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Hazardous waste status of discarded electronic cigarettes

Max J. Krause, Timothy G. Townsend *

Department of Environmental Engineering Sciences, University of Florida, 220 Black Hall, Gainesville, FL 32611, USA

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ABSTRACT

The potential for disposable electronic cigarettes (e-cigarettes) to be classified as hazardous waste was investigated. The Toxicity Characteristic Leaching Procedure (TCLP) was performed on 23 disposable e-cigarettes in a preliminary survey of metal leaching. Based on these results, four e-cigarette products were selected for replicate analysis by TCLP and the California Waste Extraction Test (WET). Lead was measured in leachate as high as 50 mg/L by WET and 40 mg/L by TCLP. Regulatory thresholds were exceeded by two of 15 products tested in total. Therefore, some e-cigarettes would be toxicity characteristic (TC) hazardous waste but a majority would not. When disposed in the unused form, e-cigarettes containing nicotine juice would be commercial chemical products (CCP) and would, in the United States (US), be considered a listed hazardous waste (P075). While household waste is exempt from hazardous waste regulation, there are many instances in which such waste would be subject to regulation. Manufactures and retailers with unused or expired e-cigarettes or nicotine juice solution would be required to manage these as hazardous waste upon disposal. Current regulations and policies regarding the availability of nicotine-containing e-cigarettes worldwide were reviewed. Despite their small size, disposable e-cigarettes are consumed and discarded much more quickly than typical electronics, which may become a growing concern for waste managers.

1. Introduction

As new products are introduced and marketed, generators and regulatory agencies face the challenge of determining appropriate end-of-life regulatory status. For example, discarded electronic devices are often classified as regulated hazardous waste (Townsend, 2011). Electronic cigarettes (e-cigarettes) represent one type of an electronic product that has seen a great increase in use in recent years (Benowitz and Goniewicz, 2013). The units are shaped like a cigarette and contain a battery that heats a filament to vaporize liquid nicotine in a cartridge (Grana et al., 2014). Some devices are disposable, meant for a single use, while others may last as long as one year with nicotine solution (called "juice") refills. Distributors advertise them as an alternative to conventional cigarettes, as opposed to smoking cessation tools which in the US avoids more stringent regulation by the Food and Drug Administration (FDA) (Sottera, Inc. vs. FDA, 2010). Some countries classify them as medicines, while others prohibit the importation or sale of these electronic nicotine delivery systems (ENDS) (Baker, 2013). Proponents promote e-cigarettes as a safer alternative to conventional cigarettes, but their emergence and widespread popularity has outpaced understanding of the scientific and regulatory impacts of these new electronic products.

Disposable e-cigarettes are generally discarded as a single item, but they contain multiple components: the battery, liquid container, and atomizer (Franck et al., 2014). They are uniform in shape and size, and the various products contain essentially the same configuration of components (Grana et al., 2014). E-cigarettes are similar to other small, battery-powered devices such as digital watches or medical devices currently classified as waste electrical and electronic equipment (WEEE) in the European Union (EU) (European Parliament, 2012). It is the intention of regulations such as the Restriction of Hazardous Substances (RoHS) Directive to cause fewer devices to trigger hazardous waste classification based on current regulatory criteria (European Parliament, 2011).

While no data have been reported regarding the disposal issues surrounding e-cigarettes, some research on chemical content and exposure during use has been conducted. Because an e-cigarette user inhales vaporized nicotine juice, concerns regarding the chemicals contained within the products and the quality of the manufacturing process have been raised. E-cigarette nicotine juice has been previously analyzed for impurities (Bahl et al., 2012; Etter

Abbreviations: E-cigarette, electronic cigarette; ENDS, electronic nicotine delivery systems.

* Corresponding author. Tel.: +1 (352) 392 0846; fax: +1 (352) 392 3394.
E-mail address: ttown@ufl.edu (T.G. Townsend).

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et al., 2013; Trehy et al., 2011; Westenberger, 2009), as has the composition of the emitted vapor (Goniewicz et al., 2014a; Ingebrethsen et al., 2012; McAuley et al., 2012; Williams et al., 2013). Goniewicz et al. (2014a) measured 0.03–0.57 μg of lead per e-cigarette in emitted vapor. Williams et al. (2013) found metals (e.g. lead, nickel, and silver), silicate beads, and nanoparticles in e-cigarette aerosol.

The US Environmental Protection Agency (EPA) Toxicity Characteristic Leaching Procedure (TCLP, EPA Method 1311) is the analytical method used to determine whether a solid waste meets the definition of hazardous waste based on the toxicity characteristic (TC; i.e. target constituents leach at concentrations above specified thresholds) (US EPA, 1992). US federal regulations also provide a list of chemicals that can cause discarded commercial chemical products (CCPs) to be classified as hazardous waste if that unused chemical is the sole active ingredient; nicotine is included on this list (US Congress, 1980a). While most US states regulate waste in an identical manner as the federal rules, some states have adopted additional, more stringent standards. California, for example, requires a separate leaching experiment known as the California Waste Extraction Test (WET) as part of hazardous waste determination (California Code of Regulations, 1985).

