Indoor air quality assessment of e-cigarette use in an environmental chamber

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Introduction

An electronic cigarette (e-cig) is a battery-powered consumer product that provides an inhalable vapor by turning e-liquid into an aerosol via an electrical means such as electrical heating. In order to further elucidate the reduced risk potential of switching from smoking to e-cigarette use, it is important to assess the effects of e-cigarette vapor, not only on users but also bystanders. Potential bystander exposure to exhaled vapor can be indirectly assessed through indoor air quality (IAQ) measurements under controlled conditions. Therefore, the aim of this study was to assess the indoor air quality after e-cigarette use in comparison to ambient air in an environmentally controlled chamber.

Materials and Methods

E-cigarette (Logic Compact):

- a pre-filled pod system containing 1.7 mL of e-liquid
- 18 mg/mL nicotine
- tobacco flavor
- a lithium-ion battery (3.7 V, 350 mAh)

Environmental chamber:

- an internal volume of 41.1 cubic meters
- a ceiling height of 2.5 m
- two fans to ensure mixing of the air
- filters and measurement tubes situated in the middle of the room at head height whilst seated
- the ventilation was set at 2 air changes per hour, which is indicated as “unoccupied periods” in residential buildings’ standard BS EN 15251:2007, not taking into account the number of persons inside the room

Per day, three 1-hour IAQ measurements were carried out (shown in blue):

Start	Background empty chamber (Ref 1)	Break	Background persons in chamber (Ref 2)	Break	E-cigarette test (Test)	Overnight
Door opened; New Filters & tubes	Test empty chamber for 1 hour	Door opened; Replace filters & tubes	Test chamber + volunteers for 1 hour	Door opened; Replace filters & tubes	Test chamber + voluteers vaping for 1 hour	Purge for 3 hours at 10 ACH

Fourteen adult, healthy, experienced, sole e-cigarette users (informed consent given) participated in the study (2 on day 1, 4 on day 2, 8 on day 3) and vaped ad libitum. The seating arrangements are shown in Figure 1.

For each 1-hour measurement period, Temperature, Relative Humidity, CO, CO_2, and Particulate Matter were monitored online and all other compounds were spot sampled in triplicate in the air (a listing of all compounds is shown in Table 1).

Compound	Background (B) or Above Background (AB) Result
Carbon monoxide	B
Carbon dioxide	AB
Low molecular weight carbonyls:	
• Acetaldehyde	B
• Acetone	B
• Acrolein	B
• Formaldehyde	B
Glycerol	B
Metals:	
• Aluminium	B
• Antimony	B
• Arsenic	B
• Barium,	B
• Beryllium	B
• Cadmium	B
• Chromium	B
• Cobalt	B
• Copper	B
• Lead	B
• Manganese	B
• Mercury	B
• Nickel	B
• Selenium	B
• Silver	B
• Thallium	B
• Zinc	B
Nicotine	AB
Polyaromatic hydrocarbons:	
• Acenaphthene	B
• Acenaphthylene	B
• Anthracene	B
• Benzo[a]anthracene	B
• Benzo[a]pyrene	B
• Benzo[b/k]fluoranthene	B
• Benzo[ghi]perylene	B
• Chrysene	B
• Dibenz[a,h]anthracene	B
• Fluoranthene	B
• Fluorene	B
• Indeno[1,2,3-cd]pyrene	B
• Naphthalene	B
• Phenanthrene	B
• Pyrene	B
Particulate Matter:	
• PM1	AB
• PM2.5	AB
• PM10	AB
Phenol	B
Tobacco-specific nitrosamines:	
• 4-N-Nitrosonornicotine (NNN)	B
• 4-(Methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK)	B
• N-Nitrosoanatabine (NAT)	B
• N-Nitrosoanabasine (NAB)	B
Ammonia	B
Volatile Organic Compounds:	
• TVOCs	AB
• alpha-pinene	B
• 3-carene	B
• Limonene	B
• DMCPS	AB
Propylene Glycol	AB

Table 1. *Fifty-six compounds tested to assess the IAQ inside the chamber. Eight were above background (AB) and all others remained at background (B) levels when measurements were taken in the empty chamber (Ref 1)*

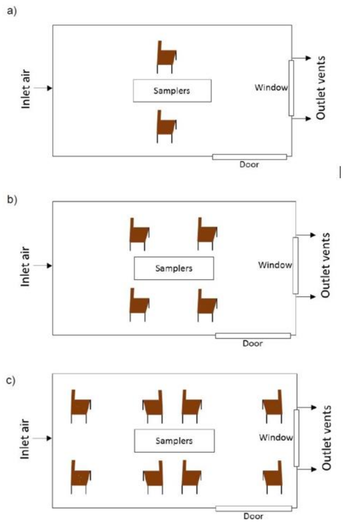

Fig. 1. *Chamber schematics illustrating the volunteers’ seating arrangements per day: a) Day 1, b) Day 2, c) Day 3.*

