Influence of fuel-bed temperatures on CO and condensed matter emissions from packed-bed residential coal combustion

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Introduction

- Coal is used as a primary source of energy for generation of electricity, industrialization and enhancement of standard of living for the increasing populations.

- In RSA the fuel is burned in self-fabricated and inefficient cooking devices.

- Particulate matter emissions from coal are receiving significant attention from regulatory authorities and environmental scientists because of their effects on health.

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Introduction

- Fine particulate formation mechanisms and partitioning, as well as factors influencing these, need to be studied in detail in order to develop novel technologies that are less polluting

- Researchers have reported on temperature profiles, product gas composition, and reaction zone propagation rates in the fuel-bed for different types of biomass systems.

- There is still scarce information available on fuel-bed temperature profiles and reaction zone propagation rates for different types of packed bed residential coal-burning devices.

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Approach

- **Investigate the reaction zone propagation rates, and the influence of fuel-bed temperatures on the emission characteristics of CO, condensed matter emissions (PM10), and resultant particle morphologies, especially during the ignition and pyrolization phases of the fire**

- **Scanning electron microscopy with energy-dispersive X-ray analysis (SEM/EDS) [Vega3 in Spectrau, UJ] has proved to be a valuable tool for analysing single particles from combustion processes.**

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Significance of research

- This work is significant in that there is still scarce information available in literature on fuel-bed temperature profiles/stratification for packed-bed residential coal-burning devices.

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Methodology – Braziers

- **A high air ventilation *imbaula* obtained from actual use in the field was tested for temperature stratification in the fuel-bed during normal use, with associated emissions of gases and particles.**
- **Tests were conducted under laboratory conditions at the SeTAR Centre situated at the University of Johannesburg.**

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Methodology – Fuel Analysis

- **Experimental fuels were tested and analysed using appropriate standard methods at an independent laboratory.**

Parameter (Air Dried Basis)	Standard Method	Slater Coal D-Grade
Moisture content (%)	ISO 5925	3.5
Volatiles (%)	ISO 562	20.3
Ash (%)	ISO 1171	24.2
Fixed carbon (%)	By difference	52.0
Calorific value (MJ kg^{-1})	ISO 1928	23.4
Calorific value (Kcal kg^{-1})	ISO 1928	5590
Total sulphur (%)	ASTM D4239	0.63
Carbon (%)	ASTM D5373	62.6
Hydrogen (%)	ASTM D5373	2.72
Nitrogen (%)	ASTM D5373	1.43
Oxygen (%)	By difference	4.96

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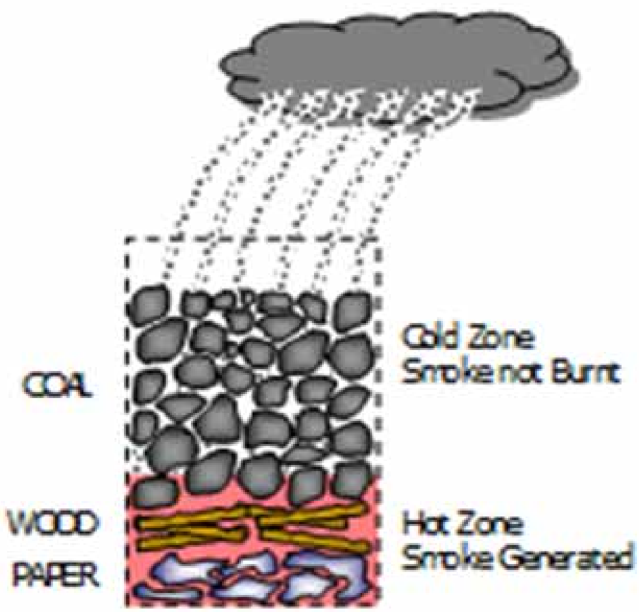
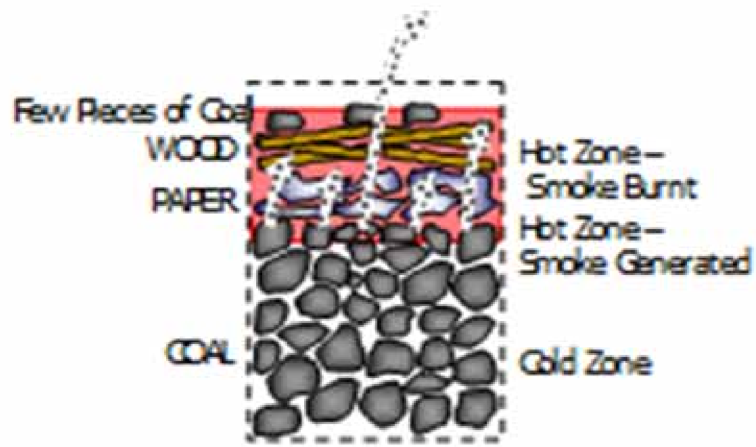
Methodology – Ignition method

