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PO-37

VOC Emissions and Exposure from E-cigarettes

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Introduction

E-cigarettes or electronic nicotine delivery systems (ENDS) are becoming more popular in use. Many, young adolescents especially, are starting to use ENDS with the perception that it is a safer alternative to cigarettes and other traditional tobacco products. However, the number of cases that the users end up in the hospital due to severe lung illnesses and other health problems after e-cigarette use is continuing to rise. Past studies have found that ENDS is a major source of particulate matter and volatile organic compounds (VOCs), impairing air quality.[1,2] Several studies have characterized VOC emissions from ENDS, but with limited identified chemicals and/or quantification of ENDS VOC emission rates.

Objective: Preliminary experiments were conducted to characterize and quantify VOC emissions (full scan between C_6 to C_{16}) from ENDS by operating it inside an environmentally controlled chamber.

Materials and Methods

Two ENDS devices (Vape pen A and B) with four different e-liquids (three tobacco and one clove flavor) were studied. Virginia tobacco (3% nicotine) and classic tobacco (5% nicotine) pods and non-nicotine containing tobacco and clove e-liquids were purchased from a local vape shop. Each ENDS device was operated inside the 0.055 m^3 glass chamber operating at 13 ACH (Figure 1), mimicking a person taking one puff every 4 minutes. The puff length and flow rate followed CORESTA CRM No.81[3] (1.1 Lpm flow rate, 3 second puff). Chamber air samples were collected directly from the chamber once the concentration inside reached steady state. VOCs were collected on Tenax® TA sorption tubes and were analyzed by thermal desorption gas chromatography-mass spectrometry. Low molecular aldehydes were collected on 2,4-dinitrophenylhydrazine (DNPH) sorbent cartridges and were analyzed by high performance liquid chromatography.

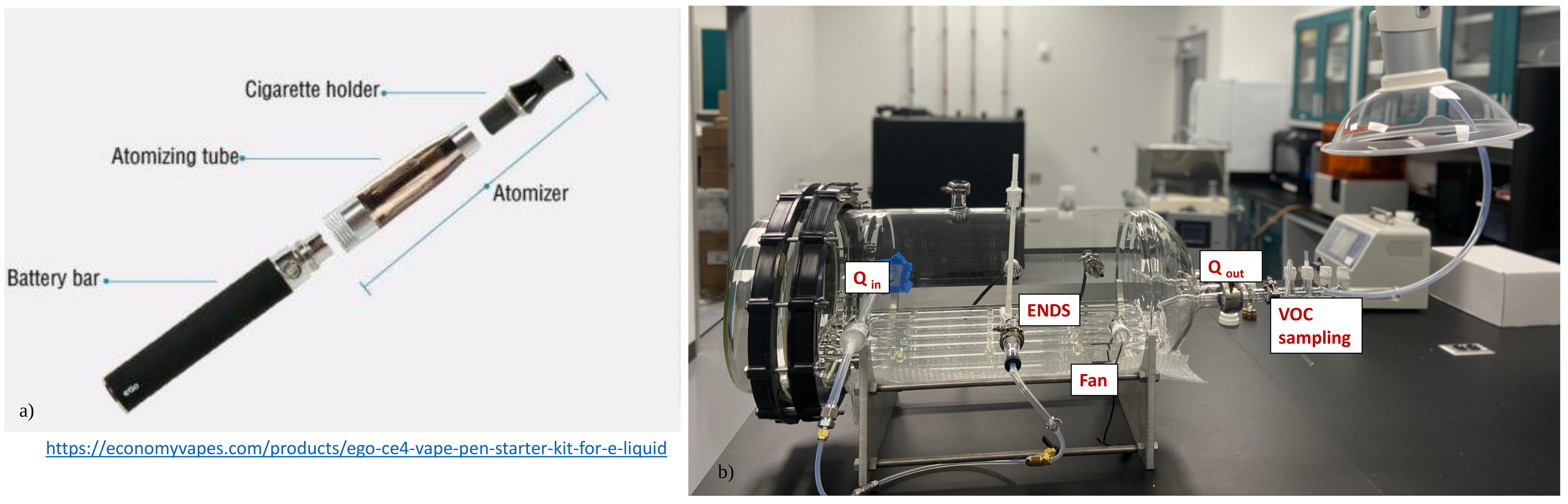

Figure 1: a) Schematic of a vape pen, b) emission chamber set up. Clean air entering the chamber on the left, vape pen operating in the middle on the glass rack, and air samples collected downstream to the right of the chamber.

