this study, the flaming and the ‘mixed’ phases were collectively used under a single umbrella term ‘flaming phase’, since the flame is still visible during the ‘mixed’ phase.

The distribution during the coking phase showed a near unimodal particle size distribution with a GMD of 32.8 ± 5.1 nm and a mode of 31 nm (Fig. 8). The size distribution indicates that particle number concentration gradually increases above 180 nm. Particle number concentration during this phase is comparable to particle number concentrations during the flaming phase. A possible explanation for this is that during the coking phase (at the top of the fuel bed) there will be some coal still igniting and pyrolyzing at the bottom of the fuel bed. As the particles pass through the burning red-hot combustion zone, they are burned resulting in the emission of particles with a lower GMD. The results presented under this phase are similar to the one presented by Li *et al.* (2017), however the study focused on particle size distribution from a coal fired power station. A unimodal distribution was found but the average particle size was above 10 μm.

In Fig. 9, the coking phase was separated into two stages (i.e. early and late coking). Separation of the combustion phase did not produce different number size distributions, with the distribution similar to the entire phase average as indicated in Fig. 8. This is because the combustion conditions at this stage are homogeneous, with no visible flame nor smoke. Heat produced is in the form of radiant heat, and all volatiles have been driven out at the end of the flaming phase, and only fixed carbon burns with oxygen adsorption and temperature limiting the rate of combustion.

In Fig. 10, number size distribution and particle number concentration corresponding to the entire burn sequence are presented. The average number size distribution for the whole combustion sequence was found to be near bimodal, with a particle mode of 130 nm. After this mode, above 180 nm, particle number concentration was reduced gradually, and the GMD and mode were determined to be 51.6 ± 2.0 nm and 50.6 nm, respectively.

Other studies also showed PSD from all combustion phases to be bimodal with particle concentrations peaking between 30 and 150 nm (Hedberg *et al*., 2002; Hays *et al*., 2002; Zhang *et al*., 2011; Zhang *et al*., 2012; Hosseini *et al*., 2010). Bond *et al*. (2002) observed that when burning coal briquettes particles are emitted in size range between 20 and 100 nm. Earlier lab-based studies have found bimodal PSD from pulverized coal combustion with fine particle mode peaking at around 100 nm (McElroy *et al*., 1982).

Based on the results given in the figures above, where combustion phases were separated, and size distribution have been reported at each stage offers a meaningful insight on this subject (Fig. 10). Since the combustion conditions are not constant throughout the whole burn-sequence, it is essential to indicate number size distribution for each identical burn sequence. Looking at Fig. 10 only, one concludes that emissions of particles above 80 nm are attributed to the entire burn sequence. While the contribution of larger particles is associated with the ignition and early transitional combustion stage (i.e. ignition to early flaming) phase (Fig. 4-6), smaller particles are associated with both flaming and coking phases (Fig. 7-9). The ignition phase produced particles in the accumulation mode, which was influenced by smouldering conditions and the release of volatile organic compounds under low-temperatures. As the combustion progressed, there was a shift in particle mode from accumulation to Aitken, where particle diameter reduced during the transitional stage. During late flaming to coking, the mode changed to nucleation, where particle diameter further decreased under stable combustion conditions. This observation is similar to the distribution reported in Zhang *et al*. (2012).

Summary and Conclusion

This paper presented results of number size distribution of the submicron particle fraction from the combustion of D-grade coal in a high air ventilated brazier using the top-lit updraft method. Particle size distributions were measured using a TSI NanoScan Scanning Mobility Particle Sizer. The monitor measured PSD throughout the entire burn sequence (from ignition to coking). The PSD curves were separated into three combustion phases: ignition, flaming, and coking. The GMD of particle size distribution was estimated to be 51.6 nm for the averaged burn sequence. Particle number concentrations were high during the flaming and coking phases compared to the ignition phase. The GMD rapidly increased during the ignition phase and gradually decreased during the flaming and the coking phases. Particle size distribution was bimodal across all combustion phases for the D-grade coal used in our experiments but was unimodal during the coking phase. The unimodal distribution suggest a homogenous combustion conditions. At this phase there is constant radiant heat flow and identical particle emissions. During coking all volatiles are driven out with only fix carbon burning under ideal combustion conditions and sufficient air supply. Although the study does not attempt to investigate particle emission composition, we can anticipate the particle emissions during coking phase is attributed to fly ash. Despite limitation on particle size distribution being carried out on small scale coal combustion, we have drawn lessons from other studies which focused on wood burning technologies. Study conducted by several researchers reported a unimodal particle size distribution under ideal wood burning condition (Hedberg *et al*., 2002; Hays *et al*., 2002; Zhang *et al*., 2011; Zhang *et al*., 2012; Hosseini *et al*., 2010); while McElroy *et al*. (1982) reported a bimodal PSD. Nevertheless, in all studies a bimodal distribution is attributed to poor combustion conditions and agglomeration process.

We have demonstrated in this study that improving combustion condition emits particles of smaller diameter. This finding is worrying given the consequences as outlined in epidemiological studies that smaller particles are easily inhaled and have a higher potential for uptake through blood circulation. However, what remains to be investigated is the toxicity of these particles at various combustion phases, to draw conclusions regarding the potential health effects of emitted particles with varied number size distributions.

Acknowledgements

This work was supported financially by the University of Johannesburg through a URC fellowship grant to TM, and in part from a grant from the Global Alliance for Clean Cookstoves (GACC) to the SeTAR Centre as a Regional Stove Testing and Development Centre. The authors thank the National Institute for Occupational Health through Joel Maseki and Kevin Kasangana for assistance with the TSI NanoScan SMPS. Extended appreciation to Nomsa Thabethe for her contribution proofreading and editing of the manuscript.