Classical Fire-lighting Methodology



- Very Smoky
- Wasted energy in smoke
- Long time to get ready

Basa njengo Magogo Methodology



- Low Smoke Emissions
- Efficient – Burn Smoke
- Longer Lasting
- Quicker Heat

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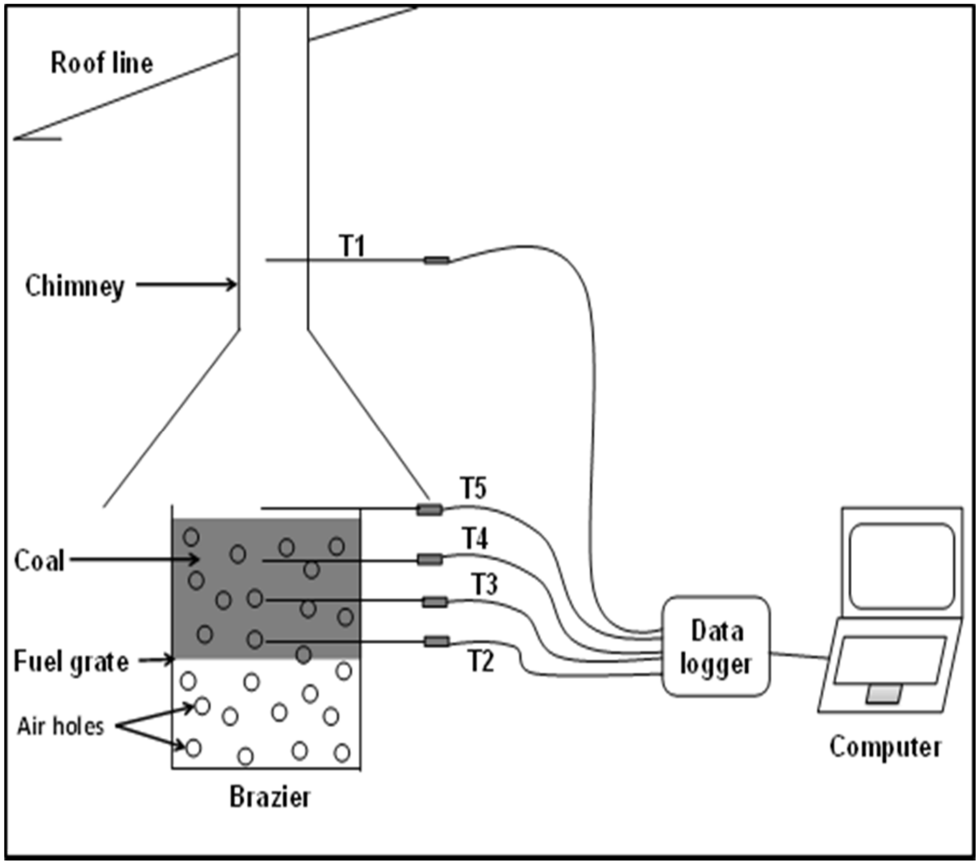
Experimental Set Up



- It can be argued that at any point of time during the combustion of coal in a brazier, the temperature distribution in the stove is a good indication of the nature of chemical reactions occurring.
- Bed temperatures were measured by introducing 5 mm K-type thermocouples at intervals along the length of the stove as shown in Fig.
- The thermocouples were placed at least 100 mm apart from each other, and it is assumed that they maintained this distance during the entire burn cycle.

