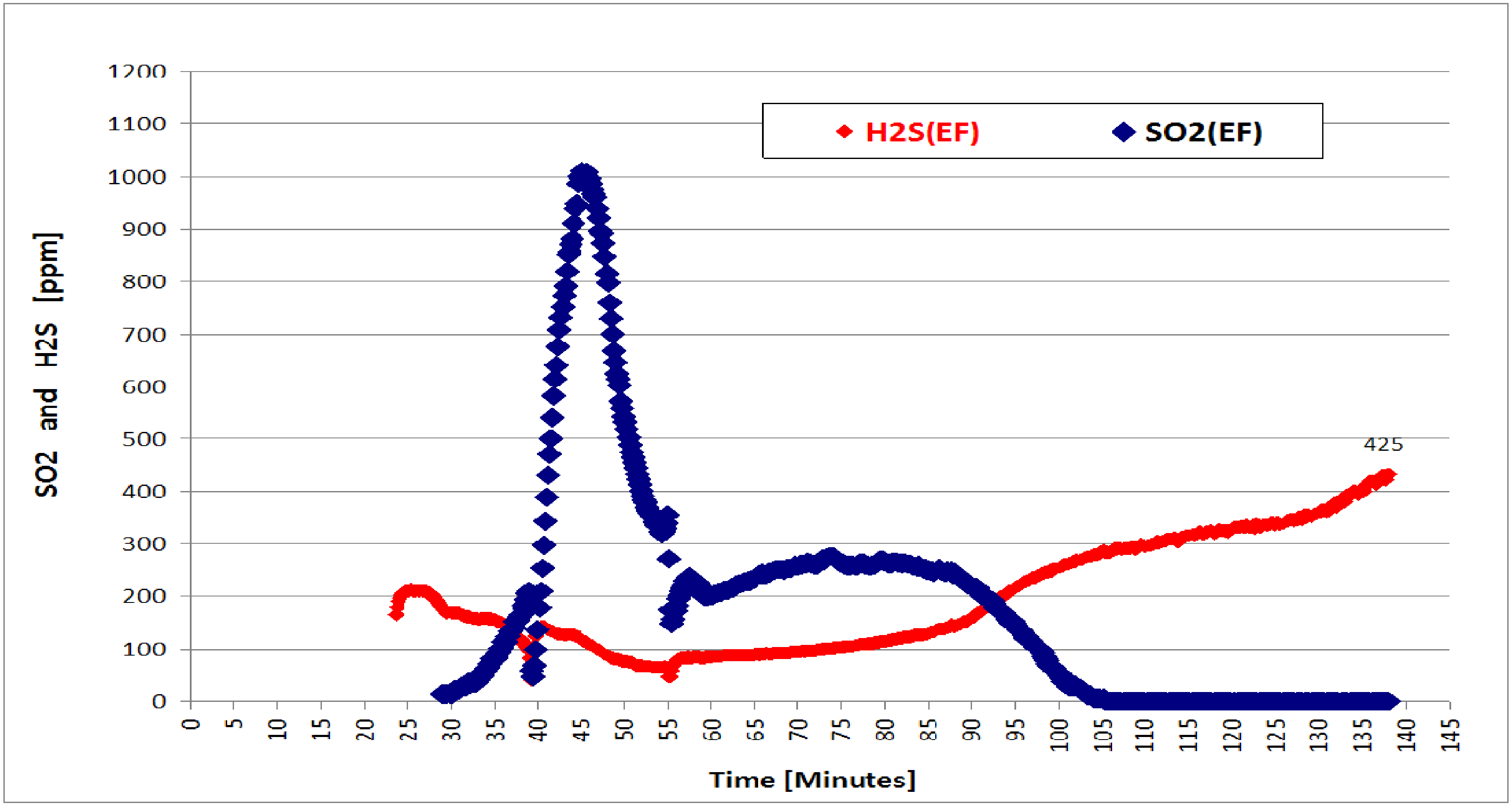


# Sulphur is liberated throughout the burn: emitted as $SO_2$ or $H_2S$



# Ignition phase – no secondary air supplied to the combustion chamber

