Chemical Composition of *my*blu™ Pod-System E-Cigarette Aerosols: A Quantitative Comparison with Conventional Cigarette Smoke

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1. Introduction

- Electronic cigarette (e-cigarette) aerosol is considered by a number of public health bodies to provide reduced exposure to toxicants and carcinogens compared to conventional cigarette smoke, as it delivers nicotine and flavours without burning tobacco.
- While recent studies show that e-cigarette aerosol is chemically simple when compared to cigarette smoke [1,2,3], comprehensive analytical assessments of many widely available products are limited.
- In this study, two commercially available *my*blu™ e-liquids (1.6% nicotine, tobacco flavour; 1.6% nicotine, menthol flavour) in a *my*blu™ pod-system e-cigarette [***Figure 1***] were analysed and compared to published data for cigarette smoke [1].
- A total of 55 chemical emissions were characterised. The *my*blu™ products were analysed for the four principal e-liquid ingredients (nicotine, propylene glycol, glycerol and water) as well as 51 further constituents of public health interest (carbonyls, phenolics, volatile organic compounds [VOCs], metals, tobacco-specific nitrosamines [TSNAs], polyaromatic amines [PAAs], and polycyclic aromatic hydrocarbons [PAHs]) [1].
- The additional constituents include those on the FDA Harmful or Potentially Harmful Constituents (HPHCs) list of chemicals in cigarette smoke it considers cause or could cause harm to smokers [4].

Figure 1. *my*blu™ pod-system.

Device: battery capacity, 350 mAh; fast charging, 20 min; aluminium frame.

Pod: polypropylene plastic; 1.5 mL; gold plate connectors; organic cotton wick; coil resistance, 1.3 Ω.

E-liquid compositions: tobacco flavour, PG 64% (w/w), VG 31% (w/w), nicotine 1.6% (w/w), flavouring 3.4% (w/w); menthol flavour, PG 39% (w/w), VG 55% (w/w), nicotine 1.6% (w/w), flavouring 4.4% (w/w).

2. Analytical Methods

- The e-cigarettes were puffed in two separate 50-puff blocks using the CORESTA Recommended Method CRM81 (puffing regime: 55mL/3sec/30sec; square wave) [5]. Five replicates were measured for each e-liquid type. All analyses were conducted by Enthalpy Analytical LLC, Durham, North Carolina, USA. The methods used by the analysis laboratory are summarized in ***Table 1***.

Table 1. Summary of analytical methods used for characterisation of *my*blu™ e-cigarette aerosol emissions.