This set up allows one to create temperature plots which show the propagation of the reaction front through the packed-bed

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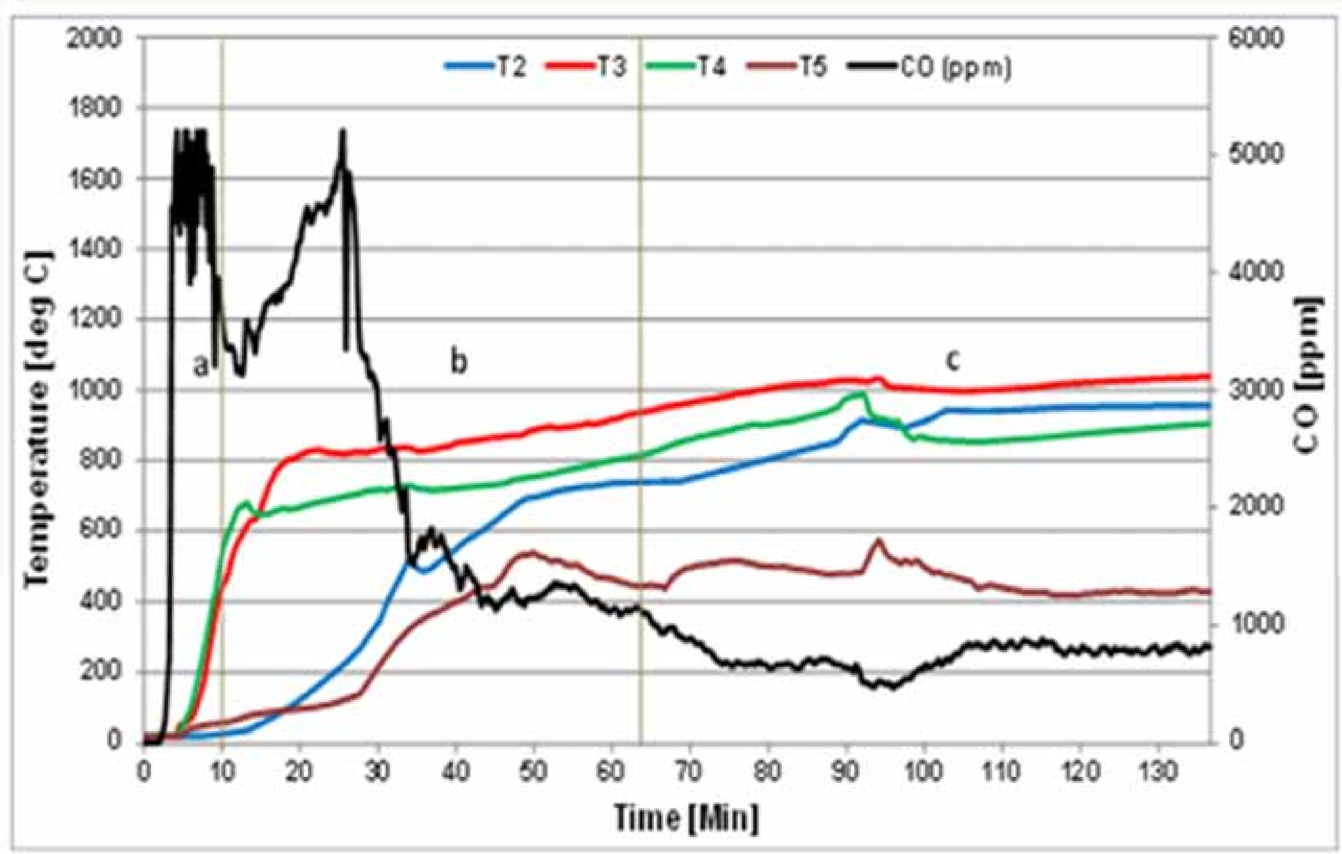
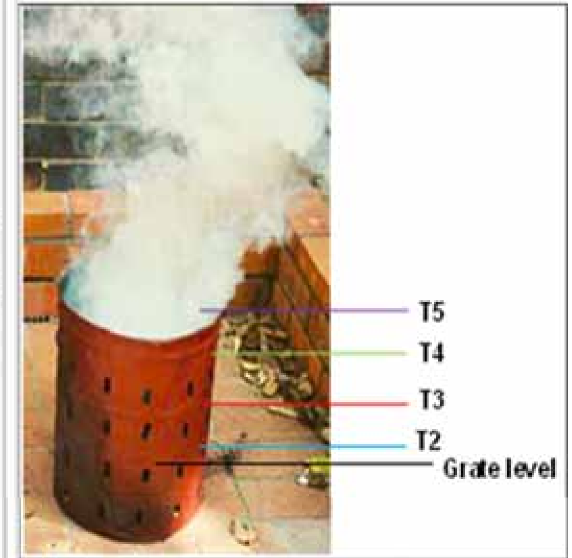
Results – *Temperature profiles for the BLUD method*





For the BLUD, ignition at the bottom creates an upward migrating pyrolytic zone that is starved of oxygen; generating a pyrolytic gas (CO, H_2O, volatile and semi-volatile organic compounds), char and low flame temperatures (indicated by curve T5, Fig. 3, from 0 to 30 min after ignition).