E-cigarettes have fast gained a wide audience because of their perception as a safer alternative to conventional cigarettes, but their impact on waste management systems is unknown. In this study, the potential for e-cigarettes to exceed regulatory thresholds for hazardous waste when discarded was examined using toxicity hazardous waste determinants TCLP and WET. Discarded e-cigarettes would be much smaller by mass than most other WEEE; however, it can be assumed their frequency of consumption and disposal would be much greater as well. Therefore, knowledge of leaching behavior and the potential for hazardous waste generation is needed at the local and national level. While the test results presented here specifically address US regulatory classification, the results will provide benefit to those in other regulatory agencies facing a similar question. An added regulatory complication encountered with e-cigarettes not seen in other WEEE is the presence of the liquid nicotine juice, and this issue is discussed within the context of current regulation and policies worldwide.

2. Materials and methods

2.1. Experimental strategy

A total of 51 e-cigarettes were examined by TCLP and WET in two phases of research. The purpose of the testing was to provide a broad indication of whether these devices had the potential to be hazardous waste in the US (and thus merit additional testing or evaluation), not to assess the hazardous waste status of any one product. E-cigarettes were purchased from convenience stores in the vicinity of Gainesville, FL, USA, as well as through online vendors to test a variety of manufacturers with a range of nicotine strengths (e.g. 1.6 mg nicotine, 2.4% nicotine, etc.) and flavors (e.g. tobacco, menthol, blueberry, etc.). TCLP was performed on 23 e-cigarette samples in a preliminary survey of disposable e-cigarette products, representing 15 unique products from eight national and regional manufacturers or distributors (as labeled on the packaging).

Four products were selected for further testing based on the results of the preliminary survey of e-cigarette leaching. Replicates of the four products were used to examine repeatability of the WET and TCLP on individual e-cigarettes and to compare the results of the two leaching methods. Along with the heavy metals arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver, the presence of copper, iron, nickel, and zinc were measured. California regulations include copper, nickel, and zinc as additional metals with a toxicity characteristic concentration; they are not included on the US federal list of TC metals (California Code of Regulations, 1985; US EPA, 1992).

While the TCLP typically requires 100 g of material (50 g for WET), the batch-leaching process was scaled down to examine each of the products individually. E-cigarette samples weighed an average of 10 grams. A 20:1 liquid:solid (*L*:*S*) ratio was maintained based on each individual sample weight (i.e. 200 mL solution:10 g e-cigarette). Other researchers have scaled TCLP sample size and extraction vessel in a similar manner to maintain a 20:1 *L*:*S* ratio (Musson et al., 2006; Vann et al., 2006b).

2.2. Leaching experiments: TCLP and WET

TCLP results from the preliminary survey were used to select 4 products to test the repeatability of the leaching experiments and compare the results of two hazardous waste leaching tests. Two products leaching elevated ($x > 1$ mg/L) amounts of lead and two products leaching undetectable ($x < 0.004$ mg/L) amounts of lead were selected for replicate analysis by TCLP and WET. These products were selected to determine the repeatability of the experiments on e-cigarettes, as well as to compare results from two hazardous waste leaching methods, which has not been documented previously. The TCLP and California WET were performed on the four disposable e-cigarette products (Samples A, B, C, and D) in triplicate (TCLP) and quadruplicate (WET). All samples were consumed of their nicotine juice and milled (Fritsch Pulverisette 25) to pass a 9.5 mm (TCLP) or 2 mm sieve (WET). Because of the small particle size required by WET and due to the design of the samples and the mill, some portions of each sample could not be further size-reduced. The mass of the non-reduced portions were noted for each applicable sample and the entire e-cigarette was used in the leaching experiment.

For all products leached by TCLP, extraction solution #1 was used in the experiment. Samples were rotated for 18 ± 2 h in high-density polyethylene extraction vessels (Fisher), then vacuum filtered with acid-washed glass fiber filters (Whatman). Control blanks were also digested. Final extract pH ranged from 4.79 to 6.16. Extracts were digested and acidified below pH 2.0 with nitric acid for sample preservation. Samples were stored at 4 °C until analysis. Samples were analyzed by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES, iCAP 6000 Thermo Scientific).

WET extraction solution and samples were placed in high-density polyethylene bottles in a 10:1 (*L*:*S*) ratio and the solutions were purged with nitrogen gas for 15 min before extraction. WET samples were rotated for 48 h. Final liquid extraction pH ranged from 5.85 to 9.91. Samples were filtered with a 0.45 μm membrane filter and acidified to 5% nitric acid by volume. Extract samples were analyzed by ICP-AES.

