Use of tubes made of electrostatic dissipative materials for sizing sub-10 nm particles

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Determining the size of particles is a fundamental requirement in aerosol science. Recently, Bezantakos *et al.* (2015) proposed the use of Electrostatic Dissipative Materials (EDMs) as a simple and cost-effective method for enabling the classification of nanoparticles. Here we show that the EDM technique is capable of sizing particles less than 10 nm in diameter. To enable particle sizing in our experiments, the EDM tube was placed downstream of a high resolution differential mobility analyser (half-mini DMA, SEADM) that produced positively charged particles. The EDM tube was operated with a grounded inlet and outlet, coupled with an intermediate point that was operated at high voltage with a positive power supply. This configuration produces a decelerating segment upstream of the high voltage region, which leads to increased particle deposition, and an accelerating segment downstream of the high voltage region, which focuses particles near the centreline of the EDM tube.

In our experiments, sub-10 nm particles were produced using two sources. Electrospray generation was used to produce 1.5 nm particles and a hot wire generator was employed to produce particles between 2 and 6 nm in diameter. Downstream of the EDM tube, particle number concentration (PNC) was measured with an ultrafine Condensation Particle Counter (uCPC; TSI Model 3025). Relative penetration ($P = \frac{N(V)}{N(0)}$) measurements were made, with $N(V)$ denoting PNC downstream of the EDM tube with the application of high voltage and $N(0)$ without. The pre-selection of different particle diameters (with a fixed EDM tube voltage) enabled the construction of penetration curves as a function of particle size. From these curves, the 50% penetration point can be used to infer particle diameter. Relative penetration was estimated for six particle diameters and four voltage settings (Figure 1).

The theoretical performance of the EDM tube can be assessed using a semi-empirical equation that considers both diffusional and electrostatic deposition (Bezantakos *et al.*, 2015), as well as an analytic model that considers the relationship between particle mobility and a threshold for different flow regimes (i.e. Poiseuille and plug flow) in the tube (Tammet, 2015). It can be shown that when the grounded inlet length is much less than the hydrodynamic entrance length of the EDM tube, a plug flow profile can be assumed (Tammet, 2015). In the plug flow regime, the threshold mobility (Z_0) is given by:

$$Z_0 = \frac{\bar{u}}{E_d},$$

where $\bar{u}$ is the average flow velocity (ms^{-1}) of the tube and $E_d = V_d/L_d$ is the electric field strength (Vm^{-1}); which is given by the applied voltage in the decelerating segment V_d, divided by the length of this segment L_d (Tammet, 2015). Furthermore, in the plug flow regime, penetration through the EDM tube can be modelled using the threshold mobility where:

$$\text{if } Z < Z_0, P = 1 - \frac{Z}{Z_0}, \text{ else } P = 0.$$

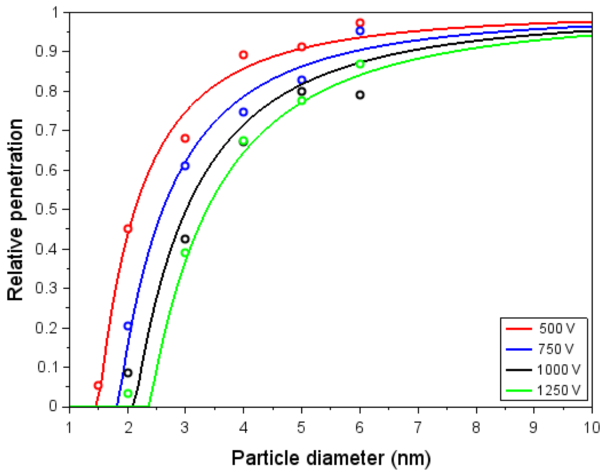

Figure 1. Experimental and theoretical results, based on Tammet (2015), showing relative penetration versus particle diameter for different voltage settings in the plug flow regime.

Two observations are evident from the results shown in Figure 1. Firstly, there is excellent agreement between our experimental results and the analytic model in the plug flow regime. Secondly, our results demonstrate very good sizing resolution near the 50% penetration region, as indicated by the steep gradient of penetration with respect to particle diameter.

Potential applications stemming from the size classification of particles include using the EDM tube as a simple and inexpensive replacement of the second DMA in tandem DMA systems and as a substitute for an electrostatic precipitator in aerosol sizers (e.g. the NanoCheck offered by Grimm). Overall, the results presented here are a step towards low-cost particle detection techniques that can be widely used for a range of environmental monitoring purposes.

References

Bezantakos, S. *et al.* (2015). *Aerosol Sci. Tech.* **49**, iv-vi.
Tammet, H. (2015). *Aerosol Sci. Tech.* **49**, 220-228.