# Pyrolyzation phase with secondary air supplied to the fire

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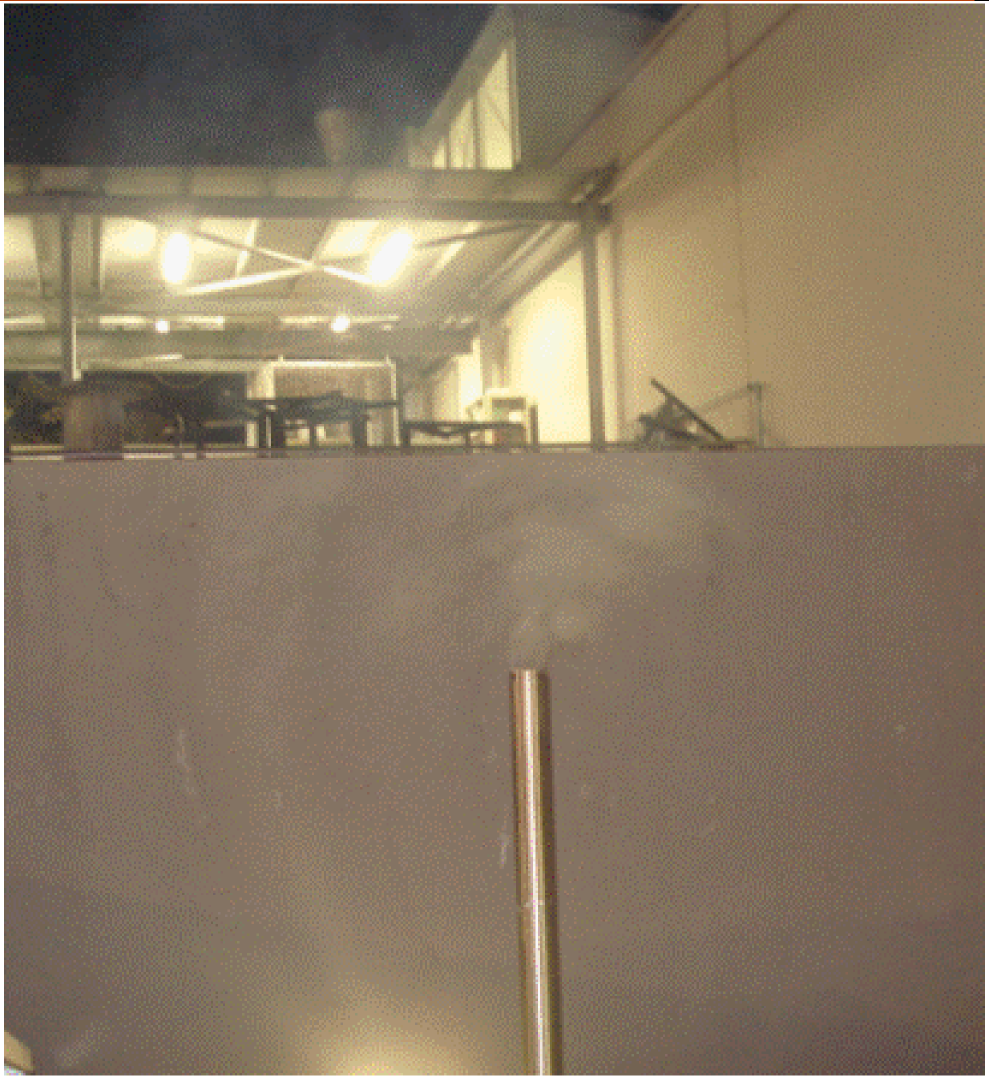
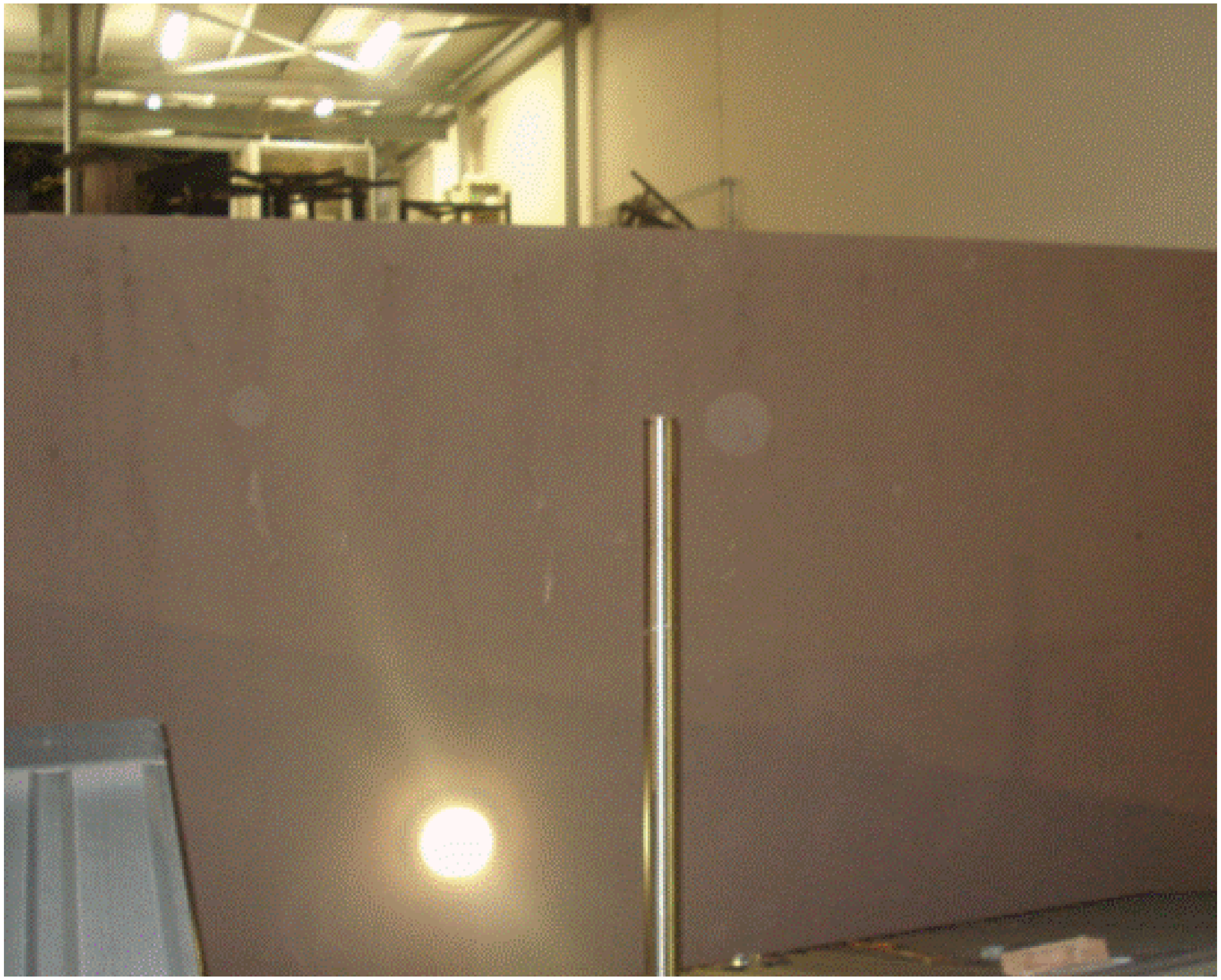