WET is generally regarded as a more aggressive test than TCLP because of the properties of the citric acid reagent, the lower liquid to solid ratio (10:1), the smaller particle size (<2 mm), and the longer extraction time (48 h). The Soluble Threshold Limit Concentration (STLC) are the regulatory limits that WET extract concentrations are compared to determine hazardous waste status. Values that exceed the STLC are considered hazardous waste in California (California Code of Regulations, 1985).

3. Hazardous waste leaching test results

3.1. Preliminary survey TCLP results

Among all samples in the preliminary survey, barium was observed from 0.067 to 0.532 mg/L (data not shown). Chromium leached from below detection limits to 0.175 mg/L. Arsenic, cadmium, mercury, selenium, and silver were not detected. Identical products (e-cigarette B) leached 20.5, 1.10, and 7.34 mg lead/L. Replicates of e-cigarette D leached 0.22 and 0.97 mg lead/L as well as 4.99 and 5.20 mg nickel/L. Eleven of the 23 e-cigarettes leached undetectable amounts of lead. The pH of the extracts was mildly acidic (pH 5.00–5.65), similar to the initial pH of the TCLP solution (4.93 ± 0.05).

3.2. TCLP and WET leaching results

Among all replicate samples, chromium TCLP extracts (0.062–1.28 mg/L) were generally half the concentration of WET extracts (0.559–2.58 mg/L). Lead was below detection limits for 11 of the WET samples (16 total) and 6 TCLP samples (12 total). Table 1 includes the leaching results for the four e-cigarettes (A, B, C, and D) in triplicate (TCLP) and quadruplicate (WET), as well as the regulatory thresholds for constituents of concern and iron. The "W" or "T" preceding the sample ID indicates the test method (e.g. TA-1 represents TCLP of e-cigarette A, replicate 1).

E-cigarette products B and D, which leached the greatest concentrations of lead in the preliminary survey, again leached lead above the regulatory thresholds. E-cigarette B exceeded the TC limit in only one of three replicates and did not exceed the STLC. However, e-cigarette D exceeded both the TC limit (2 of 3 replicates) and the STLC (2 of 4 replicates). Lead was not detected among extracts with a pH above 7, but many extracts below 7 were also found to contain undetectable amounts of lead. Samples A and C did not leach detectable amounts of lead.

The large variance of lead leaching in these samples may perhaps be attributed to the different manufacturing production lots, which were noted in the laboratory analysis but not presented here. WD-2 (3.50 mg lead/L), WD-3 (47.8 mg lead/L) WD-4 (39.5 mg lead/L), TD-1 (29.0 mg lead /L), and TD-3 (39.0 mg lead/L) were from the same production lot, while WD-1 (<0.004 mg lead/L) and TD-2 (0.979 mg lead/L) were from a different production lot. The samples leaching the three highest concentrations of lead were from the same manufacturer. The results suggest that lead content varies among manufacturers of e-cigarette products, and that some will likely not be characterized as a hazardous waste upon disposal while others will.

Chromium was measured many times near or above 1 mg/L. However, neither the TC limit nor the STLC for chromium (5 mg/L) was exceeded by any sample. The observation of chromium leaching in greater concentrations in WET relative to TCLP is consistent with published literature (Kang et al., 2013; Lincoln et al., 2007). Nickel and copper leached greater concentrations in TCLP than WET despite the greater liquid-to-solid ratio. Copper was found in many TCLP samples above 10 mg/L, but was not near the STLC (25 mg/L). Chromium, iron, lead, and zinc leached more in WET experiments. Among all four e-cigarette products, iron leached nearly an order of magnitude greater from WET than by TCLP. Vann et al. (2006a) found that the presence of zinc or iron in leachate reduces lead solubility, however no discernable trend was observed here.

Table 1
Concentrations of leached metals from e-cigarettes by TCLP and WET.

