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Shan-Shan Chung
Hong Kong Baptist University, sschung@hkbu.edu.hk

Jin-Shu Zheng
Hong Kong Baptist University

Antonio C. S. Kwong
Hong Kong Council on Smoking and Health

Vienna W. Y. Lai
Hong Kong Council on Smoking and Health

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Harmful flame retardant found in electronic cigarette aerosol

Shan-Shan Chung,[a] Jin-Shu Zheng,[a] Antonio CS Kwong,[b] Vienna WY Lai[b]

[a] Department of Biology, Hong Kong Baptist University, Kowloon Tong, Hong Kong

[b] Hong Kong Council on Smoking and Health, Wan Chai, Hong Kong

Correspondence to

Dr Chung Shan Shan, Department of Biology, Hong Kong Baptist University, Kowloon Tong, Hong Kong. sschung@hkbu.edu.hk; tel: +852-34117741; fax: +852-34117743

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Abstract

Studies on the health impact of vaping so far have largely ignored the fact that electronic cigarette (e-cigarette) is essentially an electronic product which is likely to contain a group of endocrine disrupting flame retardants, namely, polybrominated diphenyl ethers (PBDEs) as additives in the combustible components of the product. Thus, the conclusion that e-cigarette is less harmful to health than tobacco smoking may be based on incomplete information. This study reports moderate to elevated levels of PBDEs in 5 out of the 13 samples of e-cigarettes. This finding is suggestive of the continued use of PBDEs in the manufacturing of e-cigarette atomizers and the associated protective casing. This study is unique as it confirms the existence of this developmental neurotoxicant in e-cigarette aerosols. In view of the significant levels of PBDEs and other known carcinogens (polycyclic aromatic hydrocarbons and formaldehydes) in e-cigarette aerosol, there is an urgent need for conducting a thorough review of the health risks of vaping by relevant professionals. A further lesson learnt from this study is that policy makers and relevant product manufacturers should be aware of the possible presence of PBDEs in the aerosol of body care and medical electrical devices such as face steamers, inhalators and nebulizers, especially when PBDEs are utilized in the combustible components of these devices.

Harmful flame retardant found in electronic cigarette aerosol

1. Introduction

An electronic cigarette (e-cigarette) is a battery driven device mimicking tobacco cigarettes and is being marketed as a less harmful alternative to tobacco cigarette or as an aid for smoking cessation (Pearson, et al., 2012). Other than the lithium-ion battery, an e-cigarette comprises of a light-emitting diode light, an atomizer, a microprocessor, and a cartridge containing a liquid solution generally referred to as e-liquid (Lerner, et al., 2015). The atomizer assembly mounting base is usually made of rigid plastics containing holes for housing wires extending through the base (Politics and Government Week, 2016). During use, the battery heats up the liquid in the cartridge while the atomizer vaporizes the liquid, emitting it as a mist or aerosol that users inhale. An e-cigarette is essentially an electronic product that is designed to generate aerosols that are directly inhaled by vapers (smokers of e-cigarettes).

Though there is a lack of complete statistics on global e-cigarette consumption, it may be noted that e-cigarette use is growing or persisting across many countries. In the US, the number of adult vapers doubled between 2010 and 2013 (King et al., 2015). Dramatic increases in e-cigarette use among young people in the US have been found since 2013 (US Department of Health and Human Services, 2016). In EU, though the percentage of vaper has remained at 2%, 15% of the population has tried e-cigarette at some point (European Commission, 2017). The growth in the popularity of e-cigarettes is presenting two major research challenges. The first challenge is about the health risk of vapers and the associated indirect aerosol receivers. The second is about the environmental impact of e-cigarette manufacturing and disposal (Lerner et al., 2015). So far, most of the e-cigarette research attention has been directed towards the human health risks associated with vaping (Lerner, et al., 2015). A growing body of literature directed toward comparing the health impacts of vaping and smoking is also noted. One view is that there are health benefits in vaping as opposed to smoking. The Royal College of Physicians (2016) offered the view that vapers were more likely to successfully quit smoking and that e-cigarettes were "popular with smokers and offer a viable harm-reduction option" owing to reduced bodily absorption of benzene, tobacco-specific nitrosamines and PAHs in vaping than tobacco smoking. Parker and Rayburn (2017) showed that the leachate from one type of e-cigarette was about ten times less toxic on embryos than tobacco cigarette butts. Also by testing one brand of e-cigarette, Azzopardi et al. (2016) demonstrated that aerosol from e-cigarette was significantly less cytotoxic than cigarette smoke. However, some studies showed that nicotine exposure of vapers was not significantly different from smokers (Göney, et al., 2016) and the flavorings in e-liquid was causing significant levels of aldehydes to be formed in e-cigarette aerosols (Khlystov and Samburova, 2016).

