Aerosol characterisation of e-cigarettes

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Keywords: e-cigarette, smoke, particle size, particle concentration
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E-cigarettes are a new category of inhaled consumer product rapidly gaining popularity with adult cigarette smokers. Electronic cigarettes (also known as e-cigarettes or electronic nicotine delivery systems (ENDS)) are typically cigarette shaped battery-powered electronic devices which produce an aerosol containing nicotine generated by an electrically powered heating element which vaporizes a liquid formulation. The condensable material used to generate the bulk aerosol is normally a formulation of water, nicotine with glycerol, propylene glycol (PG) or a mixture of each. A coloured LED at the end is lit when the device is puffed. The system heaters are normally activated on puffing via an internal pressure detector.

Particle size measurements were conducted on a glycerol, water and nicotine based commercial e-cigarette bought from retail sources in the UK. One complication for testing is that there are no accepted standard puffing regimes for analytical testing of this new product category and hence puffing regimes similar to those used for cigarette testing were used but with some differences. In practice, there is a delay from the onset of puffing for the pressure sensor to actuate and effective heating to commence. Ingebrethsen *et al.* (2012) report this to be of the order of 1s which matches our experience. Therefore puff regimes were of 3s duration and 30s intervals rather than the 2s durations normally used for cigarette smoking. Puff volumes were 50 mL, equivalent to mouth volume in the ICRP66 inhalation model. A minimum of 144 consecutive puffs were taken on 3 examples of a commercial e-cigarette, in line with reported capacities, and tested by electrical mobility. Light scattering measurements were confined to 12 puff replicates.

Measurements were conducted by electrical mobility using the Model DMS-500 with Smoking Cycle Simulator (Cambustion, UK) and by light scattering using the Spraytec (Malvern, UK).

Table 1: Electrical mobility (EM: n=432) and light scattering (LS: n=12) measurements for e-cig aerosol.

	Count Median Diameter (nm)	Volume Median Diameter (nm)	Particle Number per puff
EM	63 ± 9	252 ± 11	4.99e10 ±2.26e9
LS		435 ± 39	

Measured geometric standard deviations (σ_g) are 1.55–1.65 and good precision is observed for both measures.

The volumetric mean particle diameter data are similar for the two methods given their different physical operating principles. The electrical mobility analyser operates at reduced pressure and there is scope for evaporation from the glycerol / nicotine / water droplets. This was observed by Ingebrethsen *et al.* (2012) who reported typical geometric mean diameters of 17-28 nm by electrical mobility. The Ingebrethsen, 2012 work used a high level of secondary dilution (200:1) and hence total dilution (3 400-5 500:1), in contrast to our own work where secondary dilution was absent. The observed data are consistent with increased evaporation at higher dilution levels as might be expected. The presence of particles for measurement was consistently observed for 2.0-2.1s of the 3s puff supporting the hypothesis of a delayed onset of approximately 1s from puff initiation to aerosol delivery. Particle number per puff are of the same order between these and the Ingebrethsen data (2.7-7.4e9.cm^{-3}), when corrected for puff volume.

For light scattering, it is known that scatter intensity from aerosol droplets decreases markedly below the wavelength of visible light and therefore there is some scope for smaller particles in the distribution to be under-represented, potentially elevating the average diameter. Reported data from this study are again similar to those of the Ingebrethsen study where measurements of diameter of average mass by a multi-wavelength light extinction apparatus were in the region of 272–351 nm.

In conclusion, the measurement data suggest that the aerosol plume from e-cigarettes can be characterised with good precision, by real-time analytical methods using commercially available equipment. Further work is clearly necessary to agree standard testing regimes between industry and regulators and further scientific investigation is required to understand and develop the most appropriate measurement technique.

This work was conducted in-house by British American Tobacco.

Ingebrethsen, BJ., Cole, SK and Alderman, SL (2012) *Inhal Toxicol.* **24**(14):976-84.

International Commission for Radiological Protection ICRP Publication 66 : (1994) *Ann. ICRP* **24** (1-3).