Sample ID[a]	Chromium (mg/L)	Copper	Iron	Lead	Nickel	Zinc
WA-1	1.61	0.830	110	<0.004	1.11	24.6
WA-2	0.928	<0.002	25.7	<0.004	0.880	7.99
WA-3	0.899	<0.002	34.8	<0.004	0.810	8.89
WA-4	1.17	0.290	32.9	<0.004	0.830	6.22
WB-1	1.67	0.380	24.3	0.727	0.930	1.97
WB-2	1.12	<0.002	25.7	<0.004	0.450	5.39
WB-3	1.57	<0.002	41.1	1.55	0.900	4.49
WB-4	2.58	0.100	41.0	<0.004	1.23	4.17
WC-1	1.14	0.580	25.4	<0.004	0.800	8.02
WC-2	0.586	<0.002	260	<0.004	0.280	8.16
WC-3	0.738	0.050	34.3	<0.004	0.950	8.51
WC-4	0.559	0.120	42.2	<0.004	0.910	7.55
WD-1	1.08	1.54	16.6	<0.004	3.48	8.64
WD-2	0.969	<0.002	22.4	3.50	4.92	10.9
WD-3	1.04	1.27	19.8	**47.8**	7.91	10.4
WD-4	0.672	4.01	20.1	**39.5**	1.85	5.22
TA-1	0.123	10.3	0.548	<0.004	1.70	2.30
TA-2	0.062	12.9	2.47	<0.004	0.454	2.58
TA-3	0.193	0.857	2.63	<0.004	1.32	1.24
TB-1	1.28	2.55	21.7	**19.6**	0.599	1.27
TB-2	1.13	1.55	27.9	0.180	0.547	3.39
TB-3	0.659	13.8	15.2	3.40	1.84	1.95
TC-1	0.238	15.7	6.21	<0.004	0.798	3.03
TC-2	0.585	2.13	6.52	<0.004	0.513	2.72
TC-3	0.306	0.703	34.6	<0.004	0.864	9.60
TD-1	0.116	0.928	4.19	**29.0**	1.18	3.91
TD-2	0.184	12.9	10.8	1.04	5.43	10.4
TD-3	0.519	0.952	13.6	**39.0**	2.78	4.10
TC Limit	5	–	–	5	–	–
STLC	5	25	–	5	20	250

[a] W and T identify WET or TCLP samples, respectively. Data in bold exceed the regulatory limit.

4. Hazardous waste analysis

4.1. Potential for hazardous waste classification

Although household wastes are excluded from the definition of hazardous waste under US federal rules, knowledge of the potential for consumer electronic products to trigger hazardous waste limits is important because (i) some US states (e.g. California) do not adopt this exclusion, (ii) products discarded from non-household sources (e.g. outdated or unwanted products from a business entity) are not excluded, and (iii) local governments often target household hazardous wastes (HHW) for collection and management as hazardous waste.

Several researchers have examined electronic wastes (e-waste) and their potential to be regulatory hazardous waste using the TCLP and other leaching methods (Musson et al., 2000, 2006; Jang and Townsend, 2003; Vann et al., 2006a, 2006b; Lincoln et al., 2007; Kang et al., 2013). In general, lead is the element most likely to cause e-waste to characterize as hazardous in the US, with the propensity for elevated lead leaching tied to both the amount of lead present and ferrous metal content (Vann et al., 2006a). While some research indicates TCLP may not be the most appropriate method to test metals mobility in landfills (Visvanthan et al., 2010), it is the current federal requirement for TC hazardous waste determination in the US.

Unlike this study, WEEE have previously been shown to leach greater concentrations of lead from TCLP than from WET (Jang and Townsend, 2003; Lincoln et al., 2007; Yadav and Yadav, 2014). This may be due to a higher affinity of lead for the acetate ion found in the TCLP extract solution. Zinc and iron concentrations were greater in WET extracts than the TCLP digestates, however this did not impact lead leachability as has been shown previously (Vann et al., 2006b).

Lead was the only element for which regulatory thresholds were exceeded and those exceedances were 1.5–10 times the threshold. Leached lead concentrations were similar to those found in other e-waste such as remotes, toys (Musson et al., 2006), and cellular phones (Lincoln et al., 2007; Yadav and Yadav, 2014), but less than cathode ray tubes (CRT) or printed wire boards (PWB) (Jang and Townsend, 2003; Keith et al., 2008). However, there

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was more observed variation of lead leaching among the products and brands than other WEEE. Table 2 reviews leached lead and chromium values observed in e-cigarettes and other e-wastes by TCLP and WET.

As with many other WEEE, lead is the only element likely to cause e-cigarettes to be classified as a TC waste (Musson et al., 2006; Vann et al., 2006a, 2006b). The sources of lead were not explored in this study, though it is likely that the lead occurs in the battery, solder, or both. However, in their analysis, Williams et al. (2013) did not detect lead in the solder joints of e-cigarettes. Leaded solder and batteries are manufacturing components the RoHS targets, and would be subject to hazardous waste regulations within the EU (European Parliament, 2011).

4.2. The role of nicotine in hazardous waste classification

As introduced earlier, a unique feature of e-cigarettes relative to other WEEE is the presence of a nicotine solution. Under the US hazardous waste regulatory system, when unused nicotine is present as the sole active ingredient in a discarded CCP, the CCP is classified as a listed hazardous waste (unless otherwise excluded). Nicotine and propylene glycol (and in some cases vegetable glycerin) are the primary components of e-cigarette juice, along with flavorings (Grana et al., 2014). Nicotine is the sole active ingredient with respect to the intended purpose of the juice. The juice is found in disposable e-cigarettes and is also sold separately for reusable e-cigarettes. Large quantities of nicotine juice are held at retail locations and users typically purchase small (10–250 mL) bottles to refill their e-cigarettes at home.

