E-Cigarettes
A Hazy Hazard

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The surge in use of electronic cigarettes (e-cigarettes or e-cigs) has raised many questions for OSH professionals as to whether use of such products should be allowed in the workplace. After all, if these are smoking-cessation devices, should we not encourage employees to quit smoking through use of these devices? What is the harm? Is it not just water vapor?

E-cigarettes were originally designed in 1963 by Herbert Gilbert and patented in 1965 as a smokeless nontobacco cigarette intended to provide a harmless means of smoking (U.S. Patent No. 3,200,819 A, 1965). Researchers estimated some 460 different brands and more than 7,700 unique flavors were on the market as of January 2014 (Zhu, Sun, Bonnevie, et al., 2014), and the numbers have likely increased since. U.S. e-cigarette sales were estimated at $2.2 billion in 2014 (Rigotti, 2015) with an expected annual growth of more than 50% for the foreseeable future (Mickle, 2015).

While configurations of these devices have evolved through many generations, the typical components include a fluid-filled reservoir, which contains the liquid e-fluid or e-juice to be vaporized, an atomizer (heating coil) to vaporize the liquid and a battery (typically lithium) to power the atomizer. First-generation e-cigarettes resemble traditional cigarettes; second-generation devices have a distinct reservoir tank and larger battery; third-generation e-cigarettes are fully modifiable by the user, often to increase vaping power, output and battery life (Floyd, Aryal, Wang, et al., 2017). The intent is for users to inhale nicotine or flavored vapors without the cancer risks associated with traditional tobacco cigarette use because the devices have no combustion source or tobacco, which forms cancer-causing by-products when burned, (Maron, 2014).

Components & By-Products

The primary components of most e-juices are propylene glycol and/or vegetable glycerin (glycerol). These are used as delivery vehicles for the nicotine and flavorings, and to create a vapor cloud that is exhaled by the user (Riker, Lee, Darville, et al., 2012). Several studies have measured varying ranges of airborne propylene glycol concentrations from e-cigarette use and reported that exposures vary depending on types and numbers of e-cigarettes used, room size and ventilation rates.

Pellegrino, Tinghino, Mangiaracina, et al. (2012), measured propylene glycol concentrations of 1,650 to 1,600 mg/m^3 and 580 to 610 mg/m^3 of glycerin in the vapor emitted from e-cigarettes. Schober, Szendrei, Batzen, et al. (2013), show ranges of propylene glycol from 110 to 215 µg/m^3 and glycerin in the range of 59 to 81 µg/m^3 in the gas phase of emissions. McAuley, Hopke, Zhao, et al. (2012), report airborne propylene glycol concentrations ranging from 2.25 to 120 mg/m^3. Geiss, Bianchi, Barahona, et al. (2015), estimate lung concentrations of 160 mg/m^3 for propylene glycol and 220 mg/m^3 for glycerol in users vaping traditional e-cigarette refill liquid.

In comparison, exposure to propylene glycol used in theatrical fog at concentrations ranging from 0.02 to 4.11 mg/m^3 has been found to contribute to various respiratory health issues, such as asthma, wheezing, chest tightness, decreased lung function, irritation and airway obstruction (Varughese, Teschke, Brauer, et al., 2005). AIHA's (2013) recommended workplace environmental exposure level value for propylene glycol is an 8-hour time-weighted average of 10 mg/m^3 and American Conference of Governmental Industrial Hygienists' threshold limit value (TLV) for glycerin mist is 10 mg/m^3 (OSHA, 2006).

