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A Reliable Method for Generation of Size Selected Soot using Aerosol Technology and Detection by Sensor Device

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Realization that particle emissions from diesel engines pose serious health problems has led to regulation and active manufacturer efforts to reduce the particle mass leaving the exhaust pipe. While this has resulted in cleaner air there is concern that modern engines release increased number concentrations of nanoparticles which are potentially more hazardous than previous black smoke emissions. A recent study has shown that Euro IV standard particles at the same mass concentration had higher toxicity than soot from old engines because of their smaller size and more active surfaces (D. S. Su et.al).

In this paper we report the generation of soot having diesel exhaust particle size distributions from liquefied petroleum gas combustion (H. Abdulhamid et.al, D. Lutic et.al). Control of the fuel/oxygen ratio allowed production of a range of particle sizes that exhibited good stability over several hours production time. The particles were characterized by a variety of techniques such as TEM and thermophoretic deposition on sensor surfaces was employed to demonstrate application to analytical method development.

EXPERIMENTAL SET-UP

The combustion soot generator (Fig. 1) had three components: flame, quenching and mixing sections. Particles were generated by a quenched diffusion flame. Propane as fuel was fed into the inner of two co-axial stainless steel pipes while air was introduced through the outer pipe as oxidant. The stability of the flame, and thus the generated soot, was very sensitive to any small variation in the flow characteristics. Two mass flow controllers (Bronkhorst High-Tech, The Netherlands) were used to precisely control the fuel and carrier air flow rates. Additionally, the carrier gas stream was stabilized with a ceramic monolith (honeycomb) flow laminarizer to further enhance the flame stability. By varying the carrier air/fuel flow ratio soot of different concentrations and size distributions could be produced. The carrier air/fuel flow rates necessary to generate soot particle size-distributions with geometrical mean diameters (GMD) of 60, 90 and 120 (nm) soot particles were 3.2/85, 3.1/85 and 3.0/85 (l/ml) respectively.

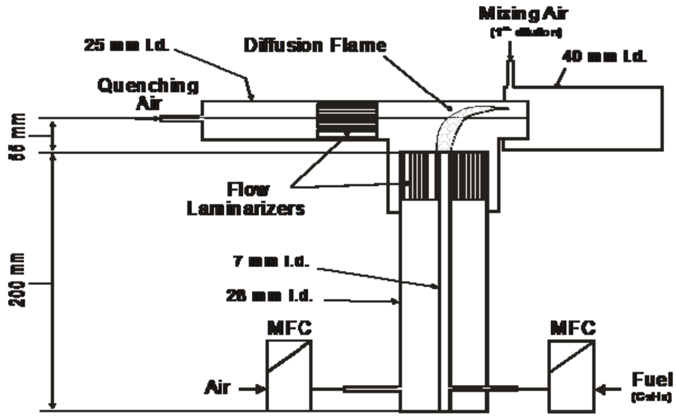

Figure 1: Illustrative sketch showing the soot generator.

The diffusion flame was quenched by the quenching line (using air with a flow of 9 l/min) at a certain height (55 mm) above the flame. The quenching line was also supplied by a flow laminarizer to prevent excessive flame disturbance. The quenching air diluted and cooled the flame which resulted in a significant decrease in soot coagulation and prevented any further oxidation of the generated soot particles. This allowed production of high concentrations of size-controlled soot particles. Thus, quenching played an important role in defining the chemical and physical properties of the produced soot particles.

The soot leaving the quenching section was subsequently diluted and completely mixed in the mixing region using air at 45 l/min. This ensured a uniform soot distribution having controlled concentration out from the burner with no need for any further mixing zone.

As the diffusion flame was completely protected from any environmental influences such as flow variation, humidity and temperature gradient, a highly stable and reproducible soot production was attained.

A scanning mobility particle sizer (SMPS 3934 from TSI Inc., USA) was used to measure the generated soot number size distribution (Fig. 2). Before the soot was analysed with the SMPS system it was diluted using an ejector (DI-1000 Dekati Diluter. Finland) to a ratio of 1:13 in order not to exceed the measurable range for the SMPS.

