Physical characteristics of e-cigarette aerosols and their implication for dosimetry

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Introduction

- Cigarettes and e-cigarettes typically produce a physically similar liquid droplet based condensation aerosol from a supersaturated vapour.
- However, their chemistry is markedly different
  - the e-cigarette rapidly evaporates a relatively simple formulation containing nicotine and water with glycerol, propylene glycol (PG) or a mixture of each.
  - the cigarette produces a complex mix of over 7000 components from combustion, pyrolysis and distillation
- Areas of regulatory interest may cover the consistency of output including droplet size and concentration, and how these impact on delivered and retained dose of the aerosol components.

Methods

- Droplet size distributions were measured by electrical mobility (EM: Model DMS-500 MkII, Cambustion, UK) and by laser diffraction (LD: Spraytec, Malvern, UK). The Smoking Cycle Simulator (SCS: Cambustion, UK) was used to generate appropriate puff profiles and to minimise dilution and potential droplet evaporation.
- Subsequent deposition modelling using the ADiC/IDEAL model applied coagulation, conductive and convective heat transport, diffusive and convective vapor transport, phase transition (e.g. hygroscopic growth), and particle deposition (Pichelstorfer *et al*, J. Aerosol Science (2013) **64**:125-142.

Summary

- Volume-weighted median droplet diameters (d_{50}) for e-cigarette aerosol were typically less than 500 nm by LD and less than 300 nm for EM, versus equivalent tobacco smoke measurements of approximately 210 nm – number concentrations were similar.
- For e-cigarette aerosol, d_{50}-EM < d_{50}-LD due to evaporative losses; partly from EM low pressure measurement, but also the difference increasing with increasing dilution ratio from sampling
- Precision data were product dependent but less than 4–5% for most products. This degree of precision meets the acceptance criteria for droplet size distribution (d_{50} ± 20% for d_{50} < 10 µm) for laser diffraction measurements for similar aerosol products. (e.g. USP Pharmacopeia <429>, ISO13320:2009).
- Key modelled events are:
  - early thermal coagulation in the mouth for both aerosols
  - hygroscopic growth in the airways for both aerosols
  - hygroscopic growth is significantly greater for the e-cigarette aerosol (~3x diameter) versus cigarettes (~1.5x diameter) and for e-cigarette aerosol correlates with the glycerol fraction.
- In the lung, deposition of nicotine is driven by evaporation from the droplet and vapor phase deposition, especially in the alveolar region.

Measurement

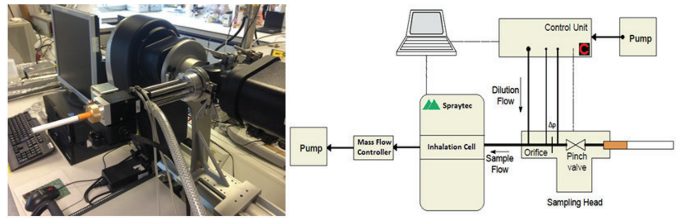

Figure 1 : Cambustion Smoking Cycle Simulator / Malvern Spraytec laser diffraction (LD)

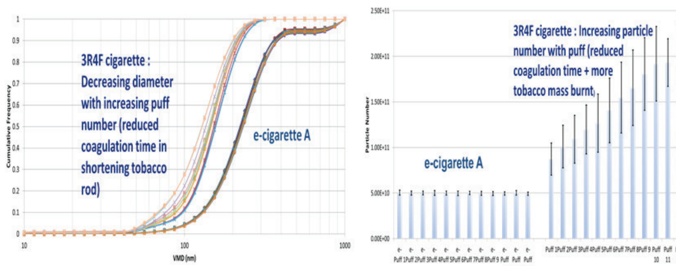

Figure 2 : Droplet diameter and number concentration (EM) for UK 3R4F research cigarette versus e-cigarette (Intellicig, CN Creative, UK)

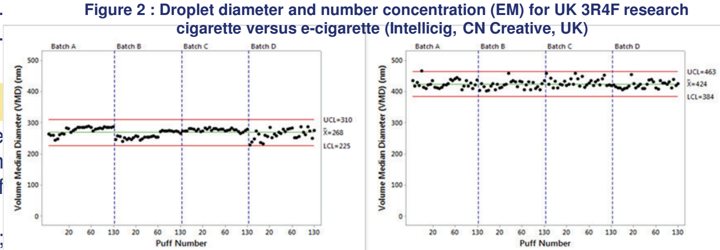

Figure 3 : Droplet diameter precision for e-cigarette @ 1:8 dilution (Intellicig, CN Creative, UK) : Electrical Mobility (left) versus Laser Diffraction (right)