Although there is no consensus as yet on the health risks of vaping, the World Health Organization (WHO) has recommended that e-cigarettes should not be used in work places or public areas in view of the harmful substances known to be emitted with the aerosol (WHO, 2014). Despite this recommendation, controversies on the merits and demerits of e-cigarettes continue. In line with the WHO recommendation, the Hong Kong Special Administrative Region (HK) government has proposed, among others, to ban the import, manufacture, sale, distribution and advertising of e-cigarettes in the city. Despite the large number of studies on the health risk associated with e-cigarette use, the potential toxicities of inhaling or absorbing the substances and additives used in the e-liquid, atomizer and protective casing continue to be incompletely understood owing to the lack of comprehensive knowledge and evaluation of its benefits and harms. To provide objective scientific evidence for the ban, the Hong Kong Council on Smoking and Health (COSH) commissioned a study to test the concentrations of harmful substances in e-cigarettes available in HK in 2015-2016. The results reported in this paper form part of the COSH study. Substances tested in the aerosols of e-cigarettes include, among others, polycyclic aromatic hydrocarbons (PAHs), nicotine, formaldehydes and polybrominated diphenyl ethers (PBDEs). This paper reports only on the concentrations of PBDEs in e-cigarette aerosol because the concentrations of nicotine, PAHs and formaldehydes in e-cigarette aerosols have already been reported comprehensively in previous studies (e.g., Cheng, 2014).

PBDEs are flame retardants widely used in many products such as building materials, textiles, cars and electronic and electrical equipment. They are applied to combustible components of target products, usually plastics. PBDEs tend to be easily leached out or carried away from the host products (Besis et al., 2014). Coupled with the widespread use of PBDEs, this phenomenon makes contamination ubiquitous. Though not all congeners of PBDEs are harmful to humans, at least one is an endocrine disruptor (BDE-47) while others have been shown to cause cancer in high doses. They exhibit developmental and reproductive toxicity and damage the central nervous system (Schecter et al., 2006). As a result, PBDEs have been recognized as hazardous substances and their use in electrical and electronic products is restricted in the European Union (Directive 2011/65/EU). Besides, they have been listed as persistent organic pollutants under the Stockholm Convention (the Secretariat of the Stockholm Convention, 2009). PBDEs are bio-accumulative and can be biomagnified. Although PBDEs have been found to be ubiquitous in food, Schecter et al. (2006) argued that dietary exposure alone could not explain the high human body burden. Other sources of exposure include ingestion of dust in workplaces and even households as well as indoor and outdoor air inhalation (Ni et al., 2013). Environmental exposure, resulting from the industrial application of PBDEs in electronic and electrical products is another reason for the high body burden noted. This paper aims to i) enrich the present knowledge on the health risks of vaping versus smoking by presenting the levels of PBDEs in thirteen e-cigarette and two tobacco cigarette samples and calculating the “safe” doses of e-cigarette with respect to specific PBDE congeners; and ii) discuss the implications of such findings on environmental sustainability, public health and clean production.