After SMPS verification for a certain stable size distribution of generated soot particles, a flow of 300 ml/min was sucked using vacuum either directly from the outlet of the burner to the thermophoretic sampler for high number soot concentration or diluted further, to a ratio of either 1:2.7 or 1:12.8, using another ejector (Q-VDF250 ANVER VACUUM PUMP, USA). The later dilution ratios were quantified by determining the dilution of CO concentration using a flue gas analyzer (testo 350-XL, Testo AG, Germany).

Resistivity sensors having interdigitated electrodes were prepared on 90 nm thick SiO_2 films grown on p-type silicon. The electrode pattern was obtained by lift-off technique after sputtering 5 nm Ti and 200 nm Au films. The electrode gap was 40 µm. Each sensor was mounted on a 16-pin holder and silicon pieces were glued around the sensor to create an aerodynamically smooth surface for the incoming carrier gas. The resistance change during soot deposition was measured using a digital multimeter device (TTI 1604 Thurlby Thandar Instruments, UK) capable of measuring in the resistance range from 1 kOhm to 40 MOhms.

The methods stability presented in Fig. 3.

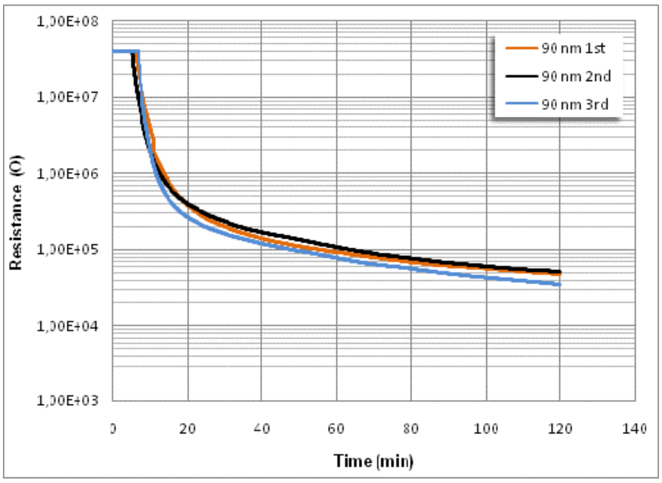

Figure 3: Resistance change for 2 hours exposure to generated soot particles of 90 nm (GMD) using three fresh sensors on different days.

D. S. S u , A L Serafino , J-O Müller, R Jentoft , R Schlögl, S Fiorito Cytotoxicity and Inflammatory Potential of Soot Particles of Low-Emission Diesel Engines Environ. Sci. Technol. 42 (2008)1761–1765

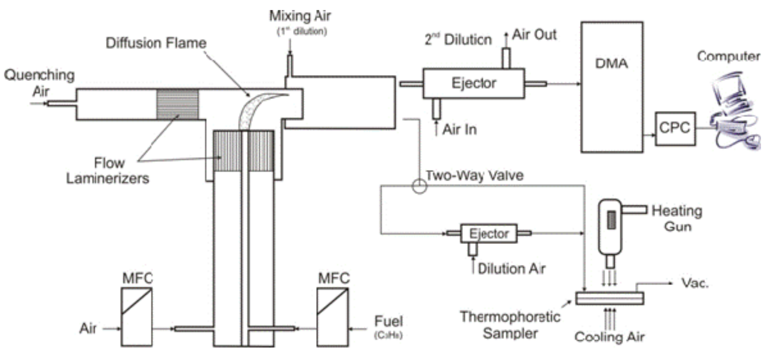

Figure 2: Schematic diagram of the experimental set-up.

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H. Abdulhamid, A. Malik, J. Pagels, R. Bjorklund, D. Lutic, Peter Josza, J. H. Visseer, A. Lloyd Spetz, and M. Sanati. Detection of diesel-like generated soot particles by thermophoretic deposition on a resistivity soot sensor. To be submitted.

D. Lutic, A. Lloyd Spetz, M. Sanati, J. Visser, P. Jozsa PCT/SE2008/050215 Method and arrangement for detecting particles, , patent filed by Volvo CC (2008)