

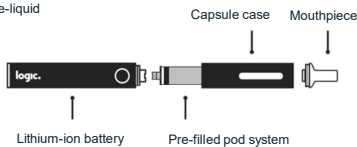
Introduction

An electronic cigarette (E-cig) is a battery-powered product that provides an inhalable vapor by turning propylene glycol and a glycerol-based liquid into an aerosol by electrical heating. Recently, the number of E-cig users has increased rapidly, and it has become important to assess the effects of e-cigarettes not only on the user but also on the indoor air quality while the product is being used. The aim of this study is to evaluate the indoor air quality (IAQ) during E-cig use compared to the air quality without E-cig use by measuring the concentrations of some constituents.

Materials and Methods

E-cig:

- marketed under the name Logic PRO
- a pre-filled pod system containing 1.7 mL of e-liquid
- 18 mg/mL nicotine
- approximately 300 puffs per pod
- a lithium-ion battery (650 mAh)



Chamber environment:

- an internal volume of 16.69 m³
- a ceiling height of 2.0 m
- a fan to ensure mixing of the air
- filters and collection tubes situated at the exhaust port on the ceiling
- referenced "Dining room 2" of ASHRAE Standards 62-2001, Addendum62, Appendix 1, to simulate a restaurant

Table 1. Test conditions.

		Dining room 2 (Restaurant)	Calculation basis
Floor area	(m ²)	8.32	
Smokers	(person)	3	Floor area (m ²) × 0.7 (person/m ²) ^{*1} × 0.5 (-) ^{*2}
Consumption rate	(cig/h·person)	2	0.6 (cig/h·person) ^{*3} × 2
Puffs per cigarette	(puffs/cig)	8	Based on the average puff numbers of major cigarettes in the Japanese market ^{*4}
Puffs per person	(puffs/h·person)	16	Consumption rate (cig/h·person) × Puff per cigarette (puffs/cig)
Total puffs	(puffs/h)	48	Smokers (person) × puffs (puffs/h·person)
Total ventilation rate	(m ³ /h)	210	36 (m ³ /h·person) ^{*4} × floor area (m ²) × 0.7 (person/m ²) ^{*1}

*1: Occupant density (person/m²) *2: Proportion of smokers (-) *3: Consumption rate (cig/h·person) *4: Ventilation rate (m³/h·person) (Reference: ASHRAE Standards 62-2001, Addendum 62, Appendix 1)

"Consumption rate" in Table 1 is doubled with ASHRAE 62-2001 to avoid underestimation.

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

Table 2. Test schedule.

Start	Without Person	Break	With Person	Break	E-cig With Person	Overnight
-	1 hour	20 min	1 hour	20 min	1 hour	-
Opened new filters and tubes	Tested empty chamber	Washout	Tested chamber and three volunteers	Washout	Tested chamber and three volunteers vaping	Overnight washout

Results and Discussion

Comparing the chamber with panelists "With Person" to an empty chamber "Without Person"

- Except CO₂, nicotine, and isoprene, all other constituents concentrations remained at "without person" level.
- Only CO₂ concentrations had showed a significant difference.
- "With person" nicotine and isoprene concentrations increased. (Statistical tests were not conducted.)
- Increasing isoprene and CO₂ concentrations was most likely generated by the panelists.
- Increasing nicotine concentration could possibly be the effect of tobacco smoke adhering to panelists' clothing.

Comparing vaping panelists "E-cig With person" to non-vaping panelists "With Person"

- Except nicotine, glycerol, and propylene glycol, all other constituent concentrations remained at "with person" level.
- For nicotine and glycerol, there was a significant difference in concentrations.
- Nicotine concentrations increased by 0.3 µg/m³, and glycerol concentrations increased by 2.3 µg/m³.
- Propylene glycol was present at a mean level of 4.8 µg/m³ at "E-cig with person." (Statistical tests were not conducted.)
- Nicotine, glycerol, and propylene glycol are all constituents originally found in the E-cig liquid.

Conclusion

- Under test conditions, except for the compounds contained in the e-liquid, there was no increase in concentration of measured compounds in room air due to the use of e-cigarettes.

Table 4. Chamber room conditions (temperature, humidity, ventilation rate).

Condition	Without Person	With Person	E-cig With Person
	Arithmetic mean ± 95% Confidence Interval (CI)		
Temperature	23.4 ± 0.4	24.7 ± 0.1	25.3 ± 0.1
Humidity	49.1 ± 4.4	47.6 ± 1.7	46.7 ± 1.8
Ventilation rate	200 ± 2	199 ± 3	199 ± 2

Nine healthy daily adult smokers (from whom informed consent was obtained) participated in the study (three smokers on each day). They inhaled 16 puffs in 20 minutes. The seating arrangements are shown in Figure 1.

