Flavour chemicals in electronic cigarette fluids

Peyton A Tierney,1 Clarissa D Karpinski,2 Jessica E Brown,1 Wentai Luo,2 James F Pankow1,2

ABSTRACT

Background Most e-cigarette liquids contain flavour chemicals. Flavour chemicals certified as safe for ingestion by the Flavor Extracts Manufacturers Association may not be safe for use in e-cigarettes. This study identified and measured flavour chemicals in 30 e-cigarette fluids.

Methods Two brands of single-use e-cigarettes were selected and their fluids in multiple flavour types analysed by gas chromatography/mass spectrometry. For the same flavour types, and for selected confectionary flavours (eg, bubble gum and cotton candy), also analysed were convenience samples of e-cigarette fluids in refill bottles from local ‘vape’ shops and online retailers.

Results In many liquids, total flavour chemicals were found to be in the ~1–4% range (10–40 mg/mL); labelled levels of nicotine were in the range of 0.6–2.4% (6 to 24 mg/mL). A significant number of the flavour chemicals were aldehydes, a compound class recognised as ‘primary irritants’ of mucosal tissue of the respiratory tract. Many of the products contained the same flavour chemicals: vanillin and/or ethyl vanillin was found in 17 of the liquids as one of the top three flavour chemicals, and/or at ≥0.5 mg/mL.

Conclusions The concentrations of some flavour chemicals in e-cigarette fluids are sufficiently high for inhalation exposure by vaping to be of toxicological concern. Regulatory limits should be contemplated for levels of some of the more worrisome chemicals as well as for total flavour chemical levels. Ingredient labeling should also be required.

INTRODUCTION

Use of electronic cigarettes (aka e-cigarettes, electronic nicotine delivery systems and ENDS) is expanding rapidly, with global sales estimated at US $1.5 billion in 2012 and US$3.5 billion in 2013; sales for 2014 were projected to be US$7 billion.1 Adoption of e-cigarettes has far out-paced our understanding of their implications for health, including the initial composition of the e-cigarette fluids as well as presence of harmful by-products formed during ‘vaping’.2 In April, US Food and Drug Administration issued a report in which it deemed that it has regulatory authority over e-cigarettes.3 No specific regulations were yet proposed, except that sales to those under 18 should be prohibited; final action is slated for June 2015. The use of flavourings in e-cigarette fluids has become a central focus for those marketing e-cigarettes4 and for those demanding regulatory control, including 29 Attorneys General.5 Centers for Disease Control and Prevention (CDC) reports that the percentage of high school students who acknowledged ever using an e-cigarette doubled from 4.7% in 2011 to 10% in 2012.6 Supporters of regulation note that cigarettes with ‘characterising flavours’ (other than with menthol) were banned in 20097 due to evidence that they were attracting youth to smoking. A recent report8 states that an astonishing 7764 unique flavour names were available online in January 2014, with 242 new flavours being added per month, and sales occurring under 466 brands. For the 7764 flavour names, only a small number relate to ‘tobacco’; the vast majority are confectionary in nature, for example, chocolate raspberry, cherry cheesecake, cotton candy, vanilla, grape, apple, coffee, bubble gum, etc. The NJJOY brand had avoided explicitly labelled confectionary flavour names, but due to rapidly losing market share, it was recently reported to have plans to offer products in ‘butter crumble’ and ‘black and blue berry’.9

Some manufacturers of e-cigarette fluids have cited that the ingredients, including the flavour chemicals used, are all ‘food grade’, and/or ‘generally recognised as safe’ (GRAS). However, GRAS certification by the Flavor Extracts Manufacturers Association (FEMA) pertains only to ingestion, not inhalation. FEMA currently states9

The [FEMA] Expert Panel does not evaluate flavor ingredients for use in tobacco products including e-cigarettes or other products that are not human food, or products that result in exposures other than ingestion. and

E-cigarette manufacturers should not represent or suggest that the flavor ingredients used in their products are safe because they have FEMA GRAS status for use in food because such statements are false and misleading.