References

Anastasio, C. and Martin, S.T. (2001). Atmospheric nanoparticles, In: Nanoparticles and the Environment, J.F. Banfield, A. Navrotsky (Eds.), pp. 293–349, Mineralogical Society of America, ISBN 0-939950-56-1, Washington, DC.

Andreae, M.O., Merlet, P., (2001). Emission of trace gases and aerosols from biomass, *Global Biogeochem Cycles,* vol. 15(4), 955 – 966.

Annegarn, H.J., Sithole, J. (1997). Soweto air monitoring-project SAM, Annual report for the period January-December 1996, Department of Environment and Tourism, Report No. AER97.094-SAM, University of Witwatersrand, Johannesburg.

Balmer, M. 2007. Household coal use in an urban township in South Africa, *JESA*, 18(3), 27-32.

Barnes, B., Mathee, A., Thomas, E., Bruce, A. (2009). Household energy, indoor air pollution and child respiratory health in South Africa, *JESA*, 20(1), 4-13.

Barnes, B.R., Mathee, A and Moiloa, K. (2006). Assessing child time activity patterns in relation to indoor cooking fires in developing countries: A methodological comparison, *International Int J Environ Res Public* Health. 208, 219–225.

Bølling, A.K., PagelS, J., Yttri, K.E., Barregard, L, Sallsten, G., *et al*., (2009). Health effects of residential wood smoke particles: the importance of combustion conditions and physicochemical particle properties, *Part Fibre Toxicol*. 6:29.

Bond T.C., Covert D.S., Kramlich J.C., Larson T.V., Charlson R.J. 2002, ‘Primary particle emissions from residential coal burning: optical properties and size distributions’, *J. Geophys. Res*. 107:8347

Bonjour, S., Adair-Rohani, H., Wolf, J., Bruce, N. G., Mehta, S., Prüss-Ustün, A., Lahiff, M., Rehfuess, E. A., Mishra, V., and Smith, K. R. (2013). Solid-fuel Use for Household Cooking: Country and Regional Estimates for 1980–2010. *Environ. Health Perspect*. 121(7):784–790.

Bruce, N., Perez-Padilla, R and Albalak R. (2000). Indoor air pollution in developing countries: a major environmental and public health challenge. *Bull WHO* (78)1078–1092.

Chakrabarty, R. K., Moosmüller, H., Garro, M. A., Stipe, C. B. (2012). Observation of super-aggregates from a reversed gravity low-sooting flame, *Aerosol Sci. Technol*, 46(1): i–iii.

Chakrabarty, R. K., Moosmuller, H., Garro, M. A., Arnott, W. P., Walker, J., Susott, R. A., Babbitt, R. E., Wold, C. E., Lincoln, E. N., and Hao, W. M.: Emissions from the laboratory combustion of wildland fuels: Particle morphology and size, J. Geophy Res. Atmos., 111, D07204, doi:10.1029/ 2005JD00665, 2006.

Chang, M.C.O., Chow, J.C., Watson, J.G., Hopke, P.K., Yi, S.M., England, G.C. (2004) .Measurement of ultrafine particle size distributions from coal–,oil–,and gas–fired stationary combustion sources. *J Air Waste Manag Assoc*. 54, 1494–1505.

Chu, H., Zheng, Z., Ren, F., Mingyan, G. (2017). Study on granularity distribution of powder by fractal models, *Fractals*. 25 (4), 1-6.

Cincinelli A. and Martellini T. (2017). Indoor Air Quality and Health, *Int. J. Environ. Res. Public Health 14*: 1286.

CSIR (2005). ‘Laboratory controlled quantitative information about reduction in air pollution using the “Basa *njengo* Magogo” methodology and applicability to low-smoke fuels (Revised)’, Division of Water, Environment and Forestry Technology, CSIR Durban, Report No. ENV-D 2005.

Department of Minerals and Energy (DME), (2006). Digest of South African Energy Statistics 2003/2004, Directorate, Energy Planning and Development, Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME). (2004). Integrated Household Clean Energy Strategy, Department of Minerals and Energy, Pretoria.

Dockery D.W., Pope C.A., Xu X., Spengler J.D., Ware J.H., Fay M.E., Ferris B.G., and Speizer F.E. (1993). An association between air pollution and mortality in six U.S. cities. *N Engl J Med*: 329: 1753 –1759.

Ezzati, M and Kammen, D.M. (2001). Indoor air pollution from biomass combustion as a risk factor for acute respiratory infections in Kenya: an exposure-response study. *Lancet*. 358:619–624.

Fernandez, A., Wendt, J.O., Wolski., Hein N, K.R.G., Wang S, Witten, M.K. Inhalation health effects of fine particles from the co-combustion of coal and refuse derived fuel, *Chemosphere 51* (2003) 1129–1137.

Forouzanfar, M. H., Alexander, L., Anderson, H. R., Bachman, V. F., Biryukov, S., Brauer, M., Burnett, R., Casey, D., Coates, M. M., Cohen, A., *et al*. (2015). Global, Regional, and National Comparative Risk Assessment of 79 Behavioural, Environmental and Occupational, and Metabolic Risks or Clusters of Risks in 188 Countries, 1990–2013.

GACC, (2009). "Global Alliance for Clean Cookstoves", GACC, [online] Available: http://cleancookstoves.org/2009.

Gladney E. S. (1974) Trace element emissions from coal-fired power plants: A study of the Chalk Point Electric Generating Station. Ph.D. Thesis, University of Maryland.

Gladney, E.S. (1976). Composition and size distribution of in-stack particulate material at a coal-fired power plant, *Atmos. Environ*. 10: 1071-1077.

Gordon, 2014 Gordon, S. B., Bruce, N. G., Grigg, J. *et al.* (2014). Respiratory risks from household air pollution in low and middle-income countries, The Lancet Respiratory Medicine Commission, http://dx.doi.org/10.1016/S2213-2600(14)70168-7.