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Discussion – *BLUD temperature profile*

- Temperature T3 (indicated by the red line) is the initial hot zone in the middle of the fire bed where the kindling and coal undergoes thermal decomposition.

- The removal of these volatiles increases the pore volume in the coal structure. The tars and semi-volatile organic compounds become pre-mixed with air around the surface of the coal macromolecules.

- Homogenous gas phase combustion of this pre-mixed fuel/air mixture occurs. The hot combusting gas mixture rises, using up available oxygen, and passes through the cooler coal above (indicated by T4) heating up the coal and thermocouples by radiation and convection.

- The semi-volatiles subsequently condensed into droplets as the cooling gas mixture passes through T5 (area above the top brim of the brazier) into the atmosphere, resulting in the formation of a dense plume of white smoke.

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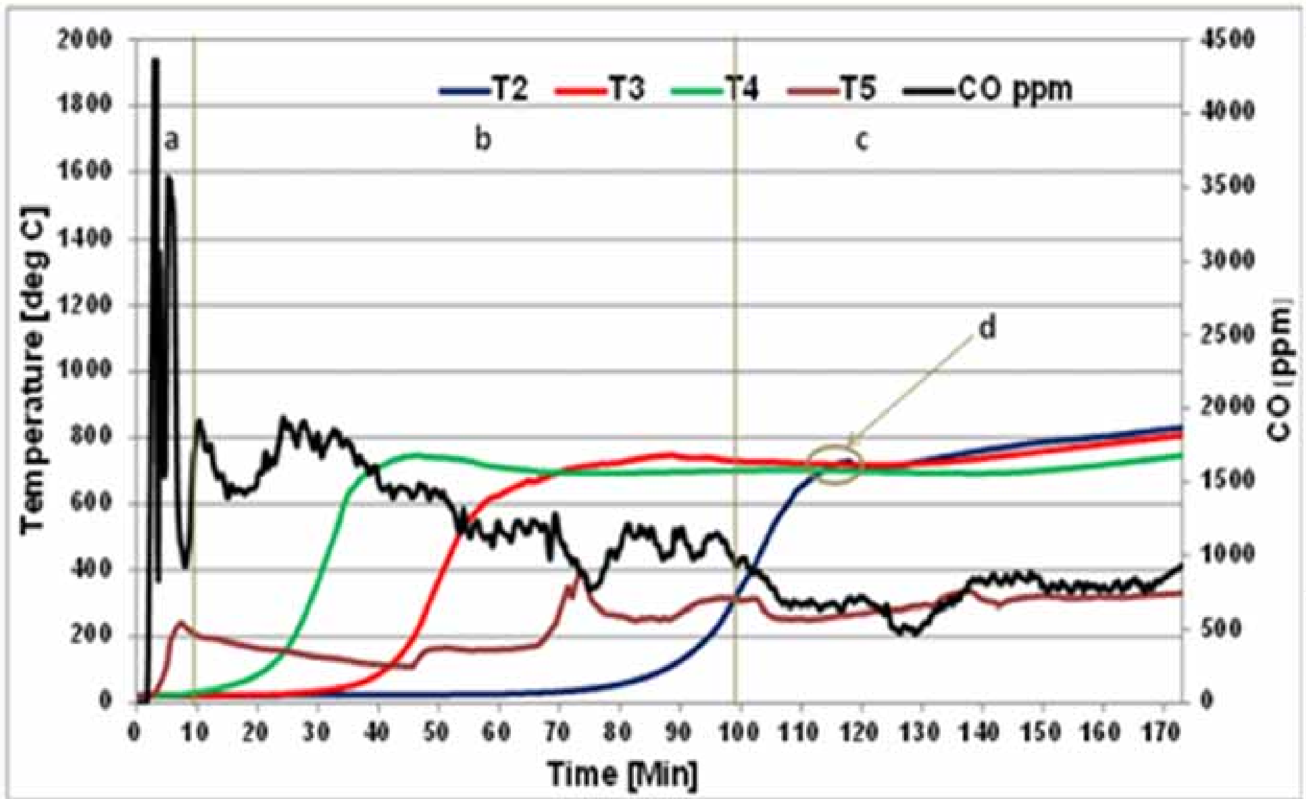
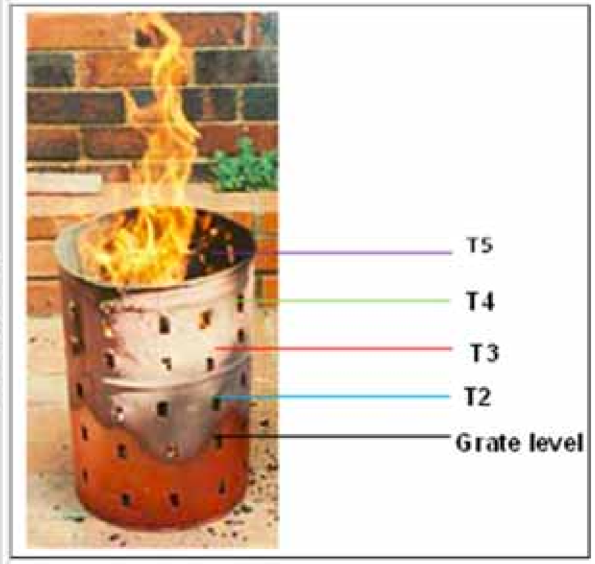
Results - *Temperature profiles for the BLUD method*