While it is likely that virtually all flavour ingredients that are popular in confectionary and food products have been included in multiple e-cigarette products, very little has been published on the levels of flavour chemicals in e-cigarette fluids. Farsalinos et al10 analysed e-cigarette refill fluids from seven countries for diacetyl (aka butanedione, often described as giving a buttery flavour), and acetyl propionyl (aka pentane-2,3-dione, often described as giving a caramel or buttery flavour). Both compounds were reported to be found in 74% of the samples tested, and the authors concluded that 47% of the diacetyl-containing samples and 42% of the acetyl propionyl-containing samples could lead to exposures higher than NIOSH safety limits. Bahl et al11 examined 41 e-cigarette refill fluids for cytotoxicity to human pulmonary fibroblasts, human embryonic stem cells and mouse neural stem cells, and concluded that
Table 1  Concentrations of flavour chemicals measured at $\geq 0.5$ mg/mL and/or for top three flavour chemicals in 30 e-cigarette products including e-cigarettes with disposable cartridges (NJOY and BLU) and refill bottles (six brands)

<table>
<thead>
<tr>
<th>Rank by total flavour level</th>
<th>Flavour name (number for flavour)</th>
<th>Refill bottle or disposable cartridge</th>
<th>Labelled nicotine (mg/mL)</th>
<th>Total for flavour chemicals determined (mg/mL)</th>
<th>Individual flavour chemicals</th>
<th>CAS Registry number</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Double Dark Chocolate (1 of 2 Chocolate/Cocoa)</td>
<td>Zeus E-Juice</td>
<td>Refill bottle 12</td>
<td>43.0</td>
<td>Vanillin 121-33-5 Aldehyde</td>
<td>118-71-8 Alcohol</td>
<td>4.7</td>
</tr>
<tr>
<td>2</td>
<td>Cotton Candy (1 of 2 Cotton Candy)</td>
<td>Mt Baker Vapor</td>
<td>Refill bottle 12</td>
<td>31.4</td>
<td>Ethyl maltol 4940-11-8 Alcohol</td>
<td>121-32-4 Aldehyde</td>
<td>27.1</td>
</tr>
<tr>
<td>3</td>
<td>Wild Cherry (1 of 3 Cherry)</td>
<td>Mt Baker Vapor</td>
<td>Refill bottle 12</td>
<td>29.7</td>
<td>Benzaldehyde 100-52-7 Alcohol</td>
<td>21.2</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>4</td>
<td>555 Menthol (1 of 4 Menthol)</td>
<td>Mt Baker Vapor</td>
<td>Refill bottle 12</td>
<td>28.5</td>
<td>Menthol 2216-51-5 Alcohol</td>
<td>21.6</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>5</td>
<td>Caught’n Pick’n Kid (2 of 2 Cotton Candy)</td>
<td>Rose City Vapors</td>
<td>Refill bottle 12</td>
<td>27.8</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
<td>23.4</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>6</td>
<td>Bubble Gum (1 of 2 Bubble Gum)</td>
<td>Mt Baker Vapor</td>
<td>Refill bottle 12</td>
<td>23.8</td>
<td>Ethyl butyrate 105-54-4 Ester</td>
<td>11.1</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>7</td>
<td>Menthol (2 of 4 Menthol)</td>
<td>NJOY</td>
<td>Disposable cartridge 18</td>
<td>21.5</td>
<td>Menthol 2216-51-5 Alcohol</td>
<td>19.7</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>8</td>
<td>French Vanilla (1 of 3 Vanilla)</td>
<td>NJOY</td>
<td>Refill bottle 12</td>
<td>18.8</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
<td>8.4</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>9</td>
<td>Cafe Mocha (1 of 3 Coffee)</td>
<td>Halo</td>
<td>Refill bottle 6</td>
<td>18.4</td>
<td>Maltol 118-71-8 Alcohol</td>
<td>10.9</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>10</td>
<td>Menthol Ice (3 of 4 Menthol)</td>
<td>Halo</td>
<td>Refill bottle 6</td>
<td>16.8</td>
<td>Menthol 2216-51-5 Alcohol</td>
<td>16.5</td>
<td>Ethyl vanillin 121-32-4 Aldehyde</td>
</tr>
<tr>
<td>11</td>
<td>Grape (1 of 2 Grape)</td>
<td>Taste E-Liquid</td>
<td>Refill bottle 24</td>
<td>13.4</td>
<td>Maltol 118-71-8 Alcohol</td>
<td>6.2</td>
<td>Ethyl acetate 141-78-6 Ester</td>
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</tbody>
</table>