2. Materials and methods

2.1. Samples and sampling

A total of six different brands of e-cigarettes (A-F) were included in the study by means of convenience and judgement sampling. A convenience sample is a sample obtained by using convenience sampling method which is a type of non-probability sampling. Samples are made up of easy-to-reach individuals. Judgement sampling is also a type of non-probability sampling and selects samples based on expert (the venders) advice. Five brands of e-cigarettes and e-liquids were chosen based on market observations at the time of the study and the results of a 2014 COSH study on the promotion and availability of e-cigarettes in HK. One additional brand (A) was also included based on a supplier's recommendation of its popularity. In total, a sample of thirteen e-cigarettes, four filled with e-liquids and nine connected with e-capsules from six brands were procured through online platforms and normal retail outlets in HK in February 2014 and in June to July 2015. As for the tobacco cigarette samples (RC1 and RC2), two packets of a common commercial brand (G) were acquired. Table 1 lists the types, flavors and nicotine information shown on the samples' labels.

Table 1

Nicotine and other information on the labels of e- and tobacco cigarette samples

Sample	Types	Brand	Flavors	Indication of nicotine levels on label
EC1	e-liquid	A	Tobacco	May contain nicotine
EC2		B	Mint	Nicotine (unless zero)[a]
EC3		C	Mint	No mention of nicotine content
EC4		C	Cola	
EC5	original e-cigarette cartridge	D	Cigarette brand flavor [a]	0 mg nicotine
EC6		D	Cigarette brand flavor [a]	
EC7		D	Strawberry	
EC8		E	Tobacco	0 mg nicotine & tar
EC9		E	Chocolate	
EC10		F	Tobacco	
EC11		F	Mint	
EC12		E	Tobacco	
EC13		F	Mint	0 mg nicotine
RC1	Tobacco cigarette pack 1	G	n.a.	n.a.
RC2	Tobacco	G	n.a.	n.a.

	cigarette pack 2

[a] exact label of the e-liquid container/e-cigarette cartridge, unclear/not informative

2.2. Experimental set up for testing e-cigarette and tobacco cigarette aerosol

Our experimental set-up was similar to the Sparging Apparatus used by US Food and Drug Administration (2009) for testing of e-cigarettes. It consisted of two 50 mL polypropylene conical test tubes connected together with glass tubes and flexible silica tubings which were further connected to a pump (Model DQA-P104-AA Volts:115 Amps:4.2 HZ 60 USA connecting with CT-1000AC-AC Converter 1000 Watt 50/60 HZ) to suck air from the e- and tobacco cigarette samples. To set the correct puff velocity, the researcher began with the lowest velocity and slowly raised it to a level where it was strong enough to light the e-cigarette. Upon activation of the pump, aerosol from the samples passed through two tubes of solvent mixture. A valid "puff" is indicated by illumination of the LED indicator at the front of the e-cigarette sample and bubbling of the solvent mixture. In each bout, a sample was "lit" for 12 min with each "puff" (by activating the pump) lasting about 4 s to 5 s with an inter-puff time of 2 s. This is translated into about 111 puffs per bout. While the 12 min duration for a bout was generally longer than a normal smoking activity and the puff regimes deployed in other e-cigarette studies, the intention was to maximize the collection of target analytes so as to ensure that no harmful substances, not known to the researchers, escape notice. A case in point is Khlystov and Samburova (2016) who admitted that “the small number of puffs” in their test regime was likely the cause of non-detection of target analytes in some samples. In their study, two puffs (each lasts 4 s) were sampled after 15 warm-up puffs (Khlystov and Samburova, 2016). Goniewicz et al. (2014) similarly admitted that since their puff regime was likely to be shorter (1.8 s) than actual situations, their findings might have understated actual quantities of harmful substances inhaled by vapers. Hence, using a longer puff regime (4.5 s) is a sensible approach in the present case. This approach is applied in Health New Zealand Ltd. (2008) and Burstyn (2014) as well.

2.3. Extraction and analysis of PBDEs

The solvents used in the two polypropylene conical test tubes consisted of 12.5 mL of dichloromethane and 12.5 mL of hexane in each tube, i.e., 25 mL in each tube. After 12 min of exposure to e- or tobacco cigarette aerosol, the solvents in the two tubes were combined and concentrated by a rotary pressure reduced evaporator to around one mL which was then transferred to specialized 1.5 mL vials for determining PBDEs.