A CCP is defined as an unused chemical product or intermediate, which includes products not typically considered to be chemicals (e.g. circuit boards or batteries) (US Congress, 1980a). The EPA has previously stated that unused, discarded nicotine products (e.g. gum, patches and inhalers) must be treated as hazardous waste (US EPA, 2010). When nicotine is the sole active ingredient in a discarded CCP, the product is considered an acutely hazardous waste by the EPA (US Congress, 1980a). Nicotine can be defined as a CCP when given in discrete dosages, such as prescription patches, inhalers or gum (US EPA, 2010). Disposable e-cigarettes and nicotine juice deliver a specified dosage (e.g. 1.6 mg/e-cigarette or 18 mg/mL) of the listed chemical. CCPs are not process-specific and are intended to be completely consumed during their use. Once a product has been consumed, the sole active ingredient has been exhausted and the delivery system (patch, gum, inhaler, etc.) is no longer a hazardous waste under federal regulation, but may be held to more stringent standards according to state law. The state of Washington, for example, regards used nicotine containers (inhalers and patches) as state-only hazardous wastes (Washington Department of Ecology, 2011), while Florida does not (Florida Department of Environmental Protection, 2009).

E-cigarettes discarded after their intended use would not be considered a CCP, thus would not be a hazardous waste under US federal rules (though they still might be TC hazardous waste for lead). Unused e-cigarettes would be CCP and thus hazardous waste (unless otherwise excluded) if nicotine solution were present. Disposal of unused e-cigarettes might occur at a commercial or retail location if a specific product or flavor does not sell well, if the facility goes out of business, or if a product were to expire. Thus, in the US, when an unused nicotine product is intended to be discarded it is considered a P075 hazardous waste. P-listed wastes have more stringent management requirements than other listed wastes. Based on previous EPA communications regarding nicotine-containing products, any commercial entity wanting to discard unused nicotine juice or unused e-cigarettes containing nicotine juice would have to comply with appropriate hazardous waste regulations (US Congress, 1980a; US EPA, 2010).

4.3. Implications for discarded e-cigarette management

The TCLP and WET analysis show that some e-cigarette products have the potential to exceed hazardous waste thresholds for lead (though a majority of those tested did not); none of the other hazardous metals surpassed their respective regulatory threshold. Also noted was a wide variation between replicate analyses and among the different products. When compared to other common consumer electronics (Musson et al., 2006), e-cigarettes less frequently were characterized as hazardous waste. The results do, however, provide sufficient justification for regulatory agencies to require testing prior to making such a determination. This study was not intended to characterize any individual brand or product, rather to provide data to assess whether exceeding such thresholds was a possibility. If more detailed product testing were performed, testing on larger batches consisting of multiple devices is warranted. Potential hazardous waste characterization because of lead leaching would apply to both used and unused e-cigarettes. The nicotine solution in unused e-cigarettes would trigger characterization as a listed hazardous waste.

Most used e-cigarettes will be discarded by consumers, excluding them from the definition of hazardous waste at the US federal level, as well as within the EU (US Congress, 1980b; European Council, 1991). Under such cases, meeting the threshold for hazardous waste lead leaching (or the presence of nicotine solution in unused devices) would not have any regulatory implications. States such as California, however, have not adopted the federal US exclusion of hazardous waste for electronic products; thus any discarded e-cigarette could potentially be a hazardous waste. In addition, many municipalities target HHW for separate collection

Table 2
Comparison of e-cigarette leachate to other e-wastes.

Product	TCLP		WET		Reference
	Lead	Chromium	Lead	Chromium	
	(mg/L)				
e-cigarettes	<0.004–39.0	0.062–1.28	0.727–47.8	0.559–2.58	This study
Cellular phones	38.2–147	0.04–0.13	0.144–2.91	0.029–0.44	Lincoln et al. (2007)
Cell phone PWB	0.91–147	0.02–0.46	2.5–8.6	0.01–0.13	Yadav and Yadav (2014)
CRT	413	–	350	–	Jang and Townsend (2003)
CRT funnel	350	0.3	–	–	Keith et al. (2008)
Electronic toys	15.5	ND	–	–	Musson et al. (2006)
PWB	162		3.15		Jang and Townsend (2003)
TV remote	51.8	ND	–	–	Keith et al. (2008)

Values are averages or ranges, as presented in the original format.
ND – Not detected.

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Table 3
Status of e-cigarettes worldwide.