Studies have shown that when glycerol is heated, such as in the coil of an e-cigarette, pyrolysis occurs; this may lead to the formation of acrolein, formaldehyde and acetaldehyde in the vapor (Geiss, et al., 2015; Goniewicz, Knysak, Gawron, et al., 2014; Uchiyama, Ohta, Inaba, et al., 2013). Formaldehyde, a recognized human carcinogen, is a known degradation product of propylene glycol and glycerol, and is found in higher airborne concentrations in e-cigarettes that operate at high voltage or that feature a variable voltage battery (Jensen, Luo, Pankow, et al., 2015). This may be

IN BRIEF

- **Electronic cigarettes (e-cigarettes, e-cigs) are battery-powered devices that deliver vaporized nicotine and other substances such as flavorings to users without smoke or combustion. They are commonly marketed as healthier alternatives to smoking and as smoking-cessation tools.**
- **A common misperception is that e-cigarettes only release water vapor. In reality, these devices release nicotine and other chemicals in a vapor form that can expose both the user and those in the immediate vicinity to the contaminants. While the health risks of using e-cigarettes are far lower than smoking regular cigarettes, many toxic compounds are still present.**
- **The rapid increase in e-cigarette use has generated concern for indoor air quality because data are still limited on potential exposures and human health risks for users and others through second- and thirdhand exposure.**

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of particular concern in newer-generation e-cigarettes with adjustable voltages that allow users to generate a thicker vapor.

While these products are for personal use, if used in the workplace and found in the employer's waste stream, compliance concerns could be raised.

Nicotine

Nicotine is present in most e-liquids, including e-cigarette cartridges labeled as containing no nicotine (FDA, 2014). Typical nicotine content ranges from zero to 3.6%, although levels as high as 15% have been found in some e-liquids (Goniewicz, Gupta, Lee, et al., 2015). Health effects from exposure to nicotine are well documented and include increased heart rate, respiratory rate, blood pressure and alertness level (NIOSH, 2014). Nicotine, which is highly addictive, is a teratogen (NIOSH, 2014) and can promote tumor growth (Davis, Rizwani, Banerjee, et al., 2009). Exposure to nicotine during adolescence can affect brain development and predispose youth to future tobacco use (Leventhal, Strong, Kirkpatrick, et al., 2015; Rigotti, 2015). Ingestion or inhalation of nicotine can cause nausea, vomiting, abdominal pain, headache, dizziness, confusion, agitation and restlessness, and possible burning sensation in the mouth, throat and stomach (NIOSH, 2014). Nicotine can also readily pass into the bloodstream via dermal contact, which is of concern if e-liquid contacts the skin.

CDC (1994) uses a human oral lethal dose of 60 mg for a 154 lb (70 kg) adult (around 0.8 mg/kg), but this value has been challenged in context with the e-cigarette movement (Mayer, 2014). However, using the 0.8 mg/kg value results in a lethal dose of around 8 to 11 mg for a 22 to 31 lb (10 to 14 kg) toddler. Nicotine content measured in 15 common brands of e-liquid cartridges in one study ranged from 1.6 to 19 mg (Goniewicz, et al., 2015), spanning this potentially lethal range for small children.

According to CDC, calls related to poisoning from the liquid nicotine used in e-cigarettes ran at a rate of roughly one per month in 2010, but jumped to 215 in February 2014 (CDC, 2014). More than half of the poison center calls involved children age 5 and younger, while 42% involved people age 20 and older. Ingestion of e-liquid accounted for nearly 70% of the exposures, while dermal exposures accounted for 6% (CDC, 2014). American Association of Poison Control Centers (AAPCC, 2016) received 3,073 exposure reports to e-cigarettes and liquid nicotine in 2015. By comparison, in 2011 a total of 271 exposures were reported.

Airborne concentrations of nicotine have been detected in secondhand emissions from e-cigarettes, although the reported average concentrations found are lower than those found in secondhand tobacco smoke (Czogala, Goniewicz, Fidelus, et al., 2013; McAuley, et al., 2012). A lack of strong quality-control standards or labeling requirements compounds the potential secondhand emission concerns from e-cigarettes (Goniewicz, Kuma, Gawron, et al., 2013). Several studies have found that cartridges containing nicotine deliver varying concentrations of nicotine, in some cases two to five times greater than stated on the packaging, while other cartridges labeled as not containing nicotine have been found to contain nicotine (FDA, 2014; Goniewicz, et al., 2013).