(1) Committee on the Review of the Health Effects of Electronic Nicotine Delivery Systems; Board on Population Health and Public Health Practice; Health and Medicine Division; National Academies of Sciences, Engineering, and Medicine. *Public Health Consequences of E-Cigarettes*; Stratton, K., Kwan, L. Y., Eaton, D. L., Eds.; National Academies Press: Washington, D.C., 2018; p 24952. https://doi.org/10.17226/24952.

(2) Cheng T. Chemical evaluation of electronic cigarettes. *Tob Control*. 2014;23(suppl 2):ii11-ii17. doi:10.1136/tobaccocontrol-2013-051482

(3) CORESTA. Coresta recommended method no.81. Published online June 2015. https://www.coresta.org/sites/default/files/technical_documents/main/CRM_81.pdf

Results

Table 1: VOC emission detected from four ENDS setup.

	CAS number	Chemical	Vape Pen A VA tobacco	Vape Pen A Classic tobacco	Vape Pen B Clove	Vape Pen B Tobacco
1	2432-11-3	[1,1':3',1''-Terphenyl]-2'-ol		X		
2	1000309-26-9	1(3H)-Isobenzofuranone	X	X		
3	1000350-63-6	1(3H)-Isobenzofuranone, 3-[(3,5-dimethylphenyl)amino]-	X	X		
4	88-99-3	1,2-Benzenedicarboxylic acid	X	X		
5	57-55-6	1,2-Propanediol (Propylene glycol)	X	X	X	X
6	1117-86-8	1.2-Octanediol				X
7	99798-78-4	13-Methyl-12-tetradecen-1-ol acetate				X
8	71-36-3	1-Butanol (N-Butyl alcohol)		X		
9	36653-82-4	1-Hexadecanol			X	
10	104-76-7	1-Hexanol, 2-ethyl	X	X		
11	13739-48-5	1H-Imidazole, 2-methyl-4-phenyl-	X			
12	1000245-40-7	1-Methyl-1-(3-tridecyl)oxy-1-silacyclopentane		X		
13	3658-77-3	2,5-Dimethyl-4-hydroxy-3(2H)-furanone				X
14	35044-68-9	2-Buten-1-one, 1-(2,6,6-trimethyl-1-cyclohexen-1-yl)-				X
15	116-09-6	2-Propanone, 1-hydroxy	X	X		
16	24070-70-0	3-Methylcyclopentyl acetate			X	X
17	1000432-21-6	3-Methylene-7,11-dimethyl-1-dodecene		X		
18	689-67-8	5,9-Undecadien-2-one, 6,10-dimethyl-	X	X	X	
19	3796-70-1	5,9-Undecadien-2-one, 6,10-dimethyl-, (E)-				X
20	75-07-0	Acetaldehyde	X	X		
21	23616-67-3	Acetamide, N-(2-phenyl-1H-pyrrolo[2,3-b]pyridin-3-yl)-	X			
22	98-86-2	Acetophenone (Ethanone, 1-phenyl)	X	X	X	
23	100-52-7	Benzaldehyde		X		
24	65-85-0	Benzoic Acid	X	X	X	X
25	119-36-8	Benzoic acid, 2-hydroxy-, methyl ester		X		
26	4889-83-2	Bicyclo[3.1.1]hept-2-ene, 3,6,6-trimethyl-		X		
27	105-60-2	Caprolactam	X	X	X	X
28	616-38-6	Carbonic acid, dimethyl ester				X
29	37139-88-1	Cyclohexanecarboxylic acid, 2-phenylethyl ester		X		
30	541-02-6	Cyclopentasiloxane, decamethyl	X	X	X	X
31	541-05-9	Cyclotrisiloxane, hexamethyl	X	X	X	X
32	112-31-2	Decanal	X	X	X	X
33	55334-42-4	Dodecane, 1,2-dibromo		X		
34	296244-70-7	Ethanone, 2,2'-(octahydro-2,3-quinoxalinediylidene)bis[1-phenyl-		X		
35	1000130-54-0	Ethenamine, N-benzoyl-2-[4-hydroxy-3-methoxyphenyl]-	X			
36	50-00-0	Formaldehyde	X	X	X	X
37	1000386-43-1	Glyceric acid (ISP-TFA)		X		
38	56-81-5	Glycerin	X	X	X	X
39	102-62-5	Glycerol 1,2-diacetate			X	
40	55124-79-3	Heptadecane, 9-hexyl-		X		
41	111-71-7	Heptanal (Heptaldehyde)		X	X	X
42	18908-66-2	Heptane, 3-(bromomethyl)-				X
43	629-80-1	Hexadecanal			X	
44	66-25-1	Hexanal			X	
45	149-57-5	Hexanoic acid, 2-ethyl				X
46	995-82-4	Hexasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11-dodecamethyl-				X
47	629-92-5	Nonadecane		X		
48	111-84-2	Nonane		X		
49	112-05-0	Nonanoic acid	X		X	
50	124-19-6	Nonyl aldehyde (Nonanal)	X	X	X	X
51	124-13-0	Octanal	X	X		
52	1000253-26-1	Octanediamide, N,N'-di-benzoyloxy-		X		
53	124-07-2	Octanoic Acid		X		
54	1000309-25-0	Oxalic acid, hexadecyl hexyl ester				X
55	629-62-9	Pentadecane	X		X	
56	1921-70-6	Pentadecane, 2,6,10,14-tetramethyl		X		
57	959261-22-4	Pentafluoropropionic acid, tridecyl ester				X
58	1000140-77-5	Pentanoic acid, 2,2,4-trimethyl-3-carboxyisopropyl, isobutyl	X		X	
59	36122-35-7	Phenylmaleic anhydride	X	X		
60	85-44-9	Phthalic anhydride (1,3-Isobenzofurandione)			X	
61	123-38-6	Propanal	X	X		
62	54-11-5	Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S)- (Nicotine)	X	X		
63	1066-42-8	Silanediol, dimethyl-	X	X	X	X
64	100-42-5	Styrene	X			
65	110-27-0	Tetradecanoic acid, 1-methylethyl ester (Isopropyl Myristate)			X	
66	108-88-3	Toluene (Methylbenzene)		X		
67	1000352-26-0	trans-2-Dodecen-1-ol, heptafluorobutyrate	X			
68	6846-50-0	TXIB (2,2,4-Trimethyl-1,3-pentanediol diisobutyrate)		X	X	
69	112-44-7	Undecanal	X	X	X	X
70	106-42-3	Xylene (para and/or meta)		X		