Hays, M.D., Geron, C.D., Linna, K.J., Dean Smith, N., Schauer, J.J. (2002). Speciation of gas-phase and fine particle emissions from burning of foliar fuels. *Environ. Sci. Technol*. 36 (11): 2281e2295.

Hedberg, E., Kristensson, A., Ohlsson, M., Johansson, C., Johansson, P., Swietlicki, E., Vesely, V., Wideqvist, U., Westerholm, R. (2002). Chemical and physical characterization of emissions from birch wood combustion in a wood stove. *Atmos. Environ*. 36 (30): 4823-4837.

Hosseini S, Li Q, Cocker D, Weise D, Miller A, Shrivastava A, Miller J.W., Mahalingam S, Princevac M, Jung H. (2010). ‘Particle size distributions from laboratory-scale biomass fires using fast response instruments’, *Atmos. Chem. Phys*. 10:8065–8076.

ISO IWA 11:2012 (2012). Guidelines for Evaluating Cookstove Performance. Available at http://cleancookstoves.org/resources_files/iso-iwa-cookstoves.pdf.

Jiang, R and Bell, M.L. (2008). A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in Northeastern China. *Environ Health Perspect*. 116 (7): 907–914.

Kasangana, K.K., Masekameni, M.D., Saliwa S, (2017). “Exploring access to clean energy for various domestic uses in Mpumalanga province, South Africa”, in *Proceedings of the 26th Domestic Use of Energy Conference* (DUE), 26, 116-120.

Kauppinen E.I., Pakkanen T.O. (1990). ‘Coal combustion aerosols: A field study’, *Aerosol Sci. Technol*. 24:1811–1818.

Kittelson, D. B. (1998). Engines and Nanoparticles: A Review. J. Aerosol Sci., 29(5–6):575–588.

Klein, E. R. H., Fransman, W., and Brouwer, D. H. (2011). How to statistically analyze nano exposure measurement results: using an ARIMA time series approach. *J Nanopart Res*. 13: 6991-7004.

Kumar, P., Gurjar, B.R., Nagpure, A., Harrison, R.M. (2011). Preliminary estimates of nanoparticle number emissions from road vehicles in megacity Delhi and associated health impacts. *Environ. Sci. Technol*. 45: 5514-5521.

Kumar, P., Robins, A., Vardoulakis, S., Britter, R. (2010). A review of the characteristics of nanoparticles in the urban atmosphere and the prospects for developing regulatory controls. Atmos. *Environ Sci. Technol*. 44: 5035-5052.

Le Roux, L. J., Cilliers, K. F. P. and Van Vuuren, D. S., (2004). Low-Smoke fuels Standard Testing and Verification. Final Report to the Department of Minerals and Energy.

Li, Z., Ji, Y., M, H. *et al*. (2017). Characterization of Inorganic Elements within $PM_{2.5}$ and PM_{10} Fractions of Fly Ashes from Coal-Fired Power Plants. *Aerosol Air Qual Res*. 17: 1105–1116.

Lim S.S., Vos T., Flaxman A.D., Danaei G., Shibuya K., Adair-Rohani H. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: A systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 380: 2224–2260.

Linak W.P., Miller A, Seames W.S., Wendt J.O.L, Ishimori T, Endo Y and Miyamae S. (2002). ‘On trimodal particle size distributions in fly ash from pulverized-coal combustion’, *Proceedings of the Combustion Institute*. 29:441–447.

Makonese T, Forbes P, Mudau L, Annegarn H. (2014). ‘Aerosol particle morphology of residential coal combustion’, *Clean Air Journal*. 24(2):24–28.

Makonese T, Masekameni D, Forbes P, Annegarn H. (2015). ‘Influence of fire-ignition methods and air ventilation rates on the gaseous and condensed matter (smoke) emissions from residential coal-burning braziers’, *JESA*: 26(4):16–28.

Makonese T. (2015). ‘Systematic investigation of smoke emissions from packed-bed residential coal combustion devices’, PhD Thesis, University of Johannesburg, South Africa.

Masekameni M D. (2015). Performance evaluation and emission characterization of domestic coal combustion in optimized braziers. MSc thesis, University of Johannesburg (*in Press*).

Masekameni, M.D., Makonese, T., Annegarn H.J. (2014). Optimisation of ventilation and ignition method for reducing emissions from coal burning imbaulas. *Proceedings of the 22nd Domestic Use of Energy (DUE) Conference*, 30 March – 2 April 2014, Cape Town. IEEE Conference Publications, DOI: 10.1109/DUE.2014.6827755, 2014, pp. 1-7.

McElroy M.W., Carr R.C., Ensor D.S., Markowski G.R. (1982). ‘Size distribution of fine particles from coal combustion’, *Science*. 215:13–19.

Morawska, L., Ristovski, Z., Jayaratne, E.R., Keogh, D.U., Ling, X. (2008). Ambient nano and ultrafine particles from motor vehicle emissions: Characteristics, ambient processing and implications on human exposure. *Atmos. Environ*. 42, 8113-8138.

Naeher LP., Brauer M., Lipsett M, Zelikoff JT., Simpson CD, Koenig JQ., Smith KR. (2007). Woodsmoke health effects: a review. *Inhal Toxicol*, (19) 67-106.

Oberdörster G. Oberdörster, E and Oberdörster, J (2005). Nanotoxicology: An Emerging Discipline Evolving from Studies, *Environ Health Perspect*. 113: 823-829.

Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Kreyling, W., Cox, C. (2004). Translocation of inhaled ultrafine particles to the brain. *Inhal. Toxicol*. 16:437–445, 2004.

Rainey, K.L., Vaganay, M. and MacIntyre, S. (2016). A Review of Literature on Residential Solid-fuel Burning, and Consequently the Implications of Meeting the European 2050 Low-Carbon Targets. *Journal of Geoscience and Environment Protection*. 4: 7-13.