Method	Compounds	Method of Capture	Analysis Method	Instrument	Method Reference Code, Accredited
Analysis of E-Cigarette Aerosol	Nicotine, propylene glycol, glycerol, water	Pad	Pads are extracted with propanol	GC FID (for nicotine, propylene glycol & glycerol) / TCD (for water)	ENT185, Accredited
Analysis of Carbonyls in E-Cigarette Aerosols	**Carbonyls**: Formaldehyde, Acetaldehyde, Acrolein, Propionaldehyde, Crotonaldehyde, Butyraldehyde	Impinger	The carbonyls are trapped in a chilled acidified solution of DNPH and neutralized with pyridine	HPLC UV	ENT305, Accredited
Phenolic Compounds in Mainstream Cigarette Smoke by HPLC with Fluorescence Detection	**Phenolics**: Hydroquinone, Resorcinol, Catechol, Phenol, m,p-Cresol, o-Cresol	Pad	The pads are extracted with a mixture of 1% acetic acid and 2.5% methanol	HPLC FLD	AM-027, Accredited for mainstream smoke
Selected Volatiles in Mainstream Smoke by GC-MS	**Volatiles**: Styrene	Pad / Impinger	Pads are extracted with the methanol from the impinger	GC-MS	AM-193, Accredited for mainstream smoke
Analysis of Volatile Organic Compounds in Cigarette Smoke and E-Cigarette Aerosol by GC/MS	**Volatiles**: 1,3-Butadiene, Isoprene, Acrylonitrile, Benzene, Toluene	Impinger	Volatiles are trapped in chilled methanol	GC-MS	ENT208, Accredited
Selected Metals in E-Cigarette Aerosol By ICP-MS	**Metals**: Arsenic, Beryllium, Cadmium, Chromium, Cobalt, Lead, Manganese, Mercury, Nickel, Selenium, Tin	Pad	Pads are extracted in a 17% nitric acid solution	ICP-MS	AM-235, Accredited
GC/MS Analysis of Nitrosamines in Cigarette Smoke, E-cigarette Aerosol, and E-Cigarette Liquid	**TSNAs**: NNN, NAT, NAB, NNK	Pad	Pads are extracted with water and solvent exchanged into methylene chloride	GC/MS/MS	ENT211, Accredited
Selected Primary Aromatic Amines (PAAS) in E-Cigarette Aerosol by GC-MS	**PAAs**: 1-Aminonaphthalene, 2-Aminonaphthalene, 3-Aminobiphenyl, 4-Aminobiphenyl	Pad	Pads are extracted in hexane while water is used to remove organic interference. The extract is then concentrated and derivatized with pentafluoropropionic acid anhydride	GC-MS (NCI)	AM-221, Accredited
Polynuclear Aromatic Hydrocarbons (PAHS) in Mainstream and Sidestream Smoke	**PAHs**: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Chrysene, Benzo(b)fluoranthene, B(a)P, Benzo(k)fluoranthene, Indeno[1, 2, 3-cd]pyrene, Benzo(g,h,i)perylene	Pad / Impinger	Pads are extracted in methanol. The extract is cleaned by passing it through a C18 cartridge after which the PAHs are eluted using toluene	GC-MS (EI)	AM-044, Accredited for mainstream smoke