Continued
Table 1
Continued

<table>
<thead>
<tr>
<th>Rank by total flavour level</th>
<th>Flavour name (number for flavour)</th>
<th>Brand (CAS Registry number Class)</th>
<th>Refill bottle or disposable cartridge</th>
<th>Labeled nicotine (mg/mL)</th>
<th>Total for flavour chemical determined (mg/mL)</th>
<th>Individual flavour chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Green Apple (1 of 2 Apple)</td>
<td>Mt Baker Vapor (928-95-0 Alcohol)</td>
<td>Refill bottle 12</td>
<td>12.2</td>
<td>(E)-2-Hexen-1-ol 4.3 (3Z)-3-Hexen-1-ol 1.7</td>
<td>Hexyl acetate 0.8 Ethyl acetate 0.7 Ethyl butyrate 0.8</td>
</tr>
<tr>
<td>13</td>
<td>Longhorn (1 of 7 Tobacco)</td>
<td>Halo (100-51-6 Alcohol)</td>
<td>Refill bottle 6</td>
<td>10.4</td>
<td>Vanillin 1.6 Maltol 0.2 Ethyl acetate 1.0</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>555 (2 of 7 Tobacco)</td>
<td>Mt Baker Vapor (121-33-5 Tobacco)</td>
<td>Refill bottle 12</td>
<td>9.3</td>
<td>Vanillin 1.7 Maltol 0.3 Ethyl vanillin 0.3</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Grape (2 of 2 Grape)</td>
<td>Mt Baker Vapor (121-33-5 Grape)</td>
<td>Refill bottle 12</td>
<td>9.0</td>
<td>Ethyl acetate 1.3 Methyl anthranilate 0.6</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Vanilla (2 of 3 Vanilla)</td>
<td>Rose City Vapors (100-51-6 Tobacco)</td>
<td>Refill bottle 12</td>
<td>7.5</td>
<td>Ethyl vanillin 1.7 Ethyl maltol 0.5</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Bubblegum (2 of 2 Bubble Gum)</td>
<td>Viquid (100-51-6 Bubble Gum)</td>
<td>Refill bottle 12</td>
<td>7.5</td>
<td>Ethyl acrylate 0.9 Benzaldehyde 0.6 2-Methylbutyl acetate 1.0</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Magnificent Menthol (4 of 4 Menthol)</td>
<td>BLU (121-32-4 Menthol)</td>
<td>Refill bottle 22</td>
<td>7.1</td>
<td>Menthol 5.7 Menthone 0.6 Ethyl maltol 0.3</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Java Jolt (2 of 3 Coffee)</td>
<td>BLU (100-51-6 Coffee)</td>
<td>Refill bottle 22</td>
<td>7.1</td>
<td>Maltol 1.5 Ethyl maltol 0.3 Ethyl vanillin 0.3</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>First Step Tobacco (3 of 7 Tobacco)</td>
<td>Rose City Vapors (121-33-5 Tobacco)</td>
<td>Refill bottle 12</td>
<td>6.6</td>
<td>Vanillin 1.1 Maltol 0.2 Ethyl vanillin 0.2</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Granny Smith Apple (2 of 2 Apple)</td>
<td>Taste E-Liquid (121-33-5 Apple)</td>
<td>Refill bottle 24</td>
<td>5.7</td>
<td>Hexyl acetate 0.8 Ethyl acetate 0.7 2-Methylbutyl acetate 0.6</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Vivid Vanilla (3 of 3 Vanilla)</td>
<td>BLU (100-51-6 Vanilla)</td>
<td>Refill bottle 22</td>
<td>4.7</td>
<td>Ethyl vanillin 1.5 Vanillin 0.3 Benzyl alcohol 0.6</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Cherry (2 of 3 Cherry)</td>
<td>Taste E-Liquid (100-51-6 Cherry)</td>
<td>Refill bottle 6</td>
<td>4.3</td>
<td>Ethyl maltol 0.9 Benzaldehyde PG acetal 0.6  Benzaldehyde 0.6</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Belgium Cocoa (2 of 2 Chocolate/Cocoa)</td>
<td>Halo (100-51-6 Chocolate/Cocoa)</td>
<td>Refill bottle 6</td>
<td>3.7</td>
<td>Vanillin 0.6 Maltol 0.8 2356-Tetramethylpyrazine 0.6</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Coffee (3 of 3 Coffee)</td>
<td>Mt Baker Vapor (100-51-6 Coffee)</td>
<td>Refill bottle 12</td>
<td>2.6</td>
<td>Benzyl alcohol 0.3 Vanillin 0.3</td>
<td></td>
</tr>
</tbody>
</table>

when present, the cytotoxicity was related to the flavour chemicals, especially for cinnamon-flavoured refill fluids. A recent opinion piece in JAMA\textsuperscript{12} states

Research is needed to characterize both the presence of toxic chemicals in ENDS flavorings and the potential adverse respiratory effects of exposure to e-liquids, especially flavorings.

