Indoor air quality and exhaled breath composition after use of nicotine delivery products

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1. Introduction

Electronic cigarettes (e-cigarettes) and heated tobacco (Heat-not-Burn) products are gaining acceptance with consumers as alternatives to traditional tobacco products. Consequently, there is a growing interest from regulators and public health organisations on whether the aerosol exhaled from such products has implications for the quality of air breathed by bystanders.

There is currently an absence of robust scientific evidence on the potential impact of exhaled aerosol on indoor air quality in everyday environments, like homes and offices. Nonetheless, there are calls, including by some by government bodies, to prohibit the use of e-cigarettes in workplaces and enclosed public spaces [1].

In the first part of our work we aimed to perform an assessment of indoor air quality by analysing the airborne concentrations of nicotine, propylene glycol and glycerol (the major components of e-cigarette liquids) before, during and after use of e-cigarettes in 'real-life' conditions. As there are no general indoor air quality guidelines or standards for nicotine, propylene glycol or glycerol, a comparison of the findings to UK workplace exposure limits (WELs) is made to provide an indication of potential bystander air quality [2].

As the quality of indoor air is influenced by the chemical composition of exhaled breath, in the second part of our work we aimed to determine whether Proton Transfer Reaction-Mass Spectrometry (PTR-MS) may be a suitable technique for the real-time analysis of chemicals released in exhaled breath following use of a range of nicotine delivery products. Please refer to our second SRNT-USA 2015 poster presented today for more information from our PTR-MS pilot studies [session 2; poster #54].

2. Air quality testing in an office before, during and after use of an electronic cigarette

An electronic cigarette (e-cigarette) air quality study was conducted by a leading independent UK accredited laboratory with recognised expertise in air quality measurements and analyses for Imperial Tobacco to assess the concentration of nicotine, propylene glycol and glycerol (the main components of e-cigarette liquid) in the ambient air before, during and after use of the Puritane™ 16 mg disposable e-cigarette (manufacturer Fontem Ventures B.V.) in an office environment.

A schematic representation of the office layout, the two independent sampling locations and the positions of the e-cigarette users and non-users is shown in ***Figure 1***. To investigate potential changes in indoor air quality, the ambient air was analysed before, during and after a 165 min vaping session. Sampling times are shown in ***Figure 2***.

The average puff rate over the three e-cigarette users during the 165 min vaping session was 3.2 puffs per minute. This level of product use may have been influenced by the no-vaping restriction during the first hour. Given the puffing frequency and 0.8 air changes per hour air exchange rate, it is likely that findings in this study may be an overestimate. ***Table 1*** summarises the results for airborne concentrations of nicotine, propylene glycol and glycerol before, during and after the vaping session.

As would be anticipated, the concentration of propylene glycol in the indoor ambient air, the major constituent of the e-liquid, was higher during the vaping session relative to the background and no vaping control period but remained within the workplace exposure limit (WEL) set for this chemical. Following cessation of vaping, there was a substantial decrease in the concentration of propylene glycol in the indoor ambient air. By contrast, there was no measurable increase in the airborne concentration of nicotine during use of the e-cigarette in the office space (limit of detection [LOD] for nicotine, 7 μg/m^3). Due to the LOD for glycerol (150 to 350 μg/m^3), glycerol was not detected in any of the samples taken, with the results being < 250 μg/m^3 for the vaping samples.