Subsequent analytical procedures used in this study were adopted from Liu et al. (2005). The presence of PBDEs was detected by a gas chromatography-mass spectrometer (GC-MS) from Agilent Technologies (7890A GC system) with a 7683B series injector for sample injection. An Agilent Technologies 5975C inert MSD with triple-axis detector was deployed for compound identification and quantity calculation. A 30m HP-5 mass fused silica capillary column (0.25 mm diameter and 0.25 μm film thickness; 95% dimethyl-polysiloxane) was used for the GC oven. The chromatographic separation was achieved by setting the oven at 80˚C for the first two min. The temperature was then increased at a rate of 8˚C/min to 280˚C and was held there for 15 min. Helium was used as the carrier gas at a flow rate of 1.9 mL/min. The injector temperature was set at 280˚C in the splitless-injection mode. The mass spectra of targeted analytes were obtained in EI mode (70 eV). After scanning in the range of 50–800 m/z with a cycle time of 1s, the MSD could identify compounds by comparing the m/z of unknown compounds against the default NIST-library database. Finally the determination of PBDEs was confirmed by standards.

For quantitative analysis, a series of standard solutions at 8 different levels: 0, 5, 10, 20, 50, 100, 250 and 500 ng/mL were prepared and injected into the GC-MS for producing the standard calculation curves (accepted R^2=0.999 or above). All parameters obtained were then analyzed by the computer. The internal standard, Mass-Labelled Polybrominated Diphenyl Ethers (MBDE-MXE) ^{13}C-PBDE (Wellington Laboratories Inc., 345 Dr. Guelph ON NIG 3M5, Canada), was spiked into the samples and used with the standard calculation curves for quantitative analysis. Fig. 1a and 1b show the chromatograms of the internal standard and EC6.