Hutzler et al\textsuperscript{11} analysed 28 e-cigarette liquids from seven manufacturers by gas chromatography/mass spectrometry (GC/MS) and used comparisons with known compound-specific MS patterns to tentatively (and qualitatively) identify the presence of 141 flavour chemicals in one or more of the products. Vanillin, ethyl maltol, ethyl vanillin and menthol were the four most frequently found flavour chemicals, reported to be present in 79\%, 57\%, 50\% and 43\% of the 28 samples, respectively. However, since authentic standards were not used, actual concentrations could not be deduced. As follow-up to Bahl et al,\textsuperscript{11} Behar et al\textsuperscript{14, 15} examined cytotoxicity and measured levels of cinnamaldehyde, 4-methoxycinnamaldehyde and vanillin for 10 ‘cinnamon’ flavoured refill fluids. For the three compounds, the highest concentrations were ∼40, 3 and 8 mg/mL, respectively (∼4\%, 0.3\% and 0.8\% by weight or volume).

Product labels rarely provide ingredient information beyond the level of nicotine, and the inclusion of propylene glycol and/or glycerol. To provide additionally needed information, we describe determinations of the levels of flavour chemicals in the fluids of a convenience sample of disposable e-cigarettes and refill bottles over a range of flavour types.

**METHODS**

We assumed that meaningful conclusions could be obtained by analysing 30 products. The e-cigarette fluids examined were selected from a vast and rapidly changing array of products. BLU and NJOY, two brands of disposable-cartridge e-cigarettes, were purchased in five flavours: tobacco, menthol, vanilla, cherry and coffee. Also purchased in the same flavours (from online retailers and local ‘vape’ shops in Portland, Oregon) were refill bottles for tank systems. Refill bottles in five other confectionary flavours (chocolate/cocoa, grape, apple, cotton candy and bubble gum) were also purchased. After dilution with methanol, the fluids were analysed by GC/MS. Using internal standard-based calibration procedures similar to those described elsewhere,\textsuperscript{16} analyses were performed using an Agilent (Santa Clara, California, USA) 7693 autosampler, Agilent 7890A GC and Agilent 5975C MS. The GC column type was Agilent DB-5MS UI, of 30 m length, 0.25 mm id and 0.25 mm thickness. For each replicate sample, ∼50 mg of each fluid was dissolved in 1 mL of methanol. One microlitre of the methanol solution was then injected on the GC with a 25:1 split. The GC temperature programme for all analyses was: 35°C held for 5 min; 10°C/min to 300°C; then held for 3.5 min at 300°C. No quantifications of aerosols generated from the fluids were carried out.

Qualitative analyses of the 30 e-cigarette fluids were first carried out here using the NIST 14 MS library,\textsuperscript{17} and the results were compared with data previously obtained for flavoured tobacco products.\textsuperscript{16} Quantitative analyses of the 30 fluids were then undertaken, using authentic standards, for a specific list of compounds, which formed the ‘target analyte list’. If reported here, the presence of each target analyte was confirmed by matching GC retention times and MS patterns with results obtained with the authentic standards; the level was determined by comparison with calibration standard runs. The target analyte list included the 70 compounds listed in Brown et al\textsuperscript{16} plus 20 others, namely aromadendrene, 1,4-cineol, trans-cinnamaldehyde, citronellal,
citronellyl propionate, coumarin, decanal, ethyl acetate, ethyl hexanoate, fenchol, limonene oxide, \textit{trans}-linalyl propionate, maltol, 3’-methylacetophenone, neomenthol, 2-nonenone, pentyl propionate, pulegone, \(\gamma\)-terpineol and 2,3,5,6-tetramethylpyrazine. The vicinal diketone compounds diacetyl and 2,3-pentanedione were not in the target analyte list.

**RESULTS**

Total flavour chemicals were greater than 1% by weight in 13 of the liquids analysed (table 1). Concentration values in mg/mL are nearly equivalent to values with units of mg/g; 10 mg/mL corresponds to \(\sim\)1% by weight. Six of the 24 compounds in table 1 are aldehydes, a compound class recognised toxicologically to be ‘primary irritants’ of the mucosa of the respiratory tract. For the ‘tobacco’ flavoured fluids, none of the flavour chemicals reported are obtainable at the levels found by adding a tobacco extract to the e-cigarette fluid; while extracts of tobacco may be used in some ‘tobacco’ flavoured fluids, a majority of the ‘tobacco’ flavoured products were found to contain confectionary flavour chemicals. Figure 1 provides a bar plot for numbers of fluids versus per cent by weight for the 30 e-cigarette liquids. Thirteen of the liquids (43%) contained total determined flavour chemical levels greater than 1% by weight. Seven of the liquids (23%) contained levels greater than 2% by weight. Two of the liquids (7%) contained levels greater than 3% by weight.