3. Reduced Formation of Toxicants of Public Health Interest

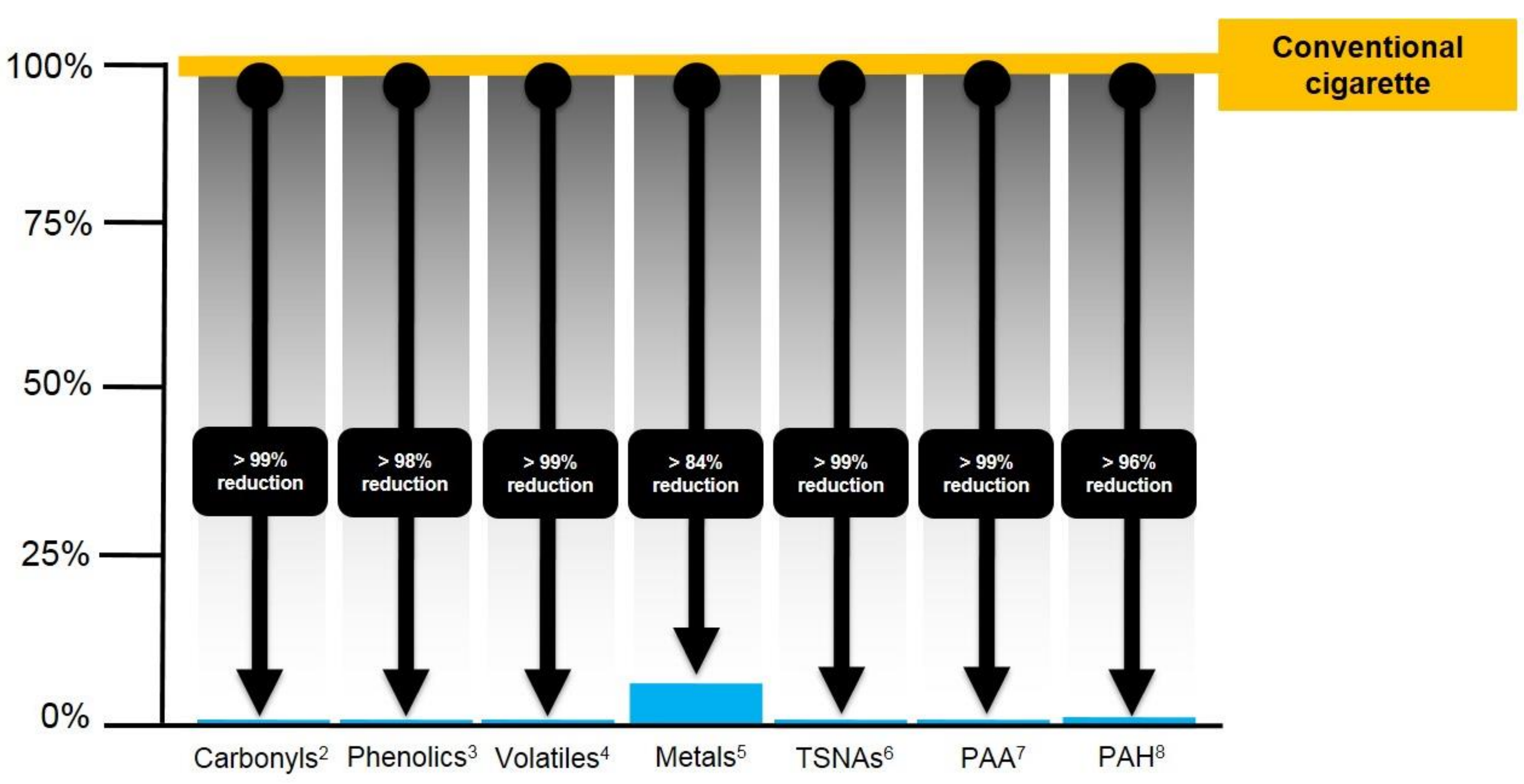
- The average aerosol collected mass for each e-liquid tested was approximately 10 mg/puff. The *my*blu™ 1.6% nicotine tobacco flavour aerosol delivered on average 6091 µg/puff propylene glycol, 3387 µg/puff glycerol and 686 µg/puff water; the *my*blu™ 1.6% nicotine menthol flavour aerosol delivered on average 3187 µg/puff propylene glycol, 5396 µg/puff glycerol and 499 µg/puff water. See e-liquid compositions in ***Figure 1***.
- The nicotine yield for the tobacco flavour variant was 150 µg/puff and for the menthol flavour variant was 125 µg/puff; correspondingly, this was 33% and 44% lower than the 226 µg/puff nicotine yield published for the cigarette [1].
- Of the 51 toxicants analysed, eight were observed at quantifiable levels, including formaldehyde, acetaldehyde and acrolein (>99% reduction vs. conventional cigarette); manganese and selenium (average 82% reduction vs. cigarette); and NNN, NAT and NNK (>99% reduction vs. conventional cigarette). See ***Table 2***. Analyte class data summarised in ***Figure 2***.
- The total analyte yield was <1 µg/puff of toxicants tested for the *my*blu™ flavours (range 0.96-0.97 µg/puff), which is 99% less than the 381 µg/puff quantified and published for cigarette smoke [1].

Table 2. Analytical characterisation of *my*blu™ e-cigarette aerosols and comparison with conventional cigarette smoke (µg/puff).