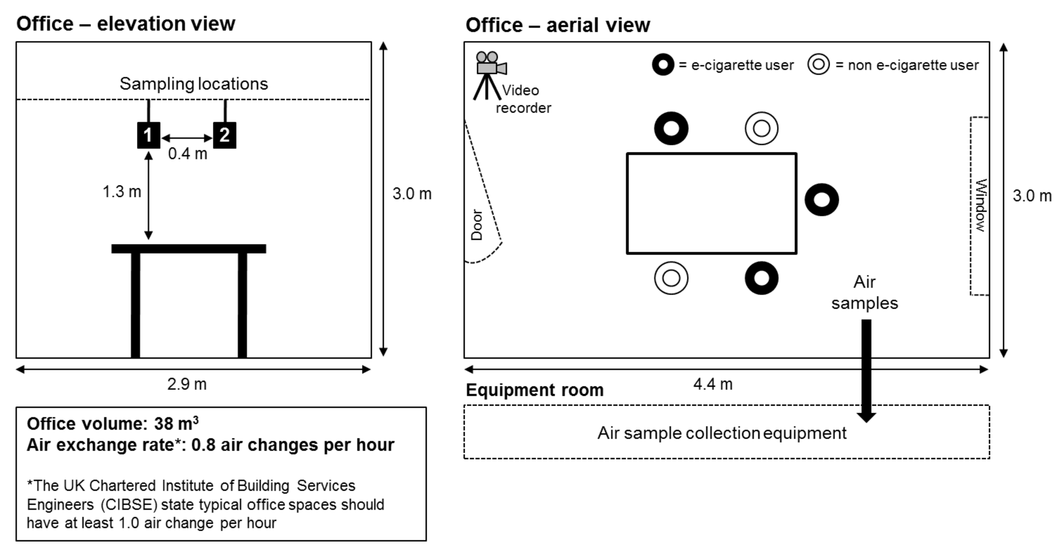

Figure 1 The layout of the office, the sampling locations and the positions of the e-cigarette users and non-users during the meeting.

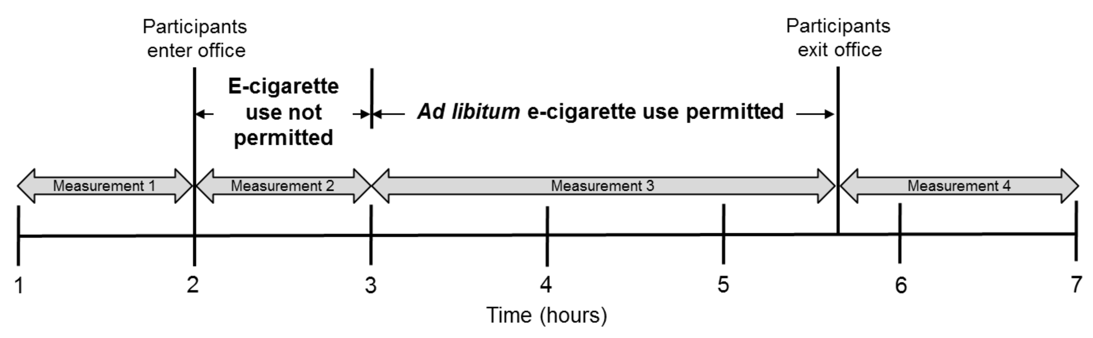

Figure 2 Timeline showing when participants entered and exited the office, when e-cigarette use was and was not permitted and the sampling times.

Table 1 Analysis of nicotine, propylene glycol and glycerol in indoor ambient air before, during and after a vaping session (average from the two sampling locations)

Chemical	Background (before participants enter room) [μg/m^3]	Room occupied (NO VAPING) [μg/m^3]	Room occupied (VAPING PERMITTED) [μg/m^3]	Room unoccupied (after participants leave room) [μg/m^3]	Workplace exposure limit (WEL) (8 h mean) [μg/m^3]	Comments
	Measurement 1	Measurement 2	Measurement 3	Measurement 4		
Nicotine	< LOD	< LOD	< LOD	< LOD	500	No measurable increase during vaping relative to background and no vaping control; below the WEL
Propylene glycol	< LOD	< LOD	204	10.2	474000 (total vapour and particulates)	Increase during vaping relative to background and no vaping control period; substantial decrease with cessation of vaping; below the WEL
Glycerol	< LOD	< LOD	< LOD	< LOD	10000	Glycerol not detected in any sample; due to large limit of detection, a more sensitive analytical method is required

Note: LOD, limit of detection

3. Analysis of VOCs released in exhaled breath following use of nicotine delivery products

The analytical technique PTR-MS (Proton Transfer Reaction-Mass Spectrometry) is a sensitive tool for the simultaneous real-time monitoring of volatile organic compounds (VOCs) with high sensitivity. PTR-MS is a tool that does not require sample preparation and so can be used for rapid determination of exhaled breath profiles e.g. in medical diagnostics.