Scorgie, Y. (2012). Urban Air Quality Management and Planning, PhD thesis University of Johannesburg, South Africa.

Scorgie, Y., Kneen, M.A., Burger, L.W., Annegarn, H.J. (2003). Air pollution in the Vaal Triangle - quantifying, source contributions and identifying cost effective solutions*, Proceedings of the 11th National Association for Clean Air Conference*.

Shonkoff S.B., Krewski D, Pope C.A. III, Thun M.J. and Thurston G. (2009). 'Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants', *Lancet*. 374:2091–2103.

Sioutas C., Dolfino R.J., Singh M. (2005). Exposure Assessment for Atmospheric Ultrafine Particles (UFPs) and Implications in Epidemiologic Research, *Environ Health Perspect*. 113(8): 947–955

Smith KR and Peel JL. (2010). Mind the gap. *Environ Health Perspect*. 118:1643–1645.

Smith KR, Mehta S, Maeusezahl-Feuz M. (2004). Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors (Ezzati M, Rodgers AD, Lopez AD, Murray CJL, eds). Geneva: World Health Organization, 1435–1493; 2004.

Smith, K. R., Apte, M. G., Yuqing, M., Wongsekiarttirat, W., and Kulkarni, A. (1994). Air Pollution and the Energy Ladder in Asian Cities. *Energy*. 19(5):587–600.

Smith, K.R., Duta, K., Chengappa, C *et al*. (2007). Monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance: conclusions from the Household Energy and Health Project. *ENERGY SUSTAIN DEV*. 11 (2): 6–18.

Statistic South Africa. (2001). Causes of death in South Africa 1997-2001, advanced recorded causes of death. Pretoria, South Africa.

Statistic South Africa. (2001). Census 2001, detailed demographic databases. Pretoria South Africa.

Stats SA. (2010). Statistical release P0309.3. Mortality and causes of death in South Africa. http://www.statssa.gov.za

Terblanche, P. and Pols, A.S. (1994). Characterisation of risk factors associated with household fuel usage in South Africa, Report compiled on behalf of Department of Minerals and Energy, Report No. EO 9303, July 1994, Pretoria, South Africa.

Terblanche, A.P., Opperman, L., Nel, C.M., Nyikos, H. (1993) Exposure to air pollution from transitional household fuels in a South African p opulation. J Expo Anal Environ Epidemiol 3, 15-22.

Tiwari, M., Sahu, S.K., Bhangare, C., Yousaf, A., Pandi, G.G. (2014). Particle size distributions of ultrafine combustion aerosols generated from household fuels. *Atmos Pollut Res*.5(2014)145-150.

Tiwari, M., Sahu, S.K., Pandit, G.G. (2015). Inhalation Risk Assessment of PAH Exposure Due to Combustion Aerosols Generated from Household Fuels. A*erosol Air Qual Res*. 15: 582–590.

Tranfield, E.M. and Walker D.C. (2012). Understanding of Human Illness and Death Following Exposure to Particulate Matter Air Pollution, In: Environmental Health – Emerging Issues and Practice, J. Oosthuizen (Ed.), pp. 81-102, Intech, ISBN 978-953-307-854-4, Rijeka, Croatia

Van Niekerk W.C.A., Britton M.T.S., Laurens J.B. (1997). 'Laboratory technical tests– determination of emission factors', Department of Minerals and Energy, Pretoria.

World Energy Outlook. (2015). Electricity Access Database, [online] Available: www.worldenergyoutlook.org.

World Health Organization. (2014). WHO Guidelines for Indoor Air Quality: Household Fuel Combustion. WHO Document Production Services, Geneva.

Xu, M., Yu, D., Yao, H., Liu, X., Qiao, Y. (2011). Coal combustion-generated aerosols: Formation and properties. *Proceedings of the combustion institute* 1681–1697.

Yi, H., Hao J., Duan, L., Tang X., Ning P., Li X. (2008). Fine particle and trace element emissions from an anthracite coal-fired power plant equipped with a bag-house in China. *Fuel*. 87: 2050-2057.

Zhang, H, Wang S, Hao J, Wan L, Jiang J, Zhang M, Mestl H *et al*. (2012). Chemical and size characterization of particles emitted from the burning of coal and wood in rural households in Guizhou, China. *Atmos. Environ*. *51*: 94 – 99.

Zhang, H.F., Hu, D.W., Chen, J.M., Ye, X.N., Wang, S.X., Hao, J.M., Wang, L., Zhang, R.Y., An, Z.S. (2011). Particle size distribution and polycyclic aromatic hydrocarbons emissions from agricultural crop residue burning. *Environ. Sci. Technol*. 45 (13): 5477e5482.

Zhang, J.J and Smith, K.R. (2007). Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions. *Environ Health Perspect*. 115 (6): 848–855.

Zhang, T.R., Wooster, M.J., Green, D.C. and Main, B. (2015). New field-based agricultural biomass burning trace gas, PM2.5, and black carbon emission ratios and factors measured in situ at crop residue fires in Eastern China. *Atmos. Environ*. 121: 22–34.

Table 1. Stove ventilation rate characterisation.

Brazier ventilation rate	Height (mm)	Dia. (mm)	Grate height (mm)	Area of holes below grate (cm2)	Area of holes above grate (cm2)	Total area of holes (cm2)
High	370	290	185 (50%)	248 (61%)	159 (39%)	407

Table 2. Fuel analysis specification.