Analyte Class	Compound	Marlboro Gold Box (µg/puff) (Data [1])	*my*blu™ 1.6% Tobacco Flavour (Average µg/puff)	% Reduction vs. Conventional Cigarette (Where >LOQ)	*my*blu™ 1.6% Menthol Flavour (Average µg/puff)	% Reduction vs. Conventional Cigarette (Where >LOQ)
Carbonyls	Formaldehyde	7.12	0.0142	>99%	0.0282	>99%
	Acetaldehyde	156	0.0132	>99%	<LOD (0.004)	-
	Acrolein	16.4	<LOD (0.003)	-	0.0038	>99%
	Propionaldehyde	11.2	<LOD (0.004)	-	<LOD (0.004)	-
	Crotonaldehyde	4.42	<LOD (0.003)	-	<LOD (0.003)	-
	Butyraldehyde	6.36	<LOD (0.003)	-	<LOD (0.003)	-
Total		**201.5**	**<0.040**	**>99%**	**<0.046**	**>99%**
Phenolics	Hydroquinone	9.3	<LOD (0.21)	-	<LOD (0.21)	-
	Resorcinol	0.53	<LOD (0.004)	-	<LOD (0.004)	-
	Catechol	9.42	<LOD (0.08)	-	<LOD (0.08)	-
	Phenol	1.53	<LOD (0.056)	-	<LOD (0.056)	-
	m,p-Cresol	1.2	<LOD (0.048)	-	<LOD (0.048)	-
	o-Cresol	0.49	<LOD (0.024)	-	<LOD (0.024)	-
Total		**22.47**	**<0.422**	**>98%**	**<0.422**	**>98%**
Volatiles	1,3-Butadiene	8.88	<LOD (0.03)	-	<LOD (0.03)	-
	Isoprene	114	<LOD (0.32)	-	<LOD (0.32)	-
	Acrylonitrile	3.04	<LOD (0.03)	-	<LOD (0.03)	-
	Benzene	10.3	<LOD (0.04)	-	<LOD (0.04)	-
	Toluene	18.5	<LOD (0.04)	-	<LOD (0.04)	-
	Styrene	2.23	<LOD (0.03)	-	<LOD (0.03)	-
Total		**156.95**	**<0.491**	**>99%**	**<0.491**	**>99%**
Metals	Arsenic	<LOQ (0.001)	<LOD (0.0005)	-	<LOD (0.0005)	-
	Beryllium	<LOQ (0.001)	<LOD (0.00003)	-	<LOD (0.00003)	-
	Cadmium	0.013	<LOD (0.0001)	-	<LOD (0.0001)	-
	Chromium	<LOQ (0.001)	<LOD (0.001)	-	<LOD (0.001)	-
	Cobalt	<LOQ (0.001)	<LOD (0.00003)	-	<LOD (0.00003)	-
	Lead	0.0038	<LOD (0.0001)	-	<LOD (0.0001)	-
	Manganese	0.0021	<0.00047*	>78%*	0.00032*	>85%*
	Mercury	0.00008	<LOQ (0.0002)	-	<LOQ (0.0002)	-
	Nickel	<LOQ (0.001)	<LOQ (0.001)	-	<LOQ (0.001)	-
	Selenium	<LOQ (0.001)	<0.00024*	>76%*	0.00012*	>88%*
	Tin	<LOQ (0.001)	<LOD (0.0005)	-	<LOD (0.0005)	-
Total		**<0.026**	**<0.004**	**>84%**	**<0.004**	**>84%**
TSNAs	NNN	0.0195	0.000009	>99%	0.000006	>99%
	NAT	0.0235	<LOD (0.000003)	-	<LOD (0.000003)	-
	NAB	0.00267	0.000002	>99%	0.000002	>99%
	NNK	0.0147	0.000004	>99%	0.000004	>99%
Total		**0.06**	**<0.00002**	**>99%**	**<0.00002**	**>99%**
PAAs	1-Aminonaphthalene	0.00122	<LOD (0.0000007)	-	<LOD (0.0000007)	-
	2-Aminonaphthalene	0.00072	<LOD (0.0000007)	-	<LOD (0.0000007)	-
	3-Aminobiphenyl	0.00042	<LOD (0.0000004)	-	<LOD (0.0000004)	-
	4-Aminobiphenyl	0.00028	<LOD (0.0000003)	-	<LOD (0.0000003)	-
Total		**0.003**	**<0.000002**	**>99%**	**<0.000002**	**>99%**
PAHs	Naphthalene	0.12	<LOQ (0.005)	-	<LOQ (0.005)	-
	Acenaphthylene	0.00877	<LOQ (0.0002)	-	<LOQ (0.0002)	-
	Acenaphthene	0.0204	<LOQ (0.0002)	-	<LOQ (0.0002)	-
	Fluorene	0.0275	<LOQ (0.0006)	-	<LOQ (0.0006)	-
	Phenanthrene	0.0229	<LOQ (0.0008)	-	<LOQ (0.0008)	-
	Anthracene	0.0106	<LOQ (0.0002)	-	<LOQ (0.0002)	-
	Fluoranthene	0.0116	<LOQ (0.0002)	-	<LOQ (0.0002)	-
	Pyrene	0.0111	<LOQ (0.0002)	-	<LOQ (0.0002)	-
	Chrysene	0.0039	<LOQ (0.00004)	-	<LOQ (0.00004)	-
	Benzo(b)fluoranthene	0.00115	<LOD (0.00001)	-	<LOD (0.00001)	-
	Benzo(k)fluoranthene	0.00055	<LOD (0.00001)	-	<LOD (0.00001)	-
	B(a)P	0.00133	<LOD (0.00001)	-	<LOQ (0.00004)	-
	Indeno[1, 2, 3-cd]pyrene	0.00062	<LOD (0.00001)	-	<LOD (0.00001)	-
	Benzo(g,h,i)perylene	0.00024	<LOD (0.00001)	-	<LOD (0.00001)	-
Total		**0.24**	**<0.007**	**>97%**	**<0.008**	**>96%**
Total Toxicant Yield (µg/puff)		**<381.25**	**<0.96**		**<0.97**	