For each 1-hour measurement, temperature; relative humidity; and CO, CO₂, and particulate matter concentrations were monitored online, and other compounds were spot-sampled in the air and tested in triplicate. A list of all compounds as well as the collection and analysis methods is presented in Table 2.

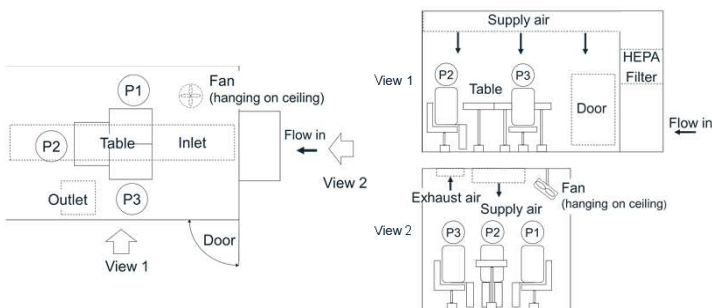


Fig. 1. Chamber schematics illustrating the volunteers' seating arrangements.

Table 3. Constituents and the collection and analysis method.

Suspended particulate matter (SPM) (<10 µm)	Piezoelectric sensor
CO	Constant-potential electrolysis
CO ₂	Non-dispersive infrared absorption method
Volatile organic compounds (VOCs) (1-3-butadiene, isoprene, benzene, toluene)	Adsorbent-collection ATD-GC/MS analysis (Ref: ISO16000-6)
Carbonyls (formaldehyde, acetaldehyde, acetone)	Adsorbent-collection HPLC/UV analysis (Ref: ISO16000-3)
Environmental tobacco smoke (ETS) - vapor marker (nicotine, 3-ethenylpyridine)	Adsorbent-collection GC/NPD analysis (Ref: ISO18145)
Propylene glycol, glycerol	Adsorbent-collection GC/MS analysis (Ref: NIOSH5523)

Reference

1: Ministry of Health, Labour and Welfare Japan. 2001. Constituent analysis of tobacco smoke in fiscal 1999-2000.

Table 5. Air quality measurements of fourteen compounds.

Constituents		Without Person	With Person	E-cig With Person	Limit of Quantitation (LOQ)	Limit of Detection (LOD)
		Mean Concentration ± 95% Confidence Interval (CI)				
ETS markers (for vapor matter)						
Nicotine	(µg/m ³)	< 0.212	0.265 ± 0.042	0.561 ± 0.105 †	0.212	0.063
3-Ethenylpyridine	(µg/m ³)	< 0.036	< 0.036 *	< 0.036 *	0.119	0.036
Carbonyls						
Formaldehyde	(µg/m ³)	10.1 ± 0.4	10.1 ± 0.4	10.6 ± 0.5	0.586	0.176
Acetaldehyde	(µg/m ³)	4.90 ± 0.42	4.92 ± 0.93	3.65 ± 0.48	0.644	0.193
Acrolein	(µg/m ³)	< 0.310	< 0.310 *	< 0.310 *	1.032	0.310
VOCs						
1,3-Butadiene	(µg/m ³)	< 0.670	< 0.670 *	< 0.670 *	0.670	0.201
Isoprene	(µg/m ³)	3.32*	5.32 ± 0.45	5.78 ± 0.92	0.467	0.140
Benzene	(µg/m ³)	< 0.410	< 0.410 *	< 0.410 *	0.410	0.123
Toluene	(µg/m ³)	3.50 ± 1.05	3.45 ± 0.23	2.69	0.357	0.107
Major ingredients e-liquid						
Propylene glycol	(µg/m ³)	< 0.666	< 0.200 *	4.83 ± 2.01 †	0.666	0.200
Glycerol	(µg/m ³)	0.826 ± 0.165	0.689 ± 0.121	3.02 ± 0.45 †	1.393	0.418
Gases						
Carbon monoxide	(ppm)	< 0.1	< 0.1 *	< 0.1 *	Measurable low concentration of 0.1	
Carbon dioxide	(ppm)	420 ± 40	650 ± 20 †	640 ± 40	Measurable low concentration of 10	
Suspended Particulate Matter (SPM) (<10µm)						
	(mg/m ³)	< 0.01	< 0.01 *	< 0.01 *	Measurable low concentration of 0.01	

(1) If all measured data were higher than the LOQ, The arithmetic mean and its 95% CI were given.
 *With Person" data and "E-cig With Person" data were statistically tested by F-test for equality of variance and by t-test for significant difference.
 (2) If the median was higher than the LOQ but at least one value was below the LOQ, the median was given and its 95% CI was not mentioned.
 (3) If the median was lower than the LOQ and equal to or higher than the LOD, "<LOQ" was given.
 (4) If the median of all data was lower than the LOD, "LOD" was given.
 *: Statistical tests were not conducted because at least one value was below the LOQ.