**LIMITATIONS**

The array of e-cigarette products is vast and growing daily. As such, this study was unable to provide a comprehensive overview of the levels of flavour chemicals in such products currently on the market. Nevertheless, the results obtained are likely to be similar to what a broad survey would have revealed, and in any case strongly suggest that very high levels of some flavour chemicals are undoubtedly present in a great number of the thousands of products currently available.

**DISCUSSION**

Recommended 8 h occupational exposure limits by inhalation for benzaldehyde and vanillin are \(\sim\)9 and 10 mg/m\(^3\), respectively. Assuming respiration at 0.83 m\(^3\)/h (20 m\(^3\)/day), these values give recommended work-place exposure limits of 60 and 67 mg/day, respectively. For e-cigarette liquid consumption rates, \(\sim\)5 mL/day is commonly self-reported in online ‘vaping’ forums. In our data, the brand with rank 3 in total flavour chemicals contained benzaldehyde at 21 mg/mL; the rank 1 brand contained vanillin (4-hydroxy-3-methoxybenzaldehyde) at 33 mg/mL; 5 mL/day then suggests possible inhalation rates of \(\sim\)105 and \(\sim\)165 mg/day, respectively, twice the recommended limits. Although the group of fluids analysed here represents only a small sample of the available products, the data suggest that a small number of flavour chemicals are particularly popular among manufacturers: for example, vanillin and ethyl vanillin, maltol and ethyl maltol, benzaldehyde and benzyl alcohol, and ethyl butyrate and ethyl acetate. Regulatory actions that should be considered include requiring ingredient identification, limiting levels of some individual flavour chemicals, and limiting total levels of flavour chemicals.

**REFERENCES**


Contributors JFP and PAT planned the study. JFP supervised the study. PAT selected the e-cigarette fluids to be analysed. PAT, CDK, JEB and WL carried out the analyses. WL managed the data QA/QC processes, and was assisted by PAT and CDK. JFP and PAT drafted the manuscript. All authors reviewed the manuscript.

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TOBACCO CONTROL

High flavouring content in some e-cigarettes may be cause for concern

Exposure levels can exceed recommended limits; some chemicals could be respiratory irritants

The levels of chemicals used to flavour some brands of e-cigarette fluid exceed recommended exposure limits and could be respiratory irritants, in some cases, suggests research published online in the journal *Tobacco Control*.

The electronic cigarette market has developed rapidly in recent years, with global sales in 2014 estimated to be in the region of US$7 billion, but the health implications of vaping remain hotly contested.

Artificial and other flavourings in e-cigarettes are mostly the same as those used in food and confectionery manufacture, and are therefore often represented as safe by e-cigarette manufacturers.

But as the US Flavor Extracts Manufacturers Association (FEMA) has pointed out, this safety relates to exposure through eating, and not inhalation. And the ingredients listed on the product labels for e-cigarettes rarely include the chemicals used for flavouring.

The researchers therefore set out to find out the levels and type of chemicals used to flavour e-cigarette fluid in a sample of 30 products.

These included two single use disposable brands in five different flavours of tobacco, menthol, vanilla, cherry and coffee; the same flavours in refill bottles; and additional flavours of chocolate/cocoa, grape, apple, cotton candy and bubble gum in refill bottles.

The flavouring chemicals totalled more than 1% by volume in 13 of the 30 liquids analysed, levels greater than 2% by weight in seven liquids, and levels greater than 3% by weight in two products.

Seventeen of the products contained the same vanillin or ethyl vanillin flavourings, suggesting that a small number of chemicals are particularly popular with manufacturers and users.

And many of the ‘tobacco’ flavoured fluids contained chemicals used to flavour confectionery.

Six of the 24 compounds revealed in the analyses were aldehydes, compounds recognised to be primary respiratory irritants.

Using a consumption rate of around 5 ml/day, as commonly reported on online vaping forums, vapers would be exposed to twice the recommended occupational
exposure limits of benzaldehyde and vanillin with the products tested, say the researchers.

“And toxic degradation products may be produced by reaction of the flavour chemicals at the high temperatures present during vaping,” they caution.

They admit that their sample represents a fraction of the e-cigarette products on the market.

But they say: “Nevertheless, the results obtained are likely to be similar to what a broad survey would have revealed, and in any case, suggest that very high levels of some flavour chemicals are undoubtedly present in a great number of the thousands of products currently available.”

Regulations are needed, they argue. These should include compulsory ingredient listing, limiting the levels of certain flavourings, and limiting the total permissible levels of flavourings, particularly as there is some concern that flavoured products might make e-cigarettes more attractive to young people, they suggest.