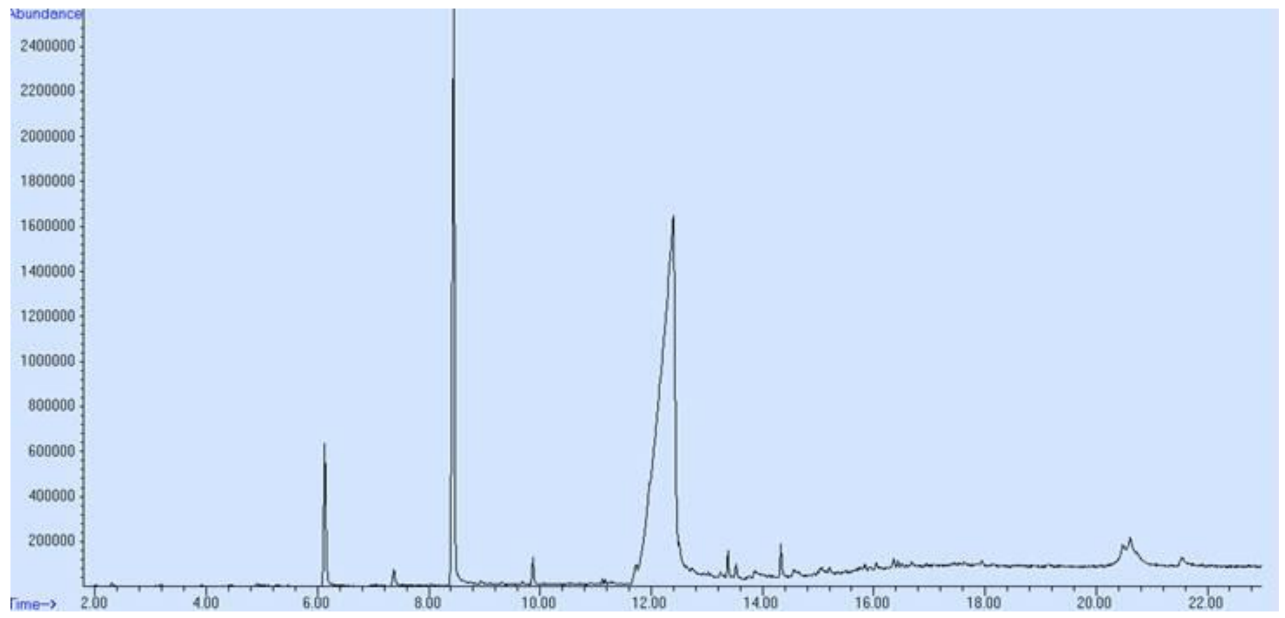

Figure 2: Example chromatograph of an ENDs gas emission analyzed by GC/MS. The two large peaks are glycerin and propylene glycol.