Flavorings

A serious potential health concern is the widespread use of various flavoring agents in e-cigarettes. Manufacturers of e-liquids use various natural and artificial flavoring agents, many of which are used as flavoring in food products. Flavors such as cotton candy, bubble gum, gummy bear, apple pie, piña colada, cherry and buttered popcorn are readily available on the Internet and in retail shops. The use of commercially available flavors that imitate common foods, candies and liquors has raised concerns that these products may serve as a gateway for children and young adults to nicotine addiction and traditional cigarette use (Primack, Soneji, Stoolmiller, et al., 2015; Rigotti, 2015).

Many flavorings used in e-liquids were initially used in food products. Flavor and Extract Manufacturers Association (FEMA, 2016) maintains an independent program that evaluates the safety and generally recognized as safe (GRAS) status of substances for use as flavor ingredients in food products. However, the safety of the use of such products in e-cigarettes has not been tested or proven. A product that may be safe when ingested may not be similarly safe when inhaled. A classic example is the use of diacetyl as a buttery flavoring for popcorn and other food products. While ingestion of diacetyl is generally regarded as safe, inhalation of volatilized diacetyl has been associated with bronchiolitis obliterans, a rare and potentially fatal lung disease (Egilman & Schilling, 2012).

Intentional inhalation of some flavorings in a vapor form can be extremely hazardous. Farsalinos, Kistler, Gillman, et al. (2015), analyzed 159 samples of sweet-flavored e-cigarette liquids purchased from 36 manufacturers and retailers in seven different countries for the presence of diacetyl and acetyl propionyl (2,3-pentanedione). Both compounds are GRAS when ingested, but are associated with significant respiratory disease when inhaled. Diacetyl or acetyl propionyl were found in 74.2% of the samples, even in samples from manufacturers that clearly stated the chemicals were not present. The study authors estimate that an average user's consumption "would result in 490 times higher daily intake compared to the NIOSH [occupational exposure] limit" for diacetyl.

Allen, Flanigan, Leblanc, et al. (2015), found diacetyl in the vapor but not in the liquid of 39 of 51 different e-liquid flavors tested. Brown, Luo, Isabelle, et al. (2014), detected benzaldehyde in cherry flavoring, methyl anthranilate in grape flavoring and 1-hexanol in apple flavoring; none of these or other flavoring compounds have toxicological data on the potential health effects from inhaling the vapor form.

In addition, little research has been conducted on what type of thermal degradation products are generated by the heating and vaporizing of the myriad e-liquid flavors and combinations available. Although the science continues to expand, a wide

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knowledge gap exists on health effects from inhaling flavorings and other ingredients that have not been evaluated for inhalation toxicity or for potential thermal degradation products (AIHA, 2014).

Ultrafine Particulates

Adverse health effects from exposure to fine and ultrafine particles in ambient air pollution are well documented. Researchers have found significant associations between elevated cardiovascular and respiratory disease mortality, and exposure to fine and ultrafine particulates (Wichmann, Spix, Tuch, et al., 2000). Exposure to fine and ultrafine particulates may also exacerbate preexisting respiratory ailments, such as asthma (Sacks, Stanek, Luben, et al., 2010).

Studies have shown that e-cigarette emissions may contain large amounts of particulates ranging between 10 and 1,000 nm in size, with an average size of 400 nm (Zhang, Sumner & Chen, 2013). Schober, et al. (2013), report that $PM_{2.5}$ concentrations during vaping sessions with e-cigarette users were around 373 µg/m^3, with levels as high as 514 µg/m^3 measured during some vaping sessions. Floyd, et al. (2017), report that with newer, higher powered e-cigarettes, as power increases, a greater fraction of aerosol is in the respirable fraction (≤ 2.5 µm), however, the persistence of these particulates (i.e., half-life) in air can be short due to rapid evaporation (Bertholon, Becquemin, Roy, et al., 2013). E-cigarette aerosol, therefore, may present a new source of particulates in the indoor environment and pose a potential exposure hazard to bystanders, but further study is needed.