Country	Status	Sources
Australia, Finland, Switzerland	Cannot be sold. Personal importation and use is allowed	BAG, 2010; Baker, 2013; Finland National Institute for Health and Welfare, 2012
Singapore, Norway, Hong Kong, Thailand, Brazil, Argentina, Denmark[a], Canada, Panama, Uruguay, Colombia, New Zealand	Illegal to import and sell	Danish Health and Medicines Authority, 2012; FIC Argentina, 2011; Health Canada, 2009; Ingebrethsen et al., 2012; New Zealand Ministry of Health, 2013
United States, Italy, Germany, United Kingdom[a], France, South Korea, Poland	Legal to import and sell	Baker, 2013; Cahn, 2013; Capasso et al., 2014; Goniewicz et al., 2014b; Higher Administrative Court for the Land North Rhine-Westphalia, 2013; Lee et al., 2014

[a] Classified as medical devices.

and management as a hazardous waste regardless of regulatory exclusion, and the information presented here should provide insight to communities deciding whether to include e-cigarettes in such programs. HHW collection events and facilities in some cases collect both unused prescription medicines and WEEE, so it is possible that collection of e-cigarettes could occur at these events or locations as well. The EU promotes WEEE recycling by requiring member states to meet WEEE recycling targets (European Parliament, 2012). US Universal waste (UW) regulations provide an opportunity to collect and manage items that would normally be considered hazardous waste in a less stringent manner, providing the wastes are recycled (US Congress, 1995); recycling operations for e-cigarettes would be required, and given the relatively small size and mass of these devices, this might not be feasible.

The popularity of e-cigarettes has created a new and unique stream of nicotine-containing products. Because the technology is fairly new, regulation of ENDS is being debated in many countries (Benowitz and Goniewicz, 2013). Much of the discussion is in regards to the management and sale of nicotine, which in many countries, is exclusively considered a medicine. Table 3 highlights the status of e-cigarettes in several countries and the current regulatory approach taken, which varies greatly even across the EU. The US does not consider e-cigarettes to be medical devices because they do not claim medical benefits (Sottera, Inc. vs. FDA, 2010). The United Kingdom recently announced that it will regulate e-cigarettes as a medicine, though they can still be sold with government regulation for non-therapeutic purposes (Baker, 2013). French courts have ruled that e-cigarettes are tobacco products and only available for sale through government-licensed vendors (Cahn, 2013). Denmark and Finland regulate nicotine as a medicine, and are not allowed to be sold without regulatory authorization (Danish Health and Medicines Authority, 2012; Finland National Institute for Health and Welfare, 2012). The EU has moved to prohibit sales of e-cigarettes and other nicotine-containing products not licensed as medicines (European Commission, 2014), though dates for compliance have not yet been established. The World Health Organization (WHO) does not endorse the product as a smoking cessation tool and recommends they be regulated as ENDS, not as tobacco products (WHO, 2009).

5. Conclusions

Disposable e-cigarette extracts from 8 national and regional brands constituting 15 unique products were analyzed for heavy metals by ICP-AES following TCLP and WET. Two of the twenty three samples of the preliminary survey exceeded the TC limit for lead. Replicate analysis of four disposable e-cigarettes found that two products (5 samples) exceeded the TC limit and/or the STLC for lead; these products represented the same brands as those demonstrating higher lead leaching in the preliminary survey. Thus, of the 15 products tested, two exceeded regulatory thresholds. No samples exceeded TC limits or STLC for any other metal. The results indicate that some e-cigarettes may be classified as TC hazardous waste for lead leaching, though it is likely that a majority will not. A large degree of variability was observed among brands and products, suggesting that additional testing, if desired, should be conducted on larger aggregated sample masses consisting of multiple devices. The frequency of lead leaching greater than hazardous waste thresholds was lower for the e-cigarettes tested relative to other reported values for WEEE. However, the rate of consumption and disposal of these products is assumed to be higher than many other electronic products. There are no published data regarding the amount of disposable e-cigarettes that are sold in the US or internationally. Such data would be valuable to understand the magnitude of this new waste stream and assist regulators regarding management tactics.

Since discarded CCPs containing unused nicotine are regulated as listed wastes under the US regulatory system, unused e-cigarettes containing nicotine juice (and containers of the nicotine juice itself) would be similarly regulated. This has implications for retailers that sell disposable e-cigarettes as well as nicotine juice for reusable e-cigarettes which are both widely sold in convenience stores and malls across the country. The US EPA has previously interpreted that unused patches, inhalers, or gum containing nicotine intended for disposal would be considered hazardous waste and subject to regulation. Discarded e-cigarettes that were used for their intended purpose would not be listed wastes, but may be regulated in a more stringent manner at the local level. Guidance from both national and local regulators will help determine the most appropriate waste management practices for e-cigarettes.