- The ignition of a batch of fuel from the top creates a downward migrating pyrolytic zone
- We see that for each thermocouple, the temperature remains near ambient until the pyrolysis front approaches, whereupon the temperature rises rapidly to a plateau

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Discussion – *TLUD temperature profiles*

- It took ~ 35 min for the pyrolytic front to reach thermocouple T3 and another 35 min to reach T2 from T3.
- The thermocouples were placed ~100 mm from each other inside the fuel stack. This equates to a rate of pyrolytic advance of 3 mm per min.
- T2 (indicated by the blue line) shows a colder zone filled with the bulk of the coal, which produces volatile matter and tars upon heating. This volatile matter rises through the hot flame zone (at T4) with a sufficient supply of oxygen to allow for complete homogeneous gas-phase combustion
- This results in a significant reduction in visible smoke and particulates. The flame that can be seen jumping out of the stove (T5 as indicated by the brown line) is as a result of an increase in the homogeneous gas phase combustion rate

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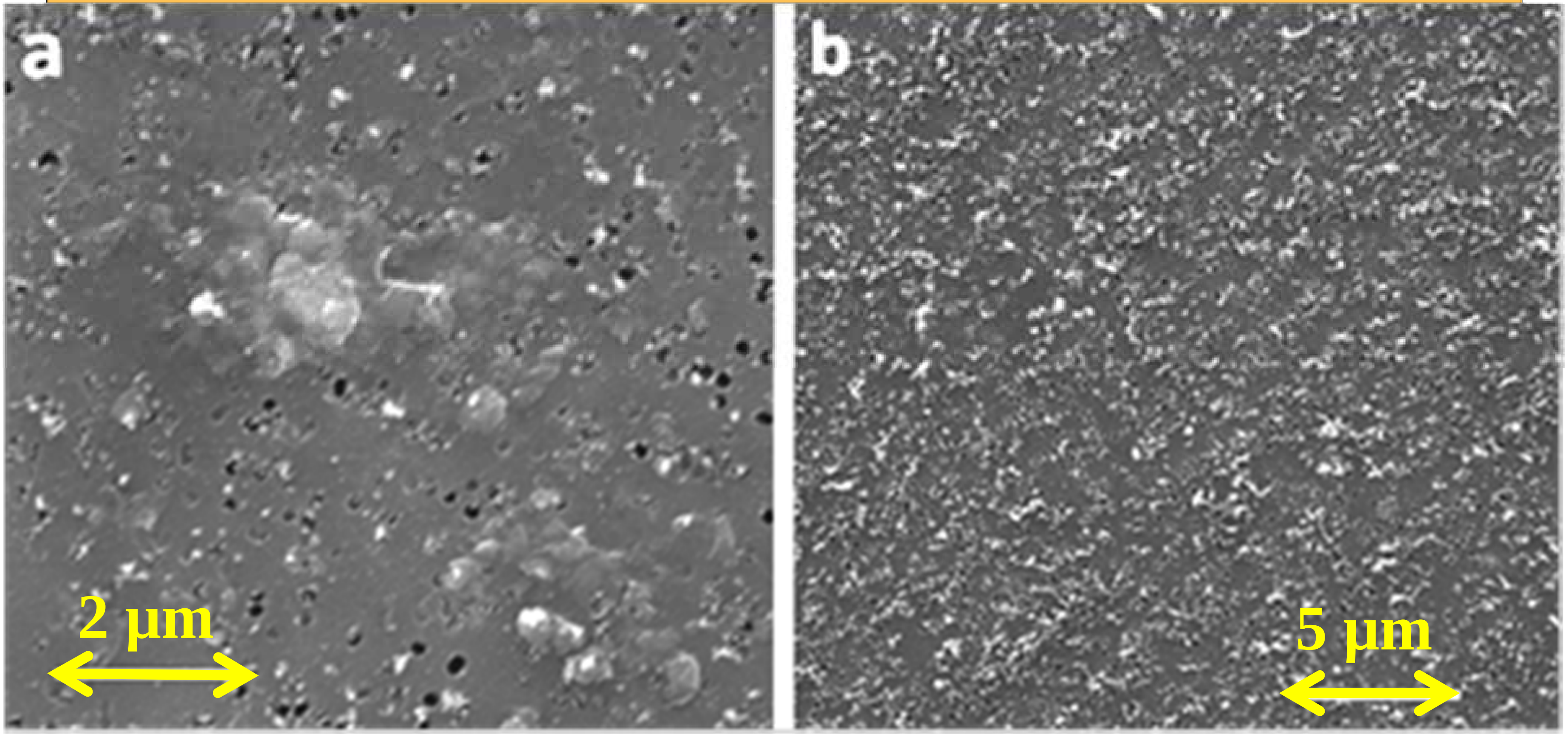
Morphological characteristics of particles



Presence of liquid condensed matter that has coalesced to form a layer which covers filter pores. Energy Dispersive Spectroscopy (EDS) showed that this thin film is dominated by C and O with traces of Mo, Zn and Fe.

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Morphology cont..

- **When employing the BLUD method, an oxygen depleted atmosphere is created in the brazier above the pyrolytic zone and the gradual heating of the coal allows for the semi-volatile organic compounds to be released from the solid fuel and, on cooling, condense.**

- **Especially during the pyrolisation phase and immediately after refuelling, conditions would favour evaporation and re-condensation, rather than combustion, of volatile and semi-volatile fractions..**