We recently published an indoor air quality mathematical model to predict potential bystander exposures to exhaled e-cigarette aerosol constituents [3]. Here we identified 'quantity of chemical constituent exhaled' as the most important factor influencing indoor air quality and bystander exposure. Therefore, it is essential that precise measurements are made regarding the quantity of compounds exhaled by the e-cigarette user (e.g. nicotine) when determining potential bystander exposure. As the composition of the exhaled breath will influence the quality of indoor ambient air, PTR-MS may be used as part of an assessment scheme for indoor air quality.

In this proof-of-concept study we aimed to identify and determine the breath concentrations of nicotine following use of a range of nicotine delivery products. Representative data presented in ***Figure 3*** shows mass spectrometric profiles of exhaled breath following a single exhalation event after product use (red) and comparison with blank control breath (black). The peaks on mass 19 and 37 *m/z* (and their isotopes) represent the reagent ions (H_3O^+) and their clusters. The PTR-MS has been calibrated for nicotine (*m/z* 163; see arrowheads) [4]; all other red peaks correspond to compounds released following use of the specific nicotine delivery product; their identities remain to be determined in future work.

Following use of a conventional cigarette and heated tobacco product, a large number of different chemicals are released in the exhaled breath, as shown by the red spectra across a range of masses. With regards to exhaled nicotine, 1150 ppb (parts per billion) nicotine were detected in the exhaled breath following use of the conventional cigarette (**a**) and 1840 ppb nicotine following use of the heated tobacco device (**b**). In contrast, with the non-tobacco products, nicotine was detected in the exhaled breath at 7 ppb following use of the e-cigarette (**c**) and 1 ppb nicotine following use of the nicotine inhalator (**d**).