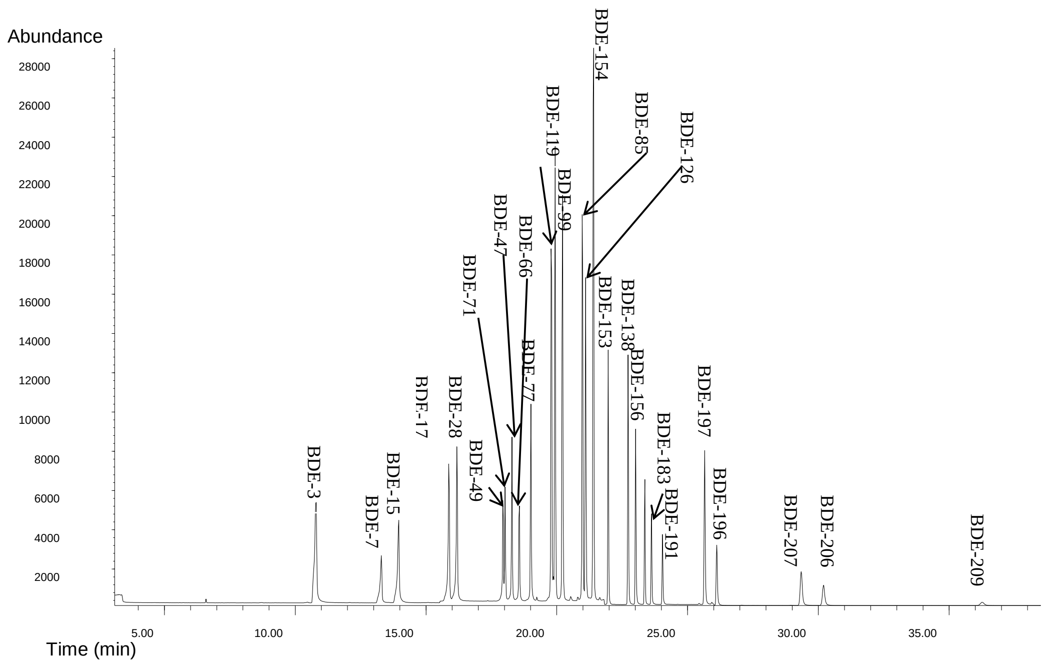

Fig. 1a Chromatogram of the internal standard

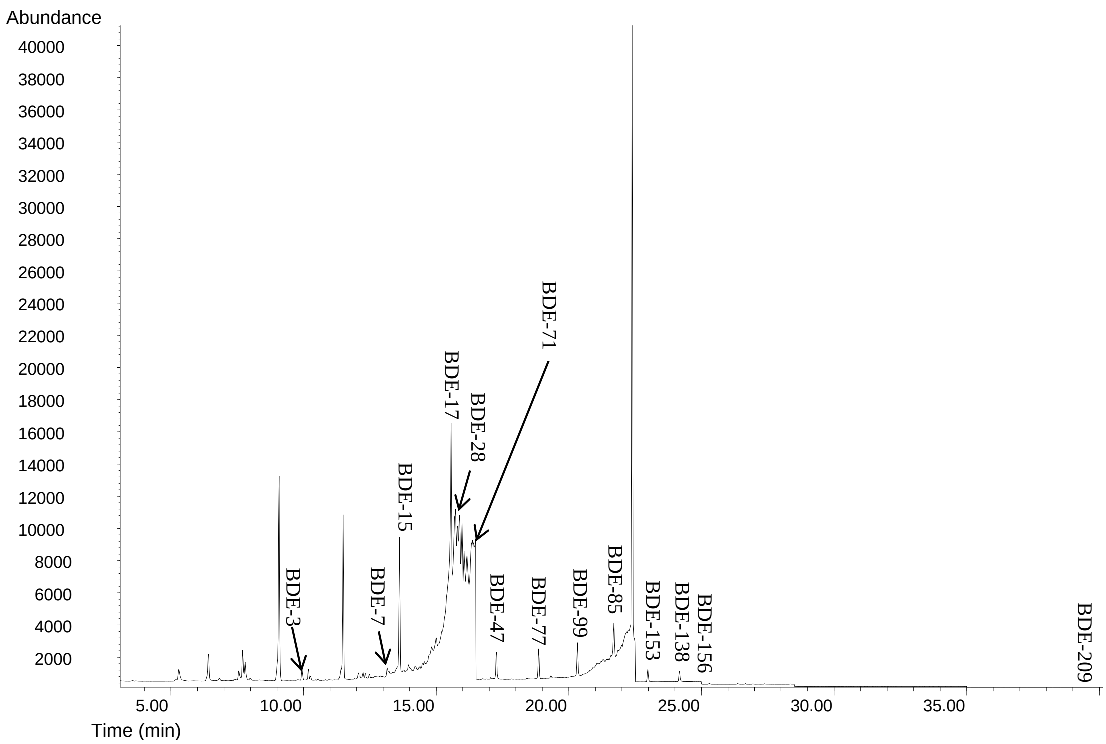

Fig. 1b Chromatogram of EC6

2.4. Quality control

The determination limits for PBDEs were set at 0.1 ng/mL for individual congener and 1.0 ng/mL for total PBDEs (Table 3). Recovery was between 74-85% for PBDE congeners from BDEs 3 to 191, and 54%-75% for high molecular BDEs 196, 197, 206, 207 and 209. Our recovery rates were on par with Liu et al. (2005) and Oros et al. (2005). Blank tests were also conducted with each e-cigarette aerosol test. Laboratory air was taken as a blank. Table 2 states the ion mass of the 27 PBDE congeners.

Table 2

BDE – MXE selected ion mass of 27 PBDEs

Congeners	Ion	Congeners	Ion
BDE-3	248.0	BDE-126	565.7
7	168.1	154	483.7
15	327.9	153	483.7
17	246.0	138	483.7
28	245.9	156	483.7
49	325.9	184	563.7
71	325.9	183	561.7
47	325.9	191	563.7
66	325.9	197	641.7
77	485.7	196	641.7
100	403.8	207	719.5
119	403.8	206	719.5
99	405.8	209	799.5
85	405.8		

2.5. Reference doses

In line with other studies (e.g. Wang et al., 2011), the reference doses (RfDs) established by USEPA (2014) for some congeners of PBDEs were used in this study for comparison purposes (second last row of Table 3).