# Pyrolyzation well established – secondary air is hot: burns the smoke



# $CO/CO_2$ defines the combustion efficiency (lower is better)

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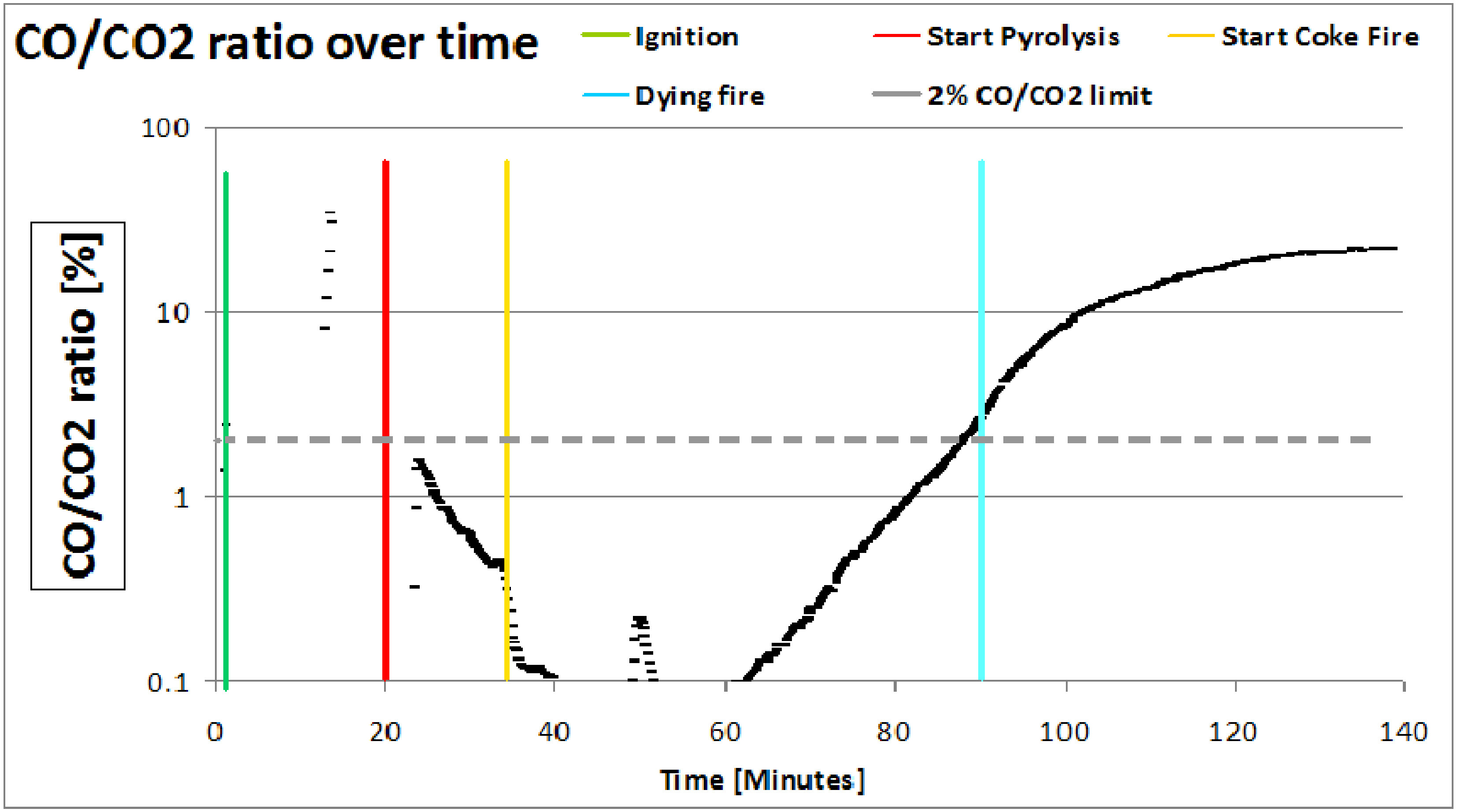
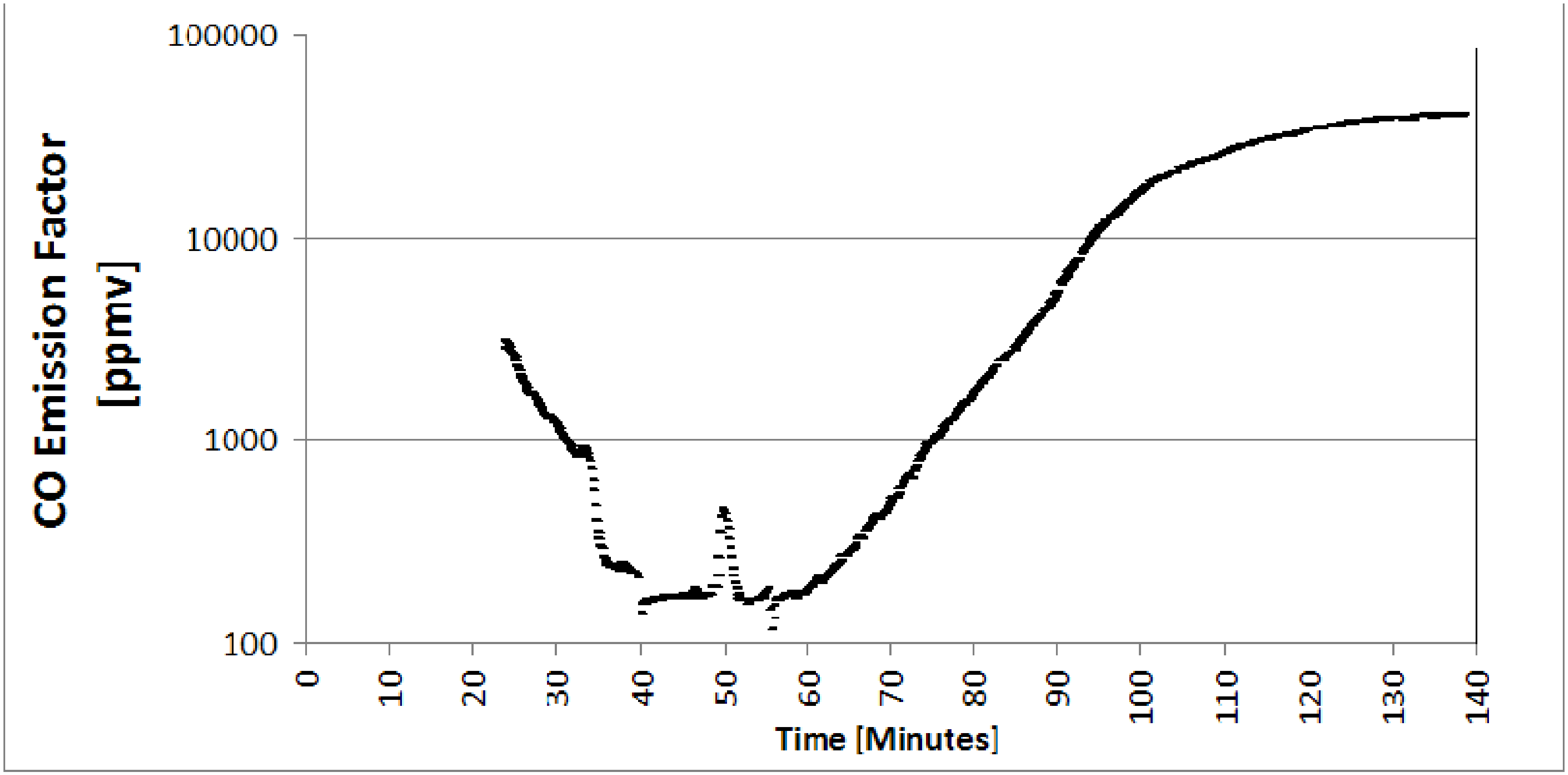
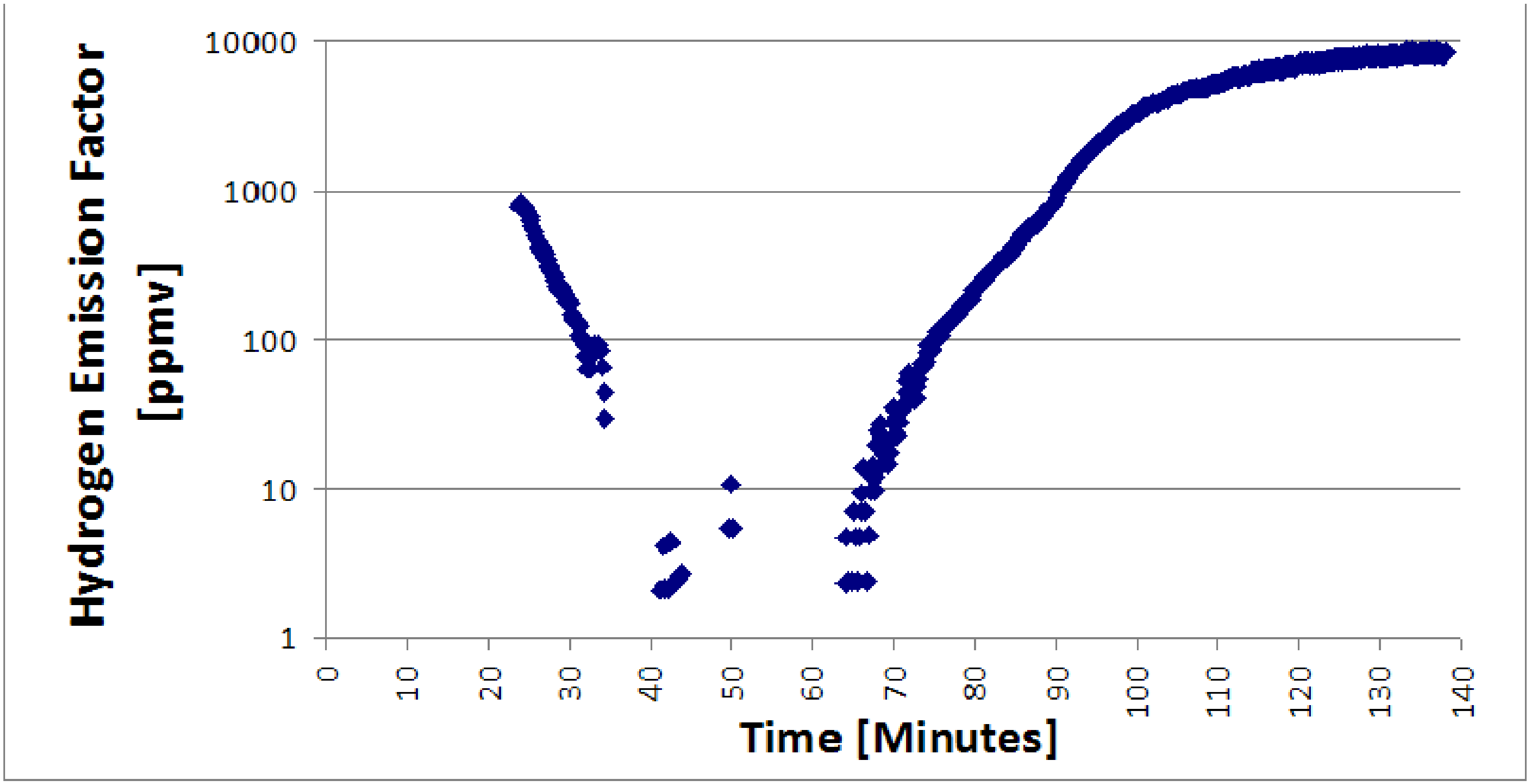