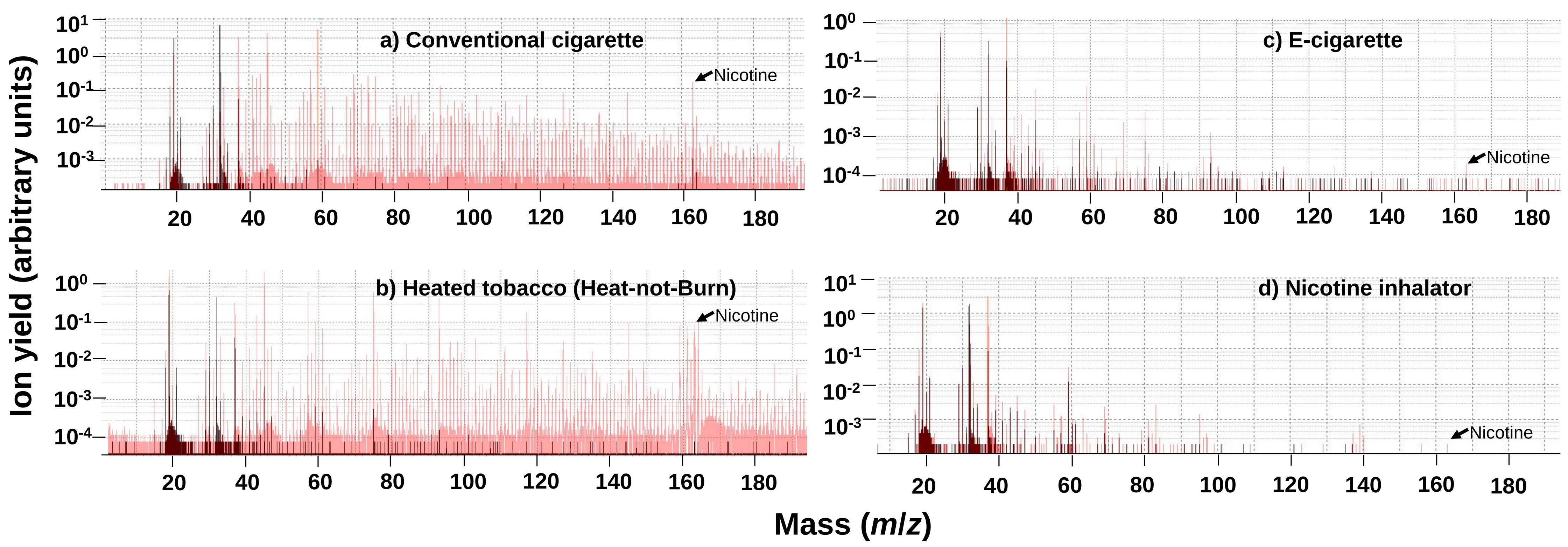

Figure 3 Representative PTR-MS mass spectra of VOCs released in a exhaled breath following use of (**a**) a conventional cigarette (0.6 mg nicotine [ISO smoking regime]), (**b**) heated tobacco device (Heat-not-Burn; iQOS with regular heatsticks) (**c**) electronic cigarette (20 mg/mL nicotine Puritane rechargeable e-cigarette device) and (**d**) 15 mg nicotine inhalator (Nicorette® Inhalator). Black peaks, VOCs released in normal exhaled breath (background control); red peaks, VOCs released in exhaled breath following product use. Results shown here are the output from a single exhalation event. Specific compound (ion trace) at *m/z* 163 is nicotine and is labelled with arrowhead. PTR-MS identification of nicotine at *m/z* 163 is shown elsewhere [4]. Three volunteers participated in this study and each volunteer used each of the four products described above. For each of the products tested: five blank breath measurements were taken directly before product use (background control) and following this the volunteer was given the product to use and become familiar with. Following this, the volunteer used the product *ad libitum* five times and exhaled into the PTR-MS each time allowing analysis on a per puff basis.

4. Conclusions & future work

During the use of the Puritane™ 16 mg disposable e-cigarette in the small office space indoor air quality study, the concentration of propylene glycol measured in the office air, and therefore breathed by bystanders, was significantly lower than the UK WEL. Exposure of bystanders to indoor ambient air following exhalation of this chemical at the levels seen in this study within the e-cigarette aerosol would not be anticipated to cause health problems, a conclusion in agreement with [5]. There was no measureable increase in the concentration of nicotine in the indoor ambient air during vaping. To explore this finding further, we aim to determine (i) the quantity of nicotine retained by the e-cigarette user (i.e. the fraction not exhaled into the ambient air); and (ii) whether any potential nicotine in the exhaled aerosol is deposited to various surfaces.

As may be expected from the tobacco basis of conventional cigarettes and heated tobacco (Heat-not-Burn), many more chemical components are detected in exhaled breath compared to simple electronic vapour products. Of note, substantially more nicotine is present in the exhaled breath following use of the tobacco based products. Due to the wide range of chemical species detected in the exhaled breath following use of the heated tobacco product, it is likely use of such products could impact indoor air quality in a similar way that has been reported for conventional cigarettes. As such, this is an important area for additional research.

The indoor air quality experimental design and methodology used in our work may be employed to evaluate the indoor ambient air quality assessment of other chemicals or particulates. Moreover, our proof-of-concept PTR-MS work showed the potential of this technology to be used as a technique to monitor the emissions from a range of nicotine delivery products and quantify released VOCs in real-time under a range of conditions and determine the impact on indoor air quality.

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Declaration

This project was supported by Imperial Tobacco Group. The e-cigarette used in this study was manufactured by Fontem Ventures, a fully owned subsidiary of Imperial Tobacco Group.