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Morphology cont..

- **This suggest that at lower particle concentration and a higher degree of drying of liquid aerosols (i.e. the decay phase), partially or completely solidified primary spherules can be formed, and as they aggregate they form conglomerates.**
- **The decrease in the yield of the conglomerates with increasing temperature (i.e. high temperatures at pyrolysis in the TLUD compared to the BLUD method) can be explained by the stability of tar molecules at high temperatures and the reactions of tar by gaseous species existing in the post-flame region of the stove**

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Conclusion

- Temperature stratification was found to depend on the fire-ignition methods. The propagation front progressed faster in the BLUD compared to the TLUD - Devolatilization reactions were faster than reduction reactions.
- Temperature difference per unit length of the fuel bed (temperature stratification) was larger during the ignition and pyrolization phases of the fire but comparatively less during steady coking phase of the fire.
- Bed temperatures were found to have an effect on the nature and characteristics of gaseous and condensed matter pollutants emitted from the braziers.

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Acknowledgements

- Spectrau - University of Johannesburg, for use of the SEM/EDS
- University of Johannesburg for financial support through a URC/Faculty of Science grant to the SeTAR Centre
- Global Alliance for Clean Cookstoves (GACC), for support of SeTAR Centre as a Regional Stove Testing and Development Centre
- Thokozile Sithole (SeTAR Centre, University of Johannesburg) and Yixiang Zhang (China Agricultural University) for assisting with sampling and interpretation of the results.
- Daniel Masekameni (University of Johannesburg) for providing the braziers from his field surveys
- David Kimemia (SeTAR Centre, University of Johannesburg) for editing the manuscript

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