Parameter (Air Dried Basis)	Standard Method	Slater Mine D-Grade Coal
Moisture content (%)	ISO 5925	1.8
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	2.76
Nitrogen (%)	ASTM D5373	1.0
Oxygen (%)	By difference	5.0
Total silica as SiO_2 (%)	ASTM D4326	58.6
Aluminium as Al_2O_3 (%)	ASTM D4326	27.6
Total iron as Fe_2O_3 (%)	ASTM D4326	6.63
Titanium as TiO_2 (%)	ASTM D4326	0.82
Phosphorous as P_2O_5 (%)	ASTM D4326	0.55
Calcium as CaO (%)	ASTM D4326	2.30
Magnesium as MgO (%)	ASTM D4326	0.83
Sodium as Na_2O (%)	ASTM D4326	0.42
Potassium as K_2O (%)	ASTM D4326	0.79
Sulphur as SO_3 (%)	ASTM D4326	1.10
Manganese as MnO_2 (%)	ASTM D4326	0.12

Table 3. Particle number concentration per combustion phase relative to the entire burn sequence.

Phase	**(#/cm^3) N=3**	**Duration (minutes)**	**GMD (nm)**	**GSD (nm)**
Entire Combustion Sequence	1,20E+07 (100%)	180	51.9	2.1
Ignition	2,71E+03 (0.02%)	20	109.8	18.4
Flaming	6,67E+06 (55%)	60	54.9	5.9
Coking	5,34E+06 (44%)	100	34.3	5,1

Table 4. Contribution of combustion phase on PSD for the three modes (Nucleation, Aitken and Accumulation).

Combustion phase	Nuclei (Dp<50 nm) (%)	Aitken (Dp 50- 100 nm) (%)	Accumulation (Dp>100 nm) (%)
Ignition	15,3	45,5	39,2
Flaming	46,8	30,8	22,4
Coking	83,9	13,4	2,6

Figure Captions

Fig. 1. Laboratory designed high ventilation stove.

Fig. 2. Schematic diagram of the SeTAR Centre testing rig.

Fig. 3. Particle size distributions corresponding to the background concentrations.

Fig. 4. Particle size distribution corresponding to the ignition phase.

Fig. 5. Particle size distribution during early and late ignition.

Fig. 6. Particle size distribution corresponding to the flaming phase.

Fig. 7. Particle size distribution during early and late flaming.

Fig. 8. Particle size distribution corresponding to the coking phase.

Fig .9. Particle size distribution during early and late coking.

Fig .10. Particle size distribution corresponding to the entire burn cycle.

Fig. 1.

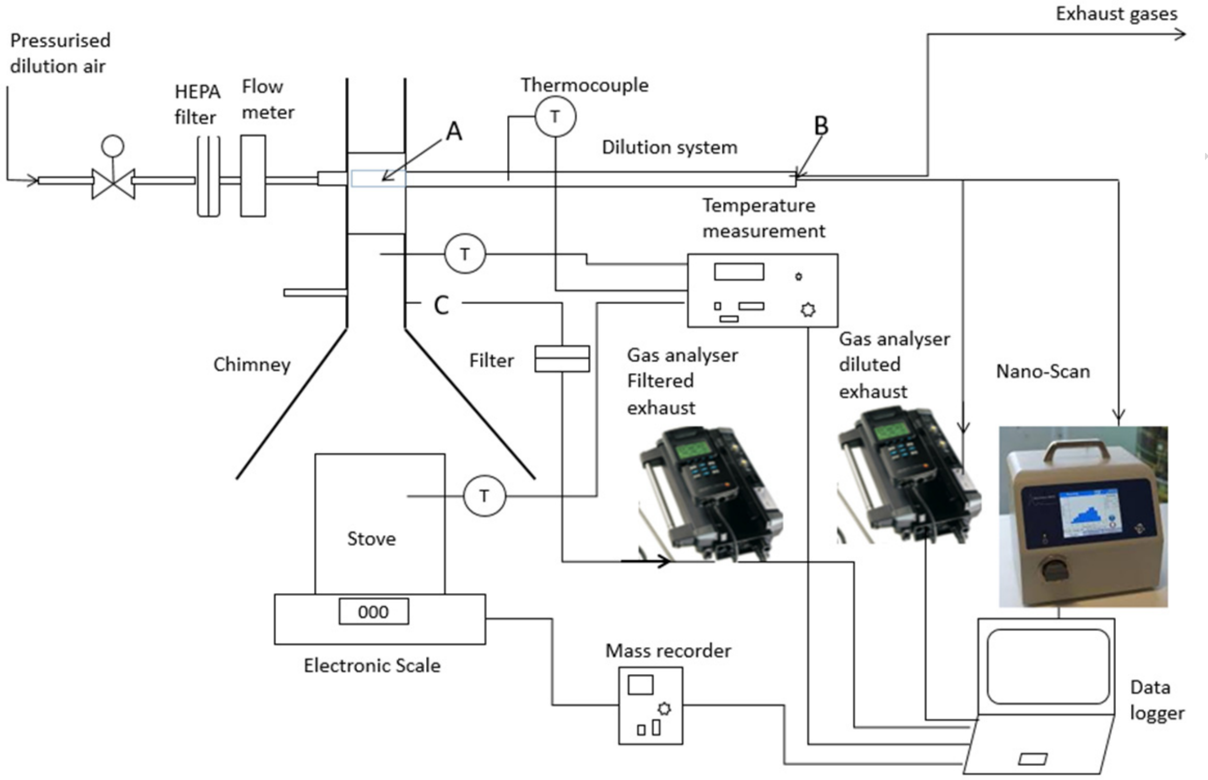
Exhaust gases
Pressurised dilution air
HEPA filter
Flow meter
Thermocouple
T
A
Dilution system
B
Temperature measurement
T
C
Chimney
Filter
Gas analyser Filtered exhaust
Gas analyser diluted exhaust
Nano-Scan
T
Stove
000
Electronic Scale
Mass recorder
Data logger

Fig. 2.