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References

BAG, 2010. Lettre d'information no 146: Cigarettes électroniques. <http://www.stop-tabac.ch/fra/images/stories/documents_stop_tabac/vs_is_146_f.pdf> (accessed 10.07.13).
Bahl, V., Lin, S., Xu, N., Davis, B., Wang, Y., Talbot, P., 2012. Comparison of electronic cigarette refill fluid cytotoxicity using embryonic and adult models. Reprod. Toxicol. 34, 529–537.
Baker, H., 2013. Regulation of electronic cigarettes. Lancet Oncol. 14, e301.
Benowitz, N.L., Goniewicz, M.L., 2013. The regulatory challenge of electronic cigarettes. JAMA 310, 685–686.
Cahn, Z., 2013. France acts on electronic cigarettes. J. Public Health Policy 34, 560–564.
California Code of Regulations, 1985. 22 CCR §66261.101 California Waste Extraction Test.
Capasso, L., Gualano, M.R., Flacco, M.E., Siliquini, R., Manzoli, L., 2014. E-cigarette regulations in Italy: fluctuating and confusing. Lancet 383, 1883.

Danish Health and Medicines Authority, 2012. Classification of electronic cigarettes. <http://sundhedsstyrelsen.dk/en/medicines/regulation/definition-of-a-medicine/special-classifications/electronic-cigarettes> (accessed 03.12.14).

Etter, J.-F., Zäther, E., Svensson, S., 2013. Analysis of refill liquids for electronic cigarettes. Addiction 108, 1671–1679.

European Commission, 2014. Directive 2014/40/EU of the European Parliament and of the Council of 3 April 2014 on the approximation of the laws, regulations and administrative provisions of the Member States concerning the manufacture, presentation and sale of tobacco and related products. Off. J. Eur. Union L 127, 1–38.

European Council, 1991. Council Directive 91/689/EEC of 12 December 1991 on hazardous waste. Off. J. Eur. Comm. L 377, 20–27.

European Parliament, 2011. Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast). Off. J. Eur. Union L 174, 88–110.

European Parliament, 2012. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (recast). Off. J. Eur. Union L 197, 38–71.

FIC Argentina, 2011. The ANMAT banned electronic cigarette sales. FIC Press Release. <http://www.ficargentina.org/index.php?option=com_content&view=article&id=92:la-anmat-prohibio-el-cigarrillo-electronico-en-argentina&catid=61:archivo-de-noticias&Itemid=17&lang=en> (accessed 10.07.13).

Finland National Institute for Health and Welfare, 2012. Insufficient knowledge of health effects of electronic cigarettes. Press Release. <http://www.thl.fi/en_US/web/en/pressrelease?id=28616> (accessed 10.07.13).

Florida Department of Environmental Protection, 2009. Pharmaceutical Waste Guidance. <http://www.dep.state.fl.us/waste/pharm/documents/Waste-Pharm-Guidance_26Mar09.pdf> (accessed 10.10.13).

Franck, C., Budlovsky, T., Windle, S.B., Filion, K.B., Eisenberg, M.J., 2014. Electronic cigarettes in North America: history, use, and implications for smoking cessation. Circulation 129, 1945–1952.

Goniewicz, M.L., Knysak, J., Gawron, M., Kosmider, L., Sobczak, A., Kurek, J., Prokopowicz, A., Jablonska-Czapla, M., Rosik-Dulewska, C., Havel, C., Jacob, P., Benowitz, N., 2014a. Levels of selected carcinogens and toxicants in vapour from electronic cigarettes. Tob. Control 23, 133–139.

Goniewicz, M.L., Kosmider, L., Delijewski, M., Knysak, J., Ochota, P., Sobczak, A., 2014b. The impact of the 2010 polish smoke-free legislation on the popularity and sales of electronic cigarettes. Eur. J. Public Health 24, 471–473.

Grana, R., Benowitz, N., Glantz, S.A., 2014. E-cigarettes: a scientific review. Circulation 129, 1972–1986.

Health Canada, 2009. To All Persons Interested in Importing, Advertising or Selling Electronic Smoking Products in Canada. Drugs Heal. Prod. <http://www.hc-sc.gc.ca/dhp-mps/prodpharma/applic-demande/pol/notice_avis_e-cig-eng.php> (accessed 10.07.13).

Higher Administrative Court for the Land North Rhine-Westphalia, 2013. The e-cigarette is not a drug (translated). Press Release. <http://www.ovg.nrw.de/presse/pressemitteilungen/01_archiv/2013/27_130917/index.php> (accessed 10.07.13).

Ingebrethsen, B.J., Cole, S.K., Alderman, S.L., 2012. Electronic cigarette aerosol particle size distribution measurements. Inhal. Toxicol. 24, 976–984.

Jang, Y.-C., Townsend, T.G., 2003. Leaching of lead from computer printed wire boards and cathode ray tubes by municipal solid waste landfill leachates. Environ. Sci. Technol. 37, 4778–4784.

Kang, D.H.P., Chen, M., Ogunseitan, O.A., 2013. Potential environmental and human health impacts of rechargeable lithium batteries in electronic waste. Environ. Sci. Technol. 47, 5495–5503.