3. Results

3.1. Congener Profiles

The unadjusted mean concentrations from two replications of analyses of the 27 PBDE congeners, expressed as ng/mL of concentrated solvent, detected in the aerosol of samples are stated in Table 3. Adjustment is not recommended because the recovery rates achieved here are typical of PBDE determination. As all the PBDEs from one bout are believed to be dissolved in the 25 mL solvent which was then concentrated to one mL for determination, the concentrations of PBDEs found in each sample of e-cigarette aerosol could also be understood as Σ_{27}PBDEs absorbable by a vaper in one bout of e-cigarette smoking.

Based on the PBDEs concentration, the e-cigarette samples were grouped into three tiers. Tier 1 samples, namely, EC1-3, 5, 8, 10, 12 and 13, had low to very low levels of PBDEs despite the use of a more intense and long puff regime. Tier 2 samples (EC4, 7, 9 and 11) had moderate levels of PBDEs. EC6 had the highest concentration of PBDEs, about 8-10 times Tier 2 samples and formed a tier (Tier 3) on its own.

Table 3

Mean concentrations of PBDEs in the aerosol of e-cigarette and tobacco cigarette samples (ng/mL) (replicate = 2)

	BDE-47	BDE-85	BDE-99	BDE-153	BDE-209	Total (Σ_{27}) PBDEs mean (sd)
EC1	0.2	0.2	0.2	0.3	0.2	2.5 (0.28)
EC2	0.1	0.2	0.1	0.2	0.1	2.1 (0.07)
EC3	1.5	1.8	0.7	0.7	0.5	9.0 (0.28)
EC4	31.4	22.4	34.7	19.8	2.8	191.9 (0.07)
EC5	1.8	0.7	0.4	1.2	0.2	7.2 (0.57)
EC6	182.7	185.5	272.6	257.9	11.5	1490.0 (7.07)
EC7	14.9	24.3	19.7	17.8	7.4	149.3 (3.82)
EC8	8.4	7.7	9.1	6.8	2.4	46.8 (0.28)
EC9	23.5	21.9	21.5	16.3	3.6	145.7 (4.24)
EC10	1.1	0.4	0.5	0.5	0.3	3.5 (0.57)
EC11	22.7	18.6	19.4	21.6	11.6	158.1 (2.97)
EC12	0.4	0.1	0.0	0.9	0.1	2.3 (0.07)
EC13	0.5	0.2	0.3	0.0	0.0	1.7 (0.07)
RC1	1.4	0.7	0.8	0.9	0.0	6.3 (0.00)
RC2	1.2	0.5	0.4	0.6	0.1	5.6 (0.42)
Control	0.0	0.0	0.0	0.0	0.0	0.0 (0.00)
RfDs (mg/kg/d)	0.0001	na	0.0001	0.0002	0.007	na
Detection limit			0.1			1.0

Notes: sd, standard deviation; na, not available; RC, tobacco cigarette; EC, e-cigarette.

4. Discussion

The views on e-cigarette continue to be polarized with each side having its own arguments. Soon after WHO's report, Financial Times reported that 53 public health academics from 15 countries appealed to WHO to not regulate e-cigarette in the same way as tobacco cigarettes since they saw e-cigarette as a solution to tobacco addiction (Duncan, 2014) with the major argument being e-cigarettes tested so far were less harmful than conventional cigarettes (McNeill et al., 2014). This was then followed by the release of The Royal College of Physicians' report (2016).

As far as harm reduction is concerned, it appears that the e-cigarette industry has significantly reduced the level of nicotine in e-cigarette (compare Table 1 with Goniewicz et al., 2013) rendering vaping less addictive. However, in view of the newly discovered group of manufacturing additive, PBDEs, and together with Khlystov and Samburova's (2016) findings, it is no longer appropriate to encourage its use even if it is later proven that e-cigarette is a solution to tobacco addiction. Neither is it correct to argue that the levels of toxins from e-cigarettes are much lower than tobacco cigarettes before a systematic and comprehensive study on the concentrations of PBDEs, aldehydes (as revealed in Khlystov and Samburova, 2016) and possibly other newly discovered harmful substances in e-cigarette aerosols has been carried out.