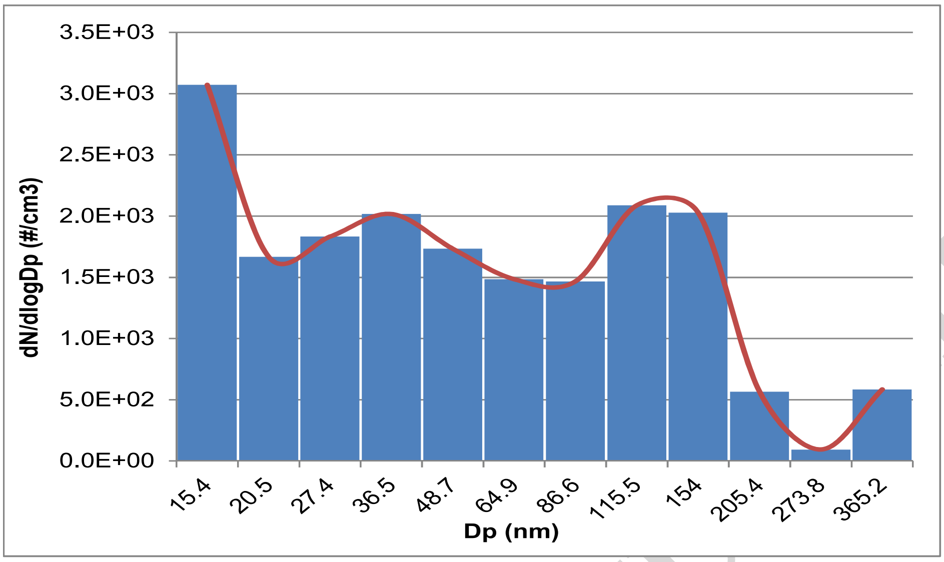
3.5E+03
3.0E+03
2.5E+03
2.0E+03
1.5E+03
1.0E+03
5.0E+02
0.0E+00
dN/dlogDp (#/cm3)
15.4
20.5
27.4
36.5
48.7
64.9
86.6
115.5
154
205.4
273.8
365.2
Dp (nm)

Fig. 3.

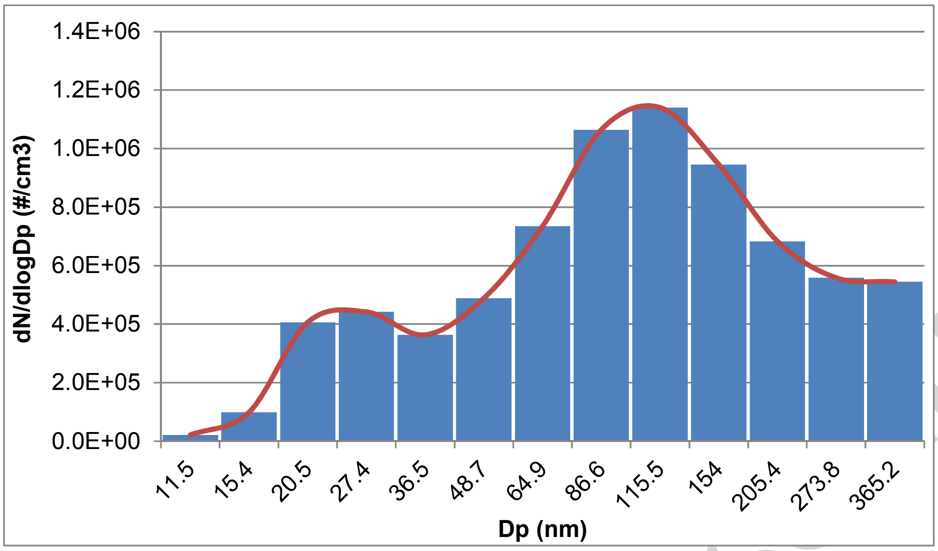
dN/dlogDp (#/cm3)
1.4E+06
1.2E+06
1.0E+06
8.0E+05
6.0E+05
4.0E+05
2.0E+05
0.0E+00
11.5
15.4
20.5
27.4
36.5
48.7
64.9
86.6
115.5
154
205.4
273.8
365.2
Dp (nm)

Fig. 4.

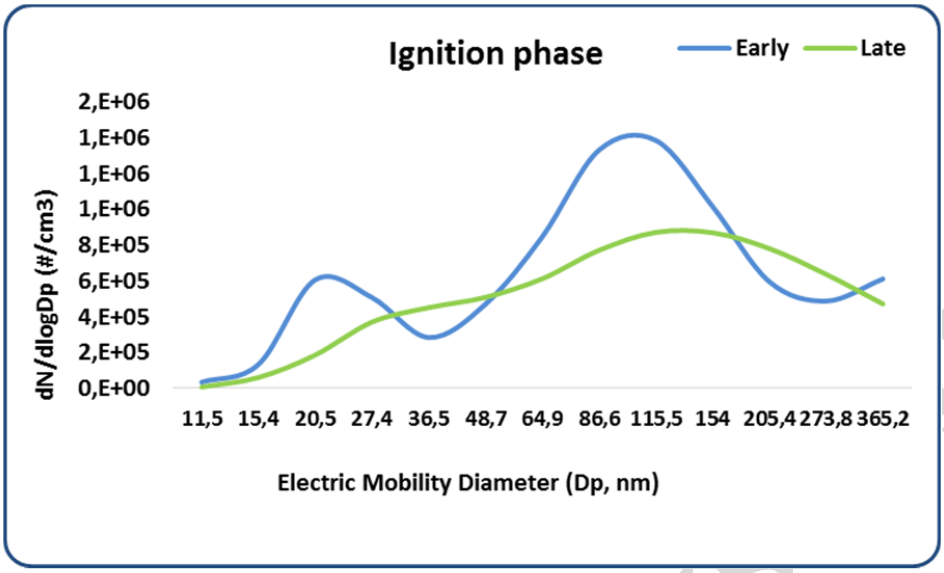
Ignition phase
Early
Late
dN/dlogDp (#/cm3)
2,E+06
1,E+06
1,E+06
1,E+06
8,E+05
6,E+05
4,E+05
2,E+05
0,E+00
11,5
15,4
20,5
27,4
36,5
48,7
64,9
86,6
115,5
154
205,4
273,8
365,2
Electric Mobility Diameter (Dp, nm)

Fig. 5.