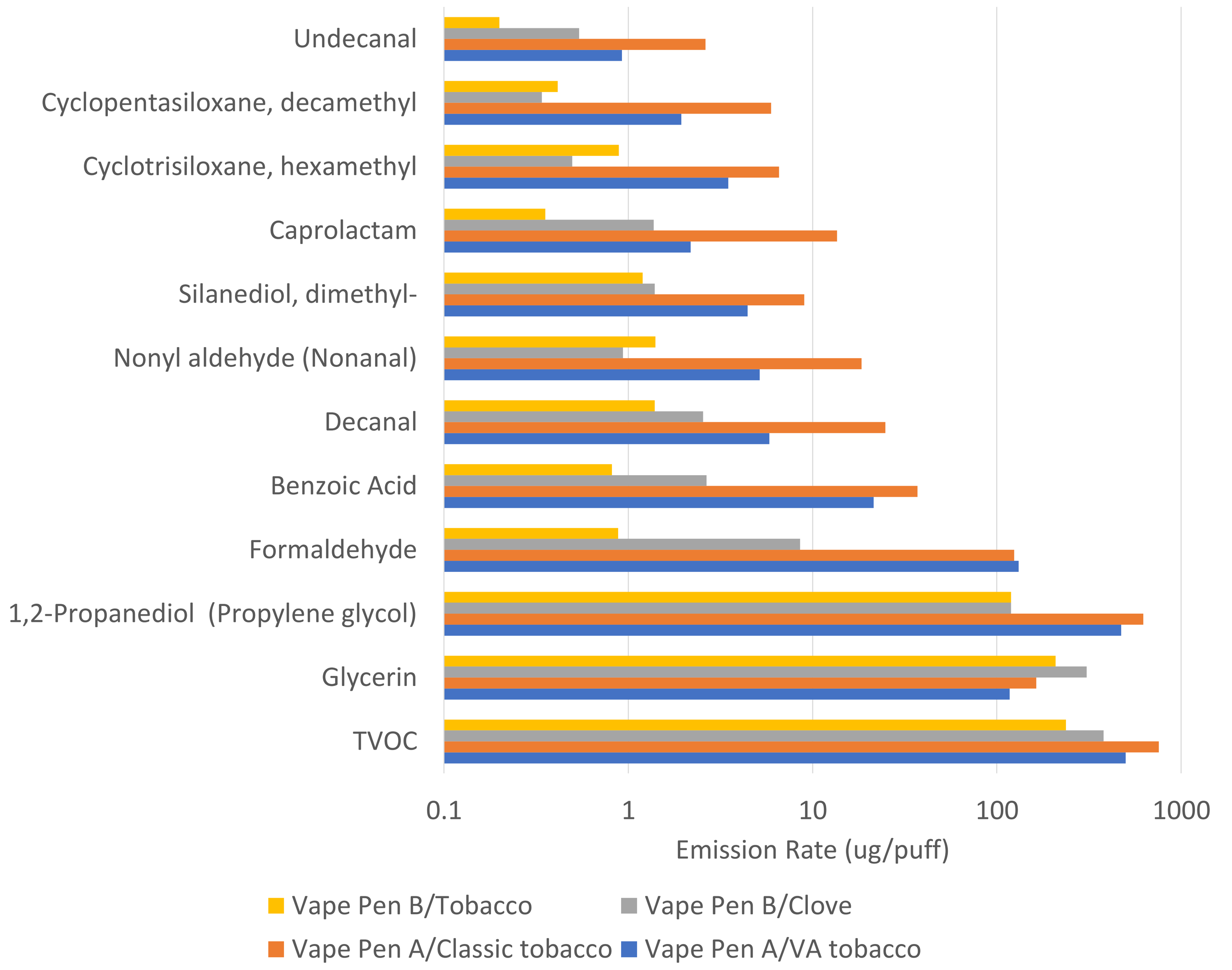

Figure 3: Emission rates of total VOC to toluene (TVOC) and VOCs detected in all four ENDS. Emission rate is normalized to per puff.

A total of 70 chemicals was identified from the ENDS emissions (Table 2). VOCs emitted included aldehydes, alcohols, ethers, ketones, esters, acids, alkanes, and cyclosiloxanes. Eleven chemicals were commonly found in all four ENDS set ups, the rest seem to be specific to either the brand, flavoring, or the e-liquid itself. Nicotine was only detected in e-liquids sold to contain it. Glycerin, propylene glycol, and benzoic acid (which is included as part of nicotine salts formulation) were detected in all four ENDS setups. Glycerin and propylene glycol were emitted higher than other VOCs detected that they make the bulk of TVOC (Figure 3). Formaldehyde, class one carcinogen, is also released by all ENDs tested. Other chemicals of concern include toluene, styrene, xylenes, caprolactam, acetaldehyde, pentanal, and more.

Future experiments will expand to more e-liquids (brands, flavors, VG/PG ratio), more ENDS types and various atomizer settings (voltage, wick), and characterization of particle emissions.