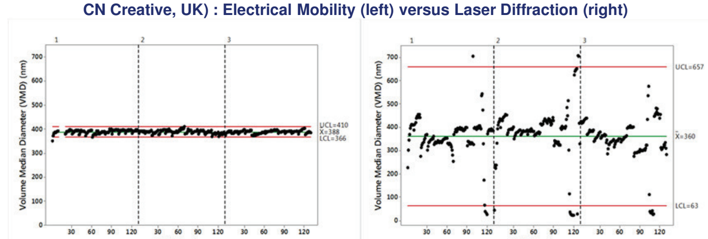

Figure 4 : Droplet diameter precision by electrical mobility – device dependence extremes : Vype e-Stick (Nicoventures, UK) (left) versus externally sourced tank system (right)

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Modelling

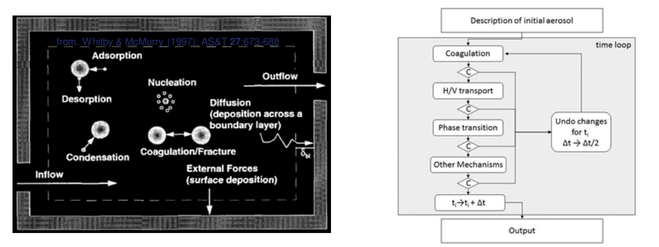

Figure 5 : Key physical processes and their incorporation into Lagrangian / Eulerian dynamic transport model (Pichelstorfer *et al*, 2013)

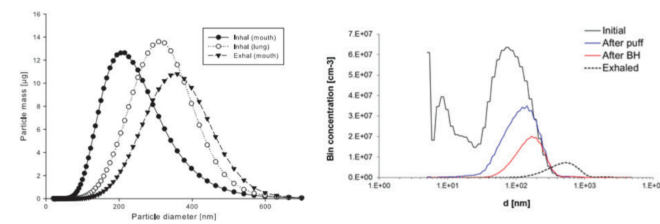

Figure 6 : Modelled particle growth post-puff, inhalation and exhalation for cigarette smoke (left) and e-cigarette aerosol (right)

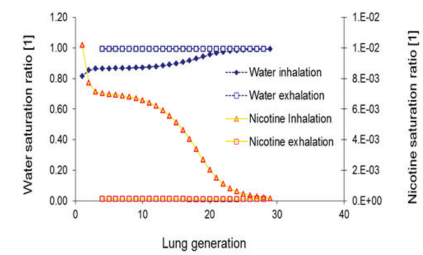

Figure 7 : Saturation ratio of water and nicotine as a function of lung generation.

In ET region, G1-3, T ↑ so nicotine saturation ratio ↓. Heat and vapor exchange effective from G10 on. In alveolar region, final water saturation ratio reaches 99.5% (at 310.15 K), nicotine saturation ratio approaches order of 10^{-5}.

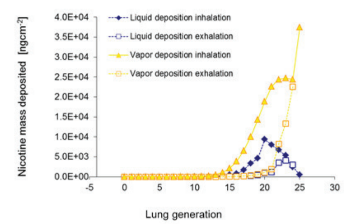

Figure 8 : Modelled nicotine deposition from e-cigarette aerosol on inhalation and exhalation

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E-cigarettes typically produce a condensation aerosol by rapidly evaporating a formulation containing nicotine and water with glycerol, propylene glycol (PG) or a mixture of each. Areas of regulatory interest may include the nature and consistency of the device output including droplet size and concentration, and how these impact on delivered and retained dose of the formulation components. Droplet size distributions were measured by electrical mobility (EM: Model DMS-500 MkII, Cambustion, UK) and by laser diffraction (LD: Spraytec, Malvern, UK). The Smoking Cycle Simulator (SCS: Cambustion, UK) was used to generate appropriate puff profiles and to minimise dilution and potential droplet evaporation.

Volume-weighted median droplet diameters (d_{50}) were typically less than 500 nm by LD and less than 300 nm for EM, versus equivalent tobacco smoke measurements of approximately 210 nm. Precision data were product dependent but less than 4–5% for most products. This degree of precision meets the acceptance criteria for droplet size distribution (d_{50} ± 20% for d_{50} < 10 µm) for laser diffraction measurements for similar aerosol products.

Subsequent deposition modelling needs to considers coagulation, conductive and convective heat transport, diffusive and convective vapor transport, phase transition and particle deposition. Key events are early thermal coagulation in the mouth and hygroscopic growth in the airways correlating with the glycerol fraction. Deposition of nicotine is driven by evaporation from the droplet and vapor phase deposition, especially in the alveolar region.

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