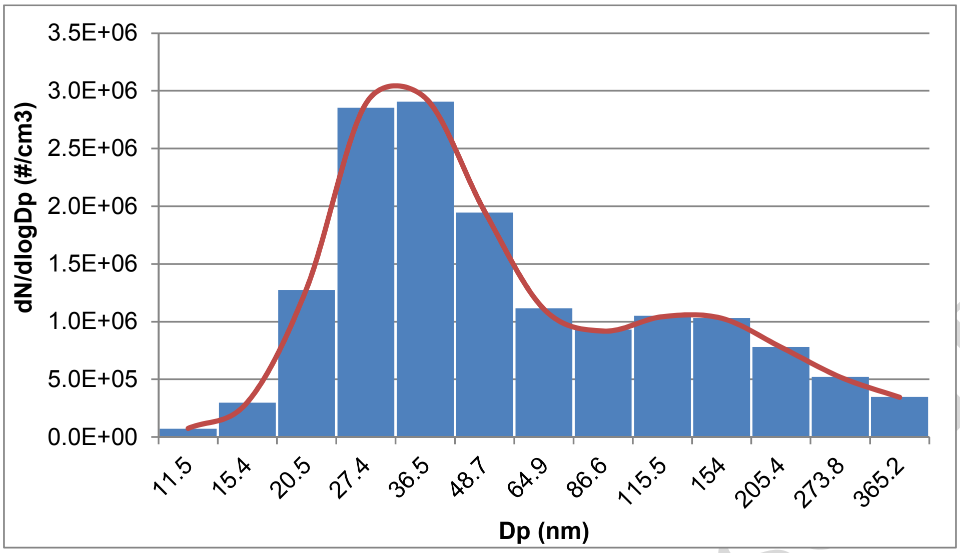
3.5E+06
3.0E+06
2.5E+06
2.0E+06
1.5E+06
1.0E+06
5.0E+05
0.0E+00
dN/dlogDp (#/cm3)
11.5
15.4
20.5
27.4
36.5
48.7
64.9
86.6
115.5
154
205.4
273.8
365.2
Dp (nm)

Fig. 6.

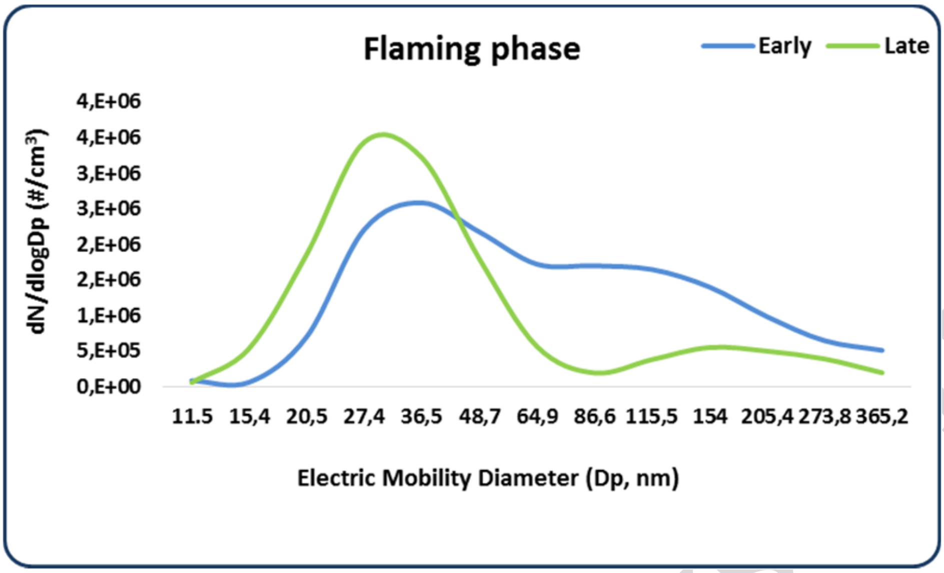
Flaming phase
Early
Late
dN/dlogDp (#/cm³)
4,E+06
4,E+06
3,E+06
3,E+06
2,E+06
2,E+06
1,E+06
5,E+05
0,E+00
11.5
15,4
20,5
27,4
36,5
48,7
64,9
86,6
115,5
154
205,4
273,8
365,2
Electric Mobility Diameter (Dp, nm)

Fig. 7.

