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The effect of flavor content in e-liquids on e-cigarette emissions of carbonyl compounds

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ABSTRACT

The effect of flavors on carbonyl compound (CC) emission factors (EF) from electronic cigarettes (ECs) vaping was investigated at the default vaping (voltage) setting in all experiments using a total of 21 lab-made e-liquid samples (five different types of retail flavorant bases: beverage/dessert/fruit/mint/tobacco). Each flavorant base was added to a separate unflavored base composed of a 1:1 mixture of propylene glycol/vegetable glycerol (PG/VG) at four levels (5/10/30/50% (v/v)). The e-liquid CC levels increased linearly with flavorant base content, 1.3–10.5 times (R^2: 0.762–0.999). The vaping CC EFs increased linearly with flavorant base content (if ≥ 10%) from 1.0 to 92 times (R^2: 0.431–0.998). For flavorant base content of 0%, 5%, and 10%, the EFs ranged from undetected to 0.11 μg puff^{-1} (acetone). The 40-year cancer risk due to formaldehyde (70 kg EC user inhaling 5% flavorant base content e-liquid: 120 puffs day^{-1}) is estimated to be 2.0E-06 (highest) compared to 1.0E-06 for the 1:1 PG:VG base. Most formaldehyde vaped from the fruit flavored e-liquid was the flavorant base. The CC concentrations in EC liquids (before vaping) were approximately linear with e-liquid flavorant base content. Retail e-liquid product information labels should be guided to provide a complete list of all ingredients, their concentrations, and carbonyl compound EFs.

1. Introduction

Electronic cigarettes (e-cigarettes or ECs) are battery-powered devices designed to deliver nicotine to a smoker and were first developed and patented by Herbert A. Gilbert in 1963 (Gilbert, 1965; Cahn and Siegel, 2011). In 2004, modern ECs were first introduced in the Chinese market as a smoking cessation device. The use of ECs has spread rapidly, and their popularity is increasing, especially in young people including school-age children (Cummings et al., 2014; Arrazola et al., 2015). The Centers for Disease Control and Prevention (CDC) reported that the percentage of high school students who admitted using ECs doubled from 4.7% in 2011 to 10% in 2012 (CDC, 2013).

The EC vapors are generated from an e-liquid containing a mixture of propylene glycol (PG), vegetable glycerin (VG), nicotine, flavors, and other chemical additives (Tayyarah and Long, 2014). The development of new flavorings in e-liquids has become a central marketing strategy to increase appeal to youths (Richtel, 2014). In 2009, 'The Family Smoking Prevention and Tobacco Control Act' banned cigarettes containing any 'characterizing flavor' (except menthol) to make them less attractive to young smokers (FSPTCA, 2009). In addition, menthol cigarettes are expected to be completely banned by 2020 in the EU under new tobacco laws that will become effective in late 2016 (ConsumerProtection, 2016). A report showed that an astonishing 7764 unique food product flavorings were available online, with 242 new flavors added every month and sold under 466 brand names. Of the 7764 flavors, only a small number are used in 'tobacco' products, whereas the majority are used in 'confectionary' products such as chocolate, cheesecake, cotton candy, apple, coffee, and bubble gum (Zhu et al., 2014).

The flavorings used in e-liquids have generally been recognized as safe when used in food products. However, the consumption of such chemicals has raised concerns due to potential toxicity arising from their inhalation (Barrington-Trimis et al., 2014). At the vaping temperature of an EC, the decomposition of molecules such as PG and VG is expected to occur and generate low molecular weight carbonyl compounds (CCs) such as formaldehyde (FA) and acetaldehyde (AA) (Paschke et al., 2014). In addition, the flavorings are believed to produce various aldehydes during EC vaping (Khlystov and Samburova, 2016).

To date, only a few studies have reported on CC emissions from flavorings during vaping. Benzaldehyde (BZA) was detected and quantified in vaped aerosols from 108 of 148 flavored e-liquids tested in a laboratory. The highest BZA levels were detected in cherry-flavored products (0.17–4.71 μg per puff) (Kosmider et al., 2016). Note that

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Table 1
Basic information of EC samples.

Order	Sample code	Information			Flavor content	Component	Calculated density	Measured density	Density difference	Measured density
		Flavor class	Flavor	Manufacturer	%	PG:VG = 1:1 (v/v)	EC liquid[a] (g/mL)	EC liquid[a] (g/mL)	(Meas - Calc)/Meas (%)	Flavor liquid[a] (g/mL)
1	NF	No Flavor		Laboratory-made	0	50% PG + 50% VG	1.137	1.139	0.18	
2	E1-a	Beverage	Green tea	Flavor Art	5	PG/VG (47.5/47.5) + 5% Flavor	1.131	1.13	−0.06	1.0024
3	E1-b				10	PG/VG (45/45) + 10% Flavor	1.124	1.132	0.71	
4	E1-c				30	PG/VG (35/35) + 30% Flavor	1.097	1.097	0	
5	E1-d				50	PG/VG (25/25) + 50% Flavor	1.07	1.07	0.01	
6	E2-a	Dessert	Cheesecake	The Perfumer's Apprentice	5	PG/VG (47.5/47.5) + 5% Flavor	1.133	1.133	0	1.0469
7	E2-b				10	PG/VG (45/45) + 10% Flavor	1.128	1.131	0.23	
8	E2-c				30	PG/VG (35/35) + 30% Flavor	1.11	1.111	0.06	
9	E2-d				50	PG/VG (25/25) + 50% Flavor	1.092	1.093	0.07	
10	E3-a	Fruit	Apple	The Perfumer's Apprentice	5	PG/VG (47.5/47.5) + 5% Flavor	1.13	1.13	−0.02	0.9921
11	E3-b				10	PG/VG (45/45) + 10% Flavor	1.123	1.123	0.01	
12	E3-c				30	PG/VG (35/35) + 30% Flavor	1.094	1.093	−0.08	
13	E3-d				50	PG/VG (25/25) + 50% Flavor	1.065	1.064	−0.07	
14	E4-a	Mint	Peppermint	The Perfumer's Apprentice	5	PG/VG (47.5/47.5) + 5% Flavor	1.127	1.126	−0.07	0.9231
15	E4-b				10	PG/VG (45/45) + 10% Flavor	1.116	1.114	−0.18	
16	E4-c				30	PG/VG (35/35) + 30% Flavor	1.073	1.067	−0.58	
17	E4-d				50	PG/VG (25/25) + 50% Flavor	1.03	1.02	−1.01	
18	E5-a	Tobacco	Cigar passion	Flavor Art	5	PG/VG (47.5/47.5) + 5% Flavor	1.133	1.133	−0.03	1.0551
19	E5-b				10	PG/VG (45/45) + 10% Flavor	1.129	1.129	−0.02	
20	E5-c				30	PG/VG (35/35) + 30% Flavor	1.113	1.113	0.02	
21	E5-d				50	PG/VG (25/25) + 50% Flavor	1.096	1.097	0.06	

[a] Density measured by weight/volume.