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Hazardous waste status of discarded electronic cigarettes

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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.

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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