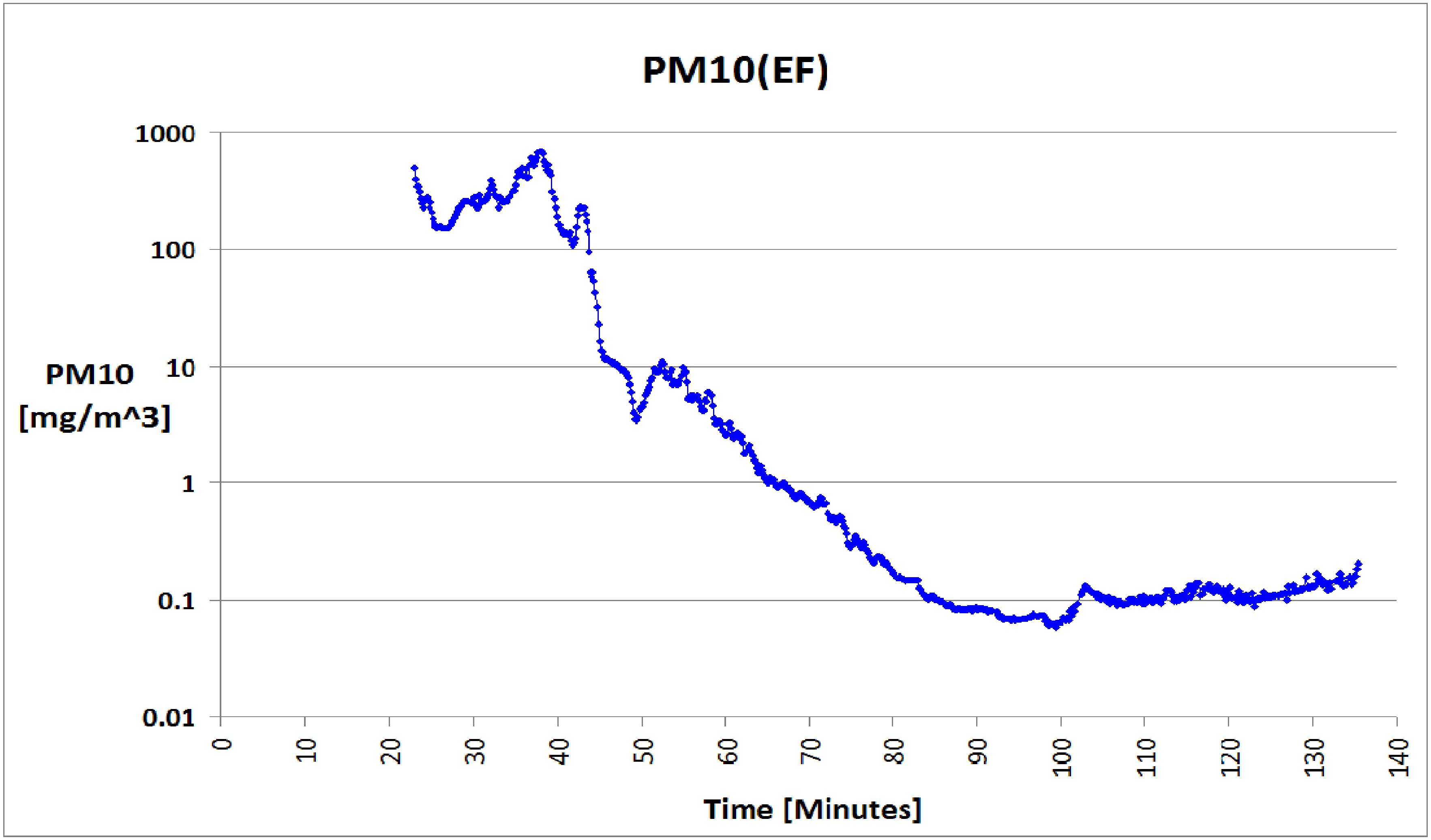
# Carbon monoxide emission factor (corrected to $O_2$=0%) vs time from ignition



