Aerosol measurement of e-cigarettes
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INTRODUCTION
Electronic nicotine delivery systems (ENDS or e-cigarettes) are a new type of product rapidly gaining popularity with adult cigarette smokers. They are typically cigarette shaped battery-powered electronic devices (Figure 1) which produce a condensation aerosol containing glycerol or propylene glycol (PG) or a mixture of each with water and nicotine. Menthol and other flavours may be included in some formulations. Early e-cigarettes originated in China as early as 2004, but they have become more prevalent in recent years with analyst sales estimates of up to $2bn in 2013. The e-cigarettes exist in a diverse regulatory landscape. This ranges from de facto bans, or regulation as consumer, tobacco or licensed medical products. The use of e-cigarettes has generated wide debate over issues such as ingredient purity, output content and consistency, indoor use, and usage intent, whether as a cessation aid or as a means of harm reduction.

This poster illustrates some initial particle size and concentration measurement for a series of e-cigarettes and compares these data versus published e-cigarette and tobacco smoke data. The data show good reproducibility of output from some of the latest generation of devices. However, this process has highlighted the need for the development of standard measurement protocols as regulatory oversight develops.

EXPERIMENTAL – MEASUREMENT
Aerosol from e-cigarettes was measured by electrical mobility (Cambustion DMS-500, UK) and light scattering (Malvern Spraytec, UK) (Figure 2). Smoking profiles were sine- or square wave, of 50, 55 and 80 mL volume, of 3s duration at 30s intervals. No secondary dilution was used. Cigarette smoking measurements were conducted by electrical mobility with a sine-wave profile of 35 or 55 mL puffs of 2s duration with 30:1 secondary dilution.

RESULTS – MEASUREMENT

\[ \text{Volume weighted median diameters were } 252 \pm 11 \text{ nm for ENDS and } 435 \pm 2 \text{ nm for cigarette smoke.} \]

In the course of the work, a transition was made from sine to square-waved puffs and 3s duration was used, improving precision. This addressed lag-time issues in the e-cigarettes due to actuation of the pressure sensor and the heating coils, also reported by Ingebrethsen et al, 2012.

SUMMARY
- Physical aerosol data similar for e- and tobacco cigarettes; chemistry differs
- e-cigarettes tested in this work showed excellent output reproducibility
- Particle or droplet diameters by optical methods were similar across devices
- Mobility measurements appeared to under-predict size but gave significantly better precision data (better characterised smoking engine)
- Smoking profile important for measurement precision – square wave over 3s
- Increasing consumer use and regulatory oversight of e-cigarettes supports the need for the development of standardised and validated testing regimes

Table 1. Current and previously reported data

| Device       | Tech | CMD (nm) | VMD (nm) | P # | Notes       | Gravimetric mass per puff from e-cigarette A was 1.86 ± 0.13 mg per puff with the aerosol composition generally matching the source formulation composition. Volume weighted median diameters were 252 ± 11 nm by electrical mobility and 435 ± 2 nm by laser diffraction. Measured geometric standard deviations (σg) were 1.55–1.65 and particle number per puff by electrical mobility was 4.99e10 ± 2.26e9. Back-calculation of the diameter of average mass from the gravimetric data, number concentration and mixture density (ρ = 1216.3 kg m⁻³) gave a volumetric diameter of average mass of 388 nm supporting a hypothesis of evaporation losses on dilution and within the mobility measurement (σ = 0.1 atmos). This was also noted by Ingebrethsen et al, 2012, where the difference between mobility and optical diameters was even more pronounced due to a high (200:1) secondary dilution used in the mobility measurement.

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Electronic nicotine delivery systems (e-cigarettes) are a new type of product rapidly gaining commercial activity. There are currently more than 250 types of e-cigarette on the market worldwide, and many people believe that they may offer a safer alternative to smoking. However, little information is currently available on the aerosol plume from e-cigarettes.

Particle size measurements were conducted on a glycerol, water and nicotine based aerosol from a commercial e-cigarette purchased in the UK and tested to a puffing regime of a 50 mL puff of 3s duration every 30s. Measurements were conducted by gravimetric filter analysis, electrical mobility using the Model DMS-500 with Smoking Cycle Simulator (Cambustion, UK) and by laser diffraction using the Spraytec (Malvern, UK).

Gravimetric mass per puff was 1.86 ± 0.13 mg per puff with the aerosol composition matching the source cartridge composition. Volume weighted median diameters were 252 ± 11 nm by electrical mobility and 435 ± 39 nm by laser diffraction. Measured geometric standard deviations (g) were 1.55–1.65 and particle number per puff was 4.99e10 ± 2.26e9. Back-calculation of the diameter of average mass from the gravimetric data, number concentration and mixture density (1216.3 kg.m⁻³) gave a volumetric diameter of average mass of 388 nm supporting the hypothesis of evaporation losses within the electrical mobility measurement.

In conclusion, the measurement data suggests that the aerosol plume from e-cigarettes can be measured with good precision. Further analytical methods using a combination of real-time and conventional methods are required to fully understand this novel aerosol.