* indicates that values are <LOD, <LOQ and >LOQ across replicates; where below the LOD or LOQ, the LOD or LOQ value is used in calculation of the average.

Figure 2. Average reductions in formation of toxicants by analyte class per puff for *my*blu™ 1.6% nicotine tobacco flavour and 1.6% nicotine menthol flavour e-cigarette aerosols compared to levels in conventional cigarette smoke.



[1] Aerosol collection with CORESTA Recommended Method 81 regime: 55 mL puff volume, 3 second puff duration, 30 second puff interval. Marlboro Gold smoke data from Tayyarah, R.; Long, G.A. *Regulatory Toxicology and Pharmacology* : RTP 2014, 70, 704-710. Comparison on a per puff basis. Reduction calculations exclude the major components of the e-liquid: nicotine, propylene glycol, glycerol and water.

[2] Formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde.
[3] Hydroquinone, resorcinol, catechol, phenol, m-+p-cresol, o-cresol.
[4] 1,3-Butadiene, isoprene, acrylonitrile, benzene, toluene, styrene.
[5] Arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin.
[6] NNN, NAT, NAB, NNK.
[7] 1-Aminonaphthalene, 2-aminonaphthalene, 3-aminobiphenyl, 4-aminobiphenyl
[8] Naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, B(a)P, indeno[1,2,3-cd]pyrene, benzo(g,h,i)perylene.

Note: To enable the percentage difference between e-cigarette aerosol and conventional cigarette smoke to be calculated for each toxicant subset, when the value for a constituent was <LOQ or <LOD, the LOQ or LOD was provided as a reference value.

4. Conclusions

- The aim of this study was to determine the composition of e-cigarette aerosols with respect to the principal e-liquid ingredients and a range of toxicants (including HPHCs) for which cigarette smoke is routinely tested and data have been published [1]. Here we report a comprehensive aerosol chemistry study for two commercially available *my*blu™ flavours in a *my*blu™ pod-system e-cigarette device.
- Testing of the *my*blu™ aerosols indicate low or no detectable levels of the toxicants tested. Overall the e-cigarettes yielded <1 µg/puff of the toxicants tested compared to the reported cigarette yield of 381 µg/puff. Of the 51 toxicants tested, eight were detected in the e-cigarette aerosols but at substantially lower levels (see ***Table 2***) than reported in cigarette smoke [1].
- These data are consistent with other studies that have found no quantifiable levels of tested toxicants, or extremely low levels of measurable constituents relative to cigarette smoke [1,2 6,7].
- Findings from several recent clinical studies indicate that smokers who have switched to e-cigarettes have significantly lower exposure to carcinogens and toxicants found in cigarette smoke, with reductions largely indistinguishable from complete smoking cessation or use of licensed nicotine replacement products [8,9,10].
- The results obtained in the aforementioned studies and in the present work demonstrate that high quality e-cigarettes and e-liquids offer the potential to substantially reduce exposure to cigarette carcinogens and toxicants in smokers who use such products as alternatives to cigarettes.
- The findings of the present study with the *my*blu™ products are highly informative. Future research studies planned include preclinical *in vitro* studies, clinical biomarker studies, and population studies to generate a body of evidence to assess the harm reduction potential of *my*blu™ products compared to conventional cigarettes.

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