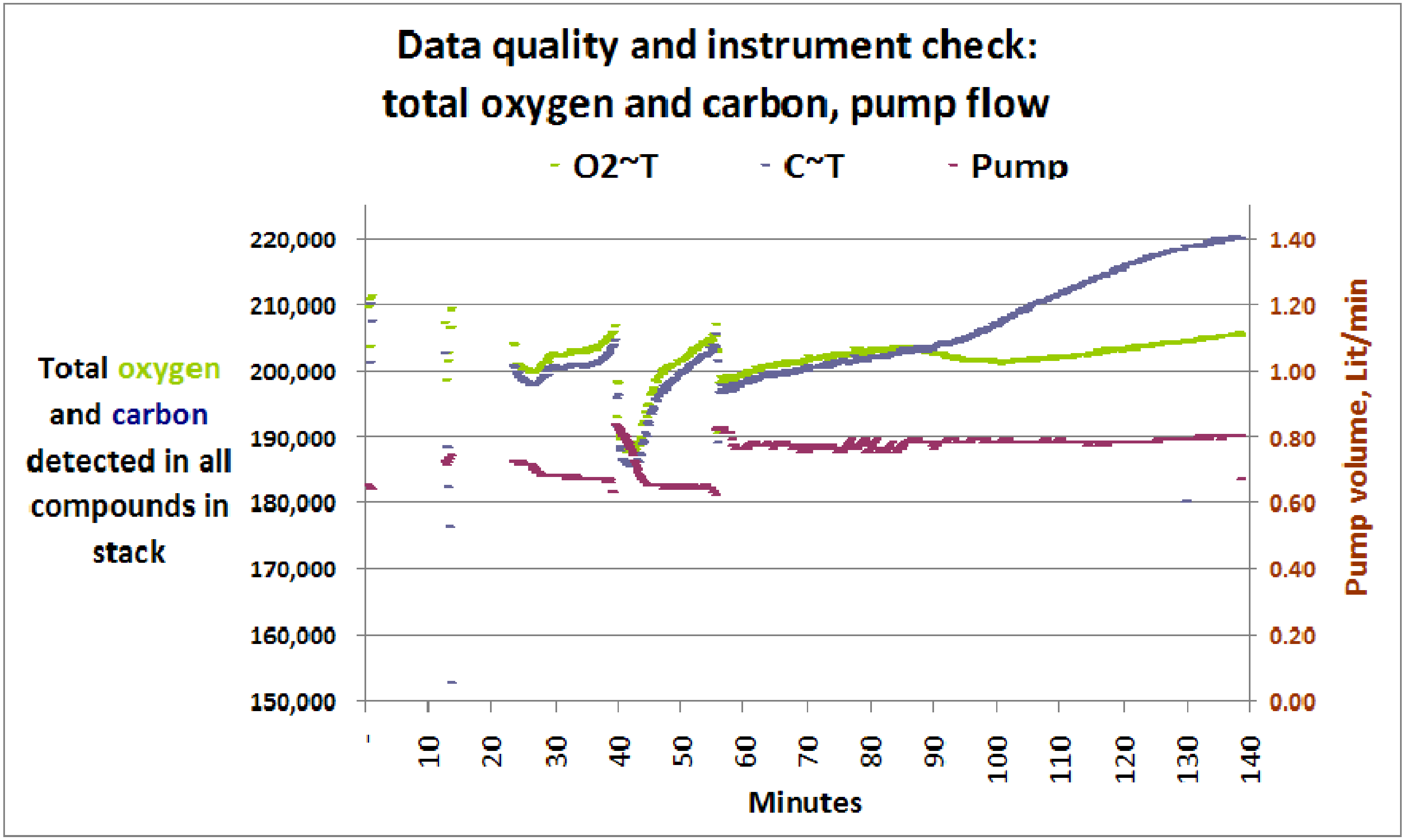
# Hydrogen emission factor $H_2$(EF), $O_2$ factored to 0%