While low levels of PBDEs were found in the aerosol of Tier 1 samples and tobacco cigarette (Table 3), moderate to high levels of PBDEs were found in Tiers 2 and 3 e-cigarettes which were available from retail outlets in HK. As no datum regarding the level of PBDEs in e-cigarette aerosols was available from the existing body of literature for comparison, concentrations of PBDEs in food and various environmental settings were cited instead (Table 4). Although direct comparison is difficult owing to the diverse nature of data in Table 4, in general, it is reasonable to conclude that the levels of PBDEs in some of our samples were many orders of magnitude higher than those in ambient air and food. The levels were comparable to those in dust particles. Besides, people do not regularly ingest or inhale dust contaminated with such levels of PBDEs.

Table 4

Concentrations of PBDE in food and various environmental settings

Nature of sample	Total PBDEs	Year & place	Reference
Air conditioner filter dust	1271 ng/g	Greece, 2014	Besis et al. (2014)
Indoor dust in workplace	138-477 ng/g	Belgium, 2010	Pearson et al. (2012)
Outdoor air	195-1450 pg/m^3	Shunde, China, 2009	Besis and Samara (2012)
Indoor air (homes)	1.3-3980 pg/m^3	Various places, 2004-2011	Besis and Samara (2012)
Pork Farmed Salmon fillet Cow's milk	41 pg/g wet weight 1590-1919 pg/g wet weight 7.9 pg/g wet weight	USA, 2004	Schecter et al., (2006)
Various freshwater fish	1.4-5.3 ng/g wet weight	Hong Kong, 2011	Wang et al. (2011)
E-cigarette aerosol	1.7-1490 ng/mL	Hong Kong, 2015	This study.

Since PBDEs (mostly BDE-209) are only physically coated on the plastic materials in an e-cigarette atomizer, they can easily migrate onto the aerosol and the external environment. The use of PBDEs as a flame retardant in e-cigarette atomizer and protective casing was suspected to be the main source of PBDEs in e-cigarette aerosol for Tiers 2 and 3 samples.

Based on EPA's RfDs, using Tier 3 sample, EC6 as an example and assuming an average human body weight of 60 kg, the "safe" doses for the PBDE congeners (see second last row of Table 3) range from 22-47 bouts/d for BDE-47, -99 and -153 and >36,500 bouts/d for BDE-209. Since EC6 has the highest PBDEs concentration among all samples, it was concluded that sufficient evidence was not yet there to show that the presence of PBDE in e-cigarette aerosols alone was enough to cause long term health damages except among very avid vapers, i.e., those who vape more than 22 bouts/d. Yet, recent preliminary study findings have shown that exposure to aerosol from e-cigarettes drastically reduces sperm counts and sperm mobility in juvenile mice and bring about genetic changes in the brain and alter behavior in adult male and female mice (Zelikoff, 2016). With the confirmation that e-cigarette aerosol also contained carcinogens such as formaldehydes and benzo(a)pyrene, the effect of the additional harms from PBDEs for vapers should not be overlooked and the toxicological implications of chemical mixtures in e-cigarette aerosol should be studied further.

Given the cost-effectiveness of PBDEs as flame retardants, it would not be realistic to expect the electronic and electrical products manufacturing industry to totally stop their use in the near future. Yet, it is exigent that the electronic and electrical industry should step up research to find a less toxic and yet cost-effective substitute for PBDEs especially for electrical products or devices that generate aerosol for direct human inhalation of which e-cigarette is one example. Other examples include at least face steamers, nebulizers and inhalators. It is also vital that before a substitute (of PBDEs) is used in production, thorough studies on how, how much and in what form the chemical or additive concerned will migrate to the external environment must be conducted. Information on the route of migration, transformation pathways and concentrations at each stage of transformation of flame retardant and/or its derivatives is essential for determining whether the use of such flame retardants or additives are safe.