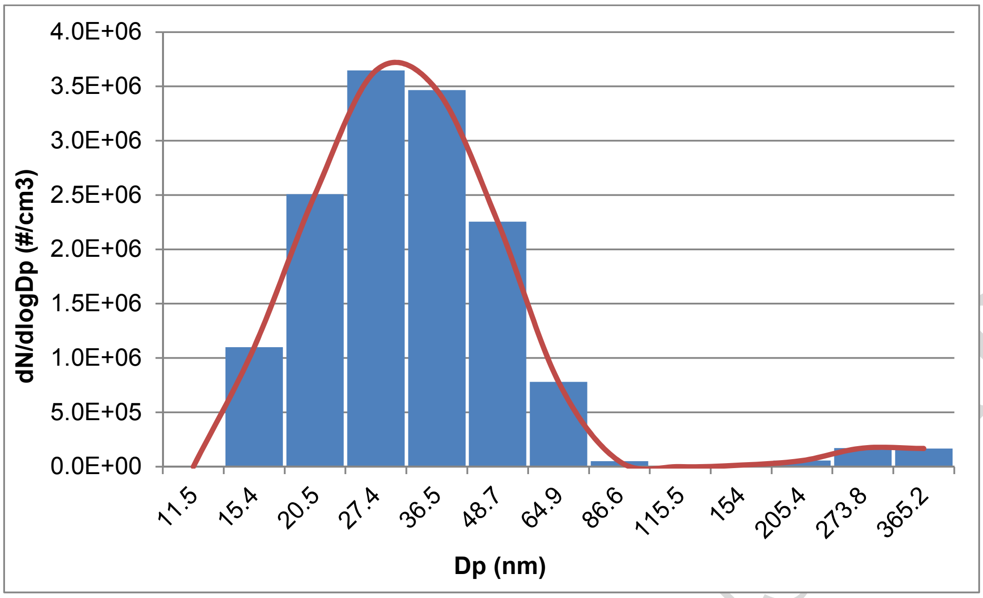
4.0E+06
3.5E+06
3.0E+06
2.5E+06
2.0E+06
1.5E+06
1.0E+06
5.0E+05
0.0E+00
dN/dlogDp (#/cm3)
11.5
15.4
20.5
27.4
36.5
48.7
64.9
86.6
115.5
154
205.4
273.8
365.2
Dp (nm)

Fig. 8.

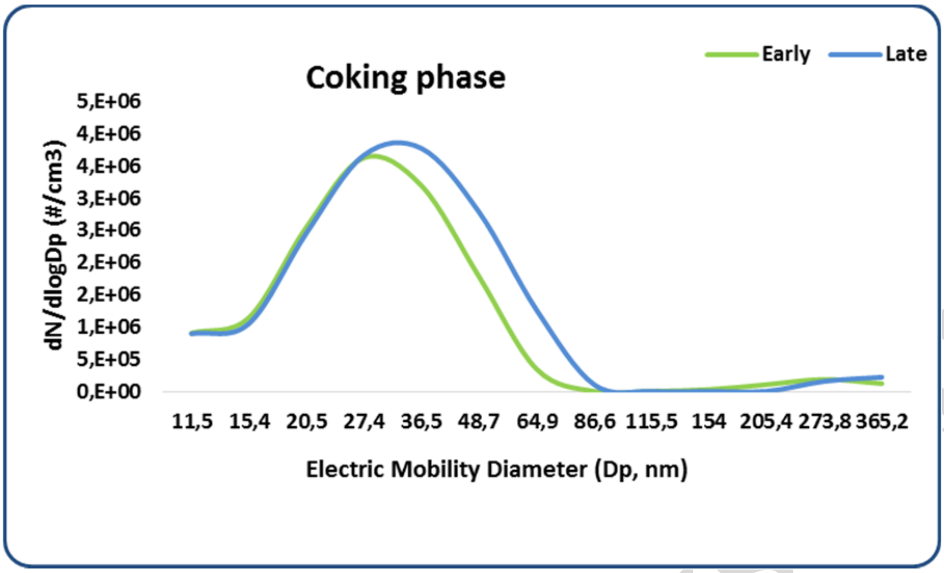
Coking phase
Early
Late
dN/dlogDp (#/cm3)
5,E+06
4,E+06
4,E+06
3,E+06
3,E+06
2,E+06
2,E+06
1,E+06
5,E+05
0,E+00
11,5
15,4
20,5
27,4
36,5
48,7
64,9
86,6
115,5
154
205,4
273,8
365,2
Electric Mobility Diameter (Dp, nm)

Fig.9.

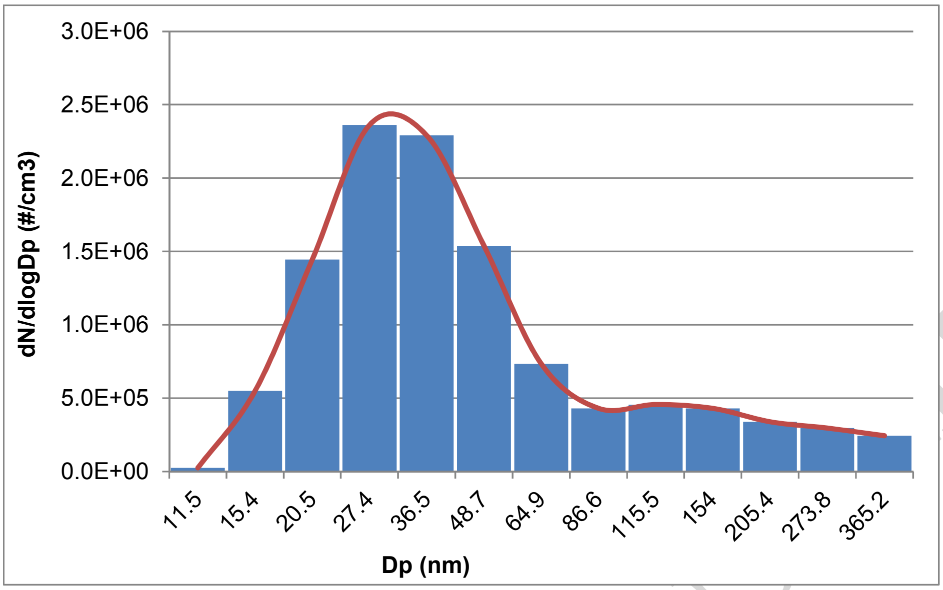
3.0E+06
2.5E+06
2.0E+06
1.5E+06
1.0E+06
5.0E+05
0.0E+00
dN/dlogDp (#/cm3)
11.5
15.4
20.5
27.4
36.5
48.7
64.9
86.6
115.5
154
205.4
273.8
365.2
Dp (nm)

Fig. 10.