# PM 10 (EF)
# $O_2$ factored to 0%



# The sum of all C and O detected is displayed to look for divergence



# Conclusions (1): Emissions reduction from a Bottom-lit down-draft stove

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A bottom-lit down-draft stove possesses unique features that hold great promise for burning low quality coals cleanly:

- A bed of red-hot coke on the grate, through which all volatiles and combustible gases pass to get to the combustion chamber below.
- This coke bed is continually shedding ash downwards into the ash hopper and being replenished from above by newly pyrolysed coal.
- If the underside of the burning coke is kept hot, the gases passing through ignite with complete combustion.
- Injection of a minimal requirement of pre-heated secondary air gives a turbulent, high temperature flame with low excess air.
- Compared with a conventional South African 'imbaula' (bucket stove) a reliable reduction in CO and particulates of 1 to 3 orders of magnitude has been achieved.

# Conclusions (2)

- Wide spread adoption of this stove technology in the poorest sectors of the population could contribute to attaining or maintaining PM10 and CO levels within the limits of current air quality standards.
- Despite widespread connection to the national electrical power grid within these communities, electricity is unaffordable for bulk uses such as cooking and space heating. Coal will remain the affordable energy option.
- This work forms part of the energy efficiency programme at the Sustainable Energy Technology Testing and Research Centre (SeTAR Centre), University of Johannesburg.

# SeTAR Centre

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- Publish and further refine testing protocols
- In process of upgrading test centre and equipment
  - Accuracy and error, speed, QA/QC
- Offer contract based testing services
- Looking to offer support where we can
- Work with other institutions in SA and wish to work with international partners
- Peoples Energy Network (PEN) – a network of African universities working on domestic energy solutions

# Compulsory Stove Standards

- South African National Standards (SANS) protocols acknowledge that the emissions result from a combination of 1.) the stove, 2.) the fuel, and 3.) the pot(s). The combination needs to be optimised, not only one of them.
- In testing, a stove should be operated at multiple power levels to look for dramatic changes in emissions. Stove tests tend to be operated at high power so the products are designed to work well in that condition. Emissions may be higher at lower power settings.
- A stove use profile relevant to the target consumers should be an element of compulsory specifications.

# Acknowledgements


- CEF and GTZ BECCAP for commissioning the work.
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# Discussion

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