Day	Volunteers
1	n=2
2	n=4
3	n=8

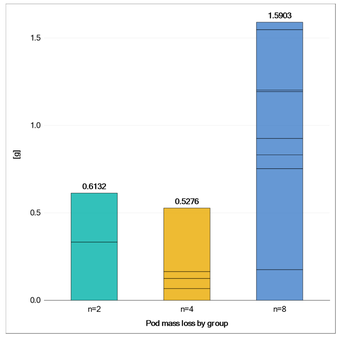

Fig. 2. *E-liquid consumption per group expressed as pod mass loss.*

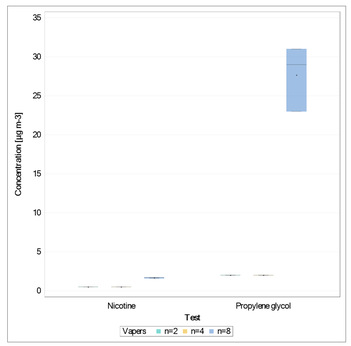

Fig. 3. *Nicotine and Propylene glycol measured during the Test inside the chamber.*

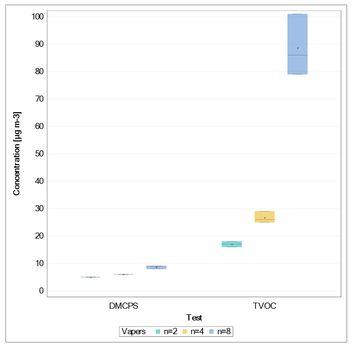

Fig. 4. *Total volatile organic compounds (TVOCs) and decamethylcyclopentasiloxane (DMCPS) measured during the Test inside the chamber.*

Acknowledgement

The authors would like to thank Simon Hugi for his assistance.

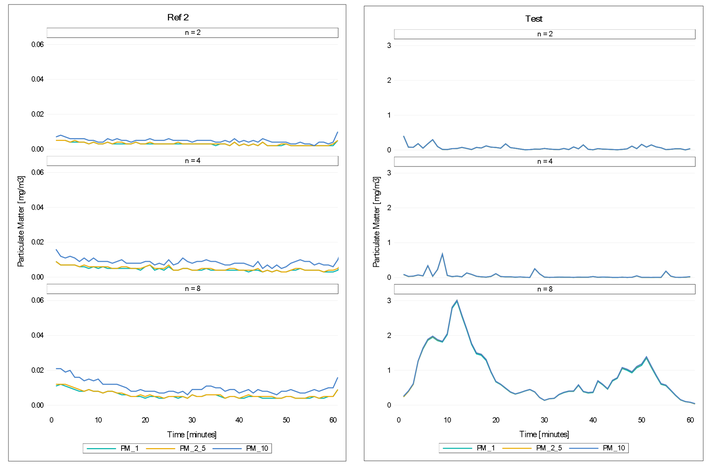

Fig. 5. *Particulate Matter (PM) 1, 2.5 and 10 were measured inside the chamber and outdoors (data not shown).*

Results

- Total e-liquid mass loss over 1 hour was 0.61, 0.53, and 1.59 grams for 2, 4, and 8 volunteers respectively (See fig.2).
- Nicotine concentrations remained at background levels for 2 and 4 volunteers vaping. When 8 volunteers vaped the e-cigarette, the nicotine concentration increased by 0.6 µg/m³ (See fig.3).
- Propylene glycol concentrations also remained at background levels for 2 and 4 volunteers vaping. However, during the e-cig test, propylene glycol was present at a mean level of 28 µg/m³ (See fig.3).
- The TVOC concentration was above background during the Test periods (See fig.4). The dominant VOC concentration seemed to be decamethylcyclopentasiloxane (DMCPS), a common component of personal care products, which was applied in the morning and reduced over time. During the E-cig test, the mean TVOC concentration for n=8 was increased by 28 µg/m³ in comparison with Ref 2.
- PM1, 2.5 and 10 remained well below 1 mg/m³ for 2 and 4 volunteers vaping in comparison with Ref 2 (See fig.5). With 8 persons vaping in the chamber, all light scattering PM fractions overlapped and showed two peaks, the highest reaching 3 mg/m³.

Discussion

- Vaping ad libitum showed a mass loss from the e-cig pods, which was more when 2 volunteers vaped than when 4 volunteers vaped, showing different vaping behaviors.
- The pods contained 18 mg/mL nicotine, but only trace levels were found in the air, implying that most is retained in the body.
- From the carrier solvents, only propylene glycol was detected. Eight volunteers consumed around 3 times the amount of e-liquid compared to 2 or 4 volunteers, which could explain the peak during the Test.
- The TVOCs detected when 8 volunteers vaped inside the chamber was possibly due to the increase in propylene glycol and DCMPS from personal care products.
- All volunteers abstained from vaping for at least 3 hours before the e-cig was tested. The first peak of PM during the Test with 8 volunteers could, therefore, represent an increase in vaping to compensate for the lack of vaping, followed by a decrease when satisfactory vaping levels were reached. The second peak is already half the concentration of the first peak when the urge for vaping leveled off.

Conclusion

- E-cigarette use had minimal impact on IAQ, especially at low and medium chamber occupancy levels.
- Future standardization of IAQ testing should focus on e-liquid consumption in addition to the number of vapers.