Keith, A., Keesling, K., Fitzwater, K.K., Pichtel, J., Houy, D., 2008. Assessment of Pb, Cd, Cr and Ag leaching from electronics waste using four extraction methods. J. Environ. Sci. Health. A. Tox. Hazard. Subst. Environ. Eng. 43, 1717–1724.

Lee, S., Grana, R.A., Glantz, S.A., 2014. Electronic cigarette use among Korean adolescents: a cross-sectional study of market penetration, dual use, and relationship to quit attempts and former smoking. J. Adoles. Health 54, 684–690.

Lincoln, J.D., Ogunseitan, O.A., Shapiro, A.A., Saphores, J.-D.M., 2007. Leaching assessments of hazardous materials in cellular telephones. Environ. Sci. Technol. 41, 2572–2578.

McAuley, T.R., Hopke, P.K., Zhao, J., Babaian, S., 2012. Comparison of the effects of e-cigarette vapor and cigarette smoke on indoor air quality. Inhal. Toxicol. 24, 850–857.

Musson, S.E., Jang, Y.-C., Townsend, T.G., Chung, I.-H., 2000. Characterization of lead leachability from cathode ray tubes using the toxicity characteristic leaching procedure. Environ. Sci. Technol. 34, 4376–4381.

Musson, S.E., Vann, K.N., Jang, Y.-C., Mutha, S., Jordan, A., Pearson, B., Townsend, T.G., 2006. RCRA toxicity characterization of discarded electronic devices. Environ. Sci. Technol. 40, 2721–2726.

New Zealand Ministry of Health, 2013. Electronic Nicotine Delivery Systems (ENDS), including E-cigarettes. <http://www.health.govt.nz/our-work/preventative-health-wellness/tobacco-control/electronic-nicotine-delivery-systems-ends-including-e-cigarettes> (accessed 10.07.13).

Sottera Inc. vs. FDA, 2010. 627 F.3d 891. USA.

Townsend, T.G., 2011. Environmental issues and management strategies for waste electronic and electrical equipment. J. Air Waste Manage. Assoc. 61, 587–610.

Trehy, M.L., Ye, W., Hadwiger, M.E., Moore, T.W., Allgire, J.F., Woodruff, J.T., Ahadi, S.S., Black, J.C., Westenberger, B.J., 2011. Analysis of electronic cigarette cartridges, refill solutions, and smoke for nicotine and nicotine related impurities. J. Liq. Chromatogr. Relat. Technol. 34, 1442–1458.

US Congress, 1980a. 40 CFR §261.33 Discarded commercial chemical products, off-specification species, container residues, and spill residues thereof. <http://www.ecfr.gov/>. USA.

US Congress, 1980b. 40 CFR §261.4(b) Exclusions. <http://www.ecfr.gov/>. USA.

US Congress, 1995. 40 CFR §273 Standards for Universal Waste Management. <http://www.ecfr.gov/>. USA.

US EPA, 1992. Method 1311 Toxicity Characteristic Leaching Procedure, Test Methods for Evaluating Solid Waste (SW-846).

US EPA, 2010. Unused discarded nicotine patches, gum and lozenges are P075; used discarded nicotine patches are not P075. Management of Hazardous Waste Pharmaceuticals. <http://www.epa.gov/wastes/hazard/generation/pharmaceuticals.htm> (accessed 09.23.13).

Vann, K.N., Musson, S.E., Townsend, T.G., 2006a. Factors affecting TCLP lead leachability from computer CPUs. Waste Manage. 26, 293–298.

Vann, K.N., Musson, S.E., Townsend, T.G., 2006b. Evaluation of a modified TCLP methodology for RCRA toxicity characterization of computer CPUs. J. Hazard. Mater. 129, 101–109.

Visvanthan, C., Yin, N.H., Karthikeyan, O.P., 2010. Co-disposal of electronic waste with municipal solid waste in bioreactor landfills. Waste Manage. 30, 2608–2614.

Washington Department of Ecology, 2011. Designation of waste nicotine. Pharmaceuticals. <http://www.ecy.wa.gov/programs/hwtr/pharmaceuticals/pages/nicotine.html> (accessed 09.23.13).

Westenberger, B.J., 2009. Evaluation of e-cigarettes. FDA. <http://www.fda.gov/downloads/Drugs/ScienceResearch/UCM173250.pdf> (accessed 09.23.13).

WHO, 2009. Report on the Scientific Basis of Tobacco Product Regulation: Third Report of a WHO Study Group. WHO Technical Report Series No. 955.

Williams, M., Villarreal, A., Bozhilov, K., Lin, S., Talbot, P., 2013. Metal and silicate particles including nanoparticles are present in electronic cigarette cartomizer fluid and aerosol. PLoS ONE 8, e57987.

Yadav, S., Yadav, S., 2014. Investigations of metal leaching from mobile phone parts using TCLP and WET methods. J. Environ. Manage. 144, 101–107.

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