Since it has already been confirmed that e-cigarette aerosols may contain elevated levels of PBDEs, more e-cigarette samples should be tested in future studies. Further, the studies should adopt the international puff profile [e.g. ISO (2012)] to more accurately represent human vaping behavior so that more realistic “safe” dose alerts can be given to vapers.

5. Limitations

Despite the important discovery, there are limitations about this study. First, since the e-cigarette samples and the control were not prepared on the same day, it is possible that the quality of indoor air might have affected the results. However, smoking and open burning are banned on all campuses of the University in which the testing laboratory of this study was situated. As evident from the results of the controls, it is believed that even if existing contamination in the air has affected the results of this study, the extent is not significant. Second, the duration of each bout and each puff was longer than usual, so the presently adopted bout regime may have led to the occurrence of dry puffs which users avoid. Since the bout regime adopted may not be realistic, the amount of PBDEs inhaled by vapers in a normal bout was likely to be less than what was detected by the study. However, this does not refute the presence of PBDEs in e-cigarette aerosols and the recovery rates of PBDEs range between 54% and 85% only (even though these are typical recovery rates for PBDE determination). The measured concentrations reported here are therefore lower than what were actually present in the aerosols.

6. Conclusions

This study has confirmed that elevated levels of PBDEs, up to 1490 ng/bout, are found in one brand of e-cigarette aerosols. Based on present findings, a person has to take 22 bouts or more of such brand of e-cigarette per day to get exposed to unsafe levels of PBDEs. When compared to the levels of aldehydes found (Khlystov and Samburova, 2016) in flavored e-cigarette liquids with which one puff is enough to take the vaper's exposure to unacceptably dangerous levels, it appears that the main health concern from e-cigarette should not be PBDEs.

However, this study has provided several other important insights to environmental sustainability, public health and clean production. This study has taken the lead in alerting vapers that e-cigarette aerosols contain more harmful substances than people think. Going beyond inhalation and incidental ingestion of dust and consumption of normal food (Wang et al., 2013), this study fills the information gap and shows that vaping is an emerging and possibly an important source of PBDEs in human body. The discovery that elevated levels of PBDEs are found in e-cigarettes (but not tobacco cigarettes) has additional implications. First, it provides new insights into the debate between WHO and supporters of e-cigarettes, e.g. the Royal College of Physicians, for the latter to re-visit their stance on e-cigarette and if e-cigarette should be seen as a solution to tobacco addiction. In the interest of a complete picture of the health hazards from vaping, future research studies on e-cigarette aerosols should broaden the scope from focusing on the composition of e-liquid to materials and additives used in e-cigarette atomizer, cartridge and even protective casing.

Second, this discovery is suggestive that commonly used manufacturing additives such as PBDEs and possibly other undisclosed but hazardous components may exist in e-cigarette aerosols as well as other electrical devices capable of generating aerosols for direct human inhalation. Such devices possibly include but are not limited to inhalators, face steamers and nebulizers. Exposure to PBDEs from vaping is avoidable if e-cigarette manufacturers can adopt clean production principles and eliminate as far as possible known hazardous substances such as PBDEs in their products. This can be achieved by using less toxic flame retardants and have their health risks duly assessed before extensive application so that unintended adverse health and environmental impact from using these products can be much reduced. Such a material change in manufacturing will also reduce the environmental loadings of PBDEs in terms of industrial emission during manufacturing and end-of-life e-cigarette waste. To this end, there is the obvious need for regulatory actions on the manufacturing, storage, recycling and disposal of e-cigarette (Lerner, et al. 2015).

Third, tests should be performed on the aerosols used in other medical and beauty electrical devices and determine whether PBDEs and/or other potentially hazardous substances are also being generated from those devices. Appropriate regulatory action should be taken on the raw materials and/or additives used in the manufacturing of these electrical devices if significant levels of PBDEs and/or other potentially hazardous substances are found.

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