Second- & Thirdhand Exposure Concerns

Williams, Villarreal, Bozhilov, et al. (2013), found that aerosols generated from e-cigarettes contain tin, silver, iron, nickel, aluminum, sodium, copper, magnesium, lead, chromium, manganese, potassium, zinc, silicates and nanoparticles of tin, chromium and nickel. Other studies of exhaled aerosol have revealed the presence of nicotine, propylene glycol, glycerin, ethylbenzene, benzene, toluene, m,p-xylene, acetone, formaldehyde, acetaldehyde, acrolein, propanal, diacetin, fine/ultrafine particles and tobacco-specific nitrosamines (TSNAs) (AIHA, 2014; Farsalinos, Gillman, Poulas, et al., 2015). TSNAs are potent carcinogenic chemicals that also have been shown to form on surfaces as a reaction of deposited nicotine and ambient nitrous acid (Sleiman, Gundel, Pankow, et al., 2010). Such deposition products and by-products can present a potential hand-to-mouth exposure from touching surfaces (i.e., thirdhand exposures), which is significant in settings with young children.

Disposal Issues

In addition to exposure concerns, e-cigarettes contain lithium-ion batteries and nicotine, both of which EPA considers hazardous waste. This may pose concerns when disposing of e-cigarettes and e-liquids. EPA's (2015) proposed rule for management of hazardous waste pharmaceuticals proposes that "unused (unsold, expired or returned) nicotine-containing products, including patches, gums, lozenges, inhalers, nasal sprays and e-cigarettes, are classified as P075 listed acute hazardous wastes when discarded" (p. 58072). While these products are for personal use, if used in the workplace and found in the employer's waste stream, compliance concerns could be raised.

Safety Issues

Several incidents have been reported of explosions and fires involving e-cigarettes. The most commonly reported cause of such fires and explosions has been from the use of incorrect chargers for the lithium-ion batteries used in the e-cigarettes (U.S. Fire Administration, 2014). Unfortunately, no requirements exist for e-cigarette manufacturers regarding overcurrent or overcharge protection. This is especially significant in newer modified e-cigarettes; devices left charging may overheat, which can cause a fire or battery explosion (U.S. Fire Administration, 2014). An unfortunate consequence of the e-cigarette design is that the battery is installed in a device that has its weakest point at the ends of the device; when a battery fails, it can be "propelled across the room like a bullet or small rocket" (U.S. Fire Administration, 2014, p. 5).

Current Regulatory Status

Although nicotine is derived from tobacco, electronic cigarettes contain no tobacco and are, therefore, not automatically regulated as a tobacco product. However, Food and Drug Administration (FDA, 2017) extended its authority to regulate e-cigarettes, vape pens and hookah tobacco effective Aug. 8, 2016. FDA can require manufacturers, importers and retailers to report ingredients, place health warnings on products and advertisements, and limit sales to persons under age 18 (FDA, 2017).

In addition, various states, municipalities and other entities have adopted their own restrictions on sales and bans on the use of e-cigarettes in public places, transportation facilities, and restaurants and bars. According to American Nonsmokers' Rights Foundation (ANRF, 2017), as of April 3, 2017, 27 states have passed laws restricting the use of e-cigarettes in certain settings. Additionally, 615 cities/counties have enacted local laws restricting e-cigarette use in venues that had previously established smoking bans (ANRF, 2017). Many U.S. airlines, commuter rail lines and transit entities have also modified their no-smoking policies to specifically include e-cigarettes (AIHA, 2014).

Recommendations

AIHA (2014) examined the available research about e-cigarettes in the indoor environment. The association recommends:

> E-cigarettes should be considered a source of [volatile organic compounds] and particulates in the indoor environment that have not been thoroughly characterized or evaluated for safety. . . . Because e-cigarettes are a potential source of pollutants (such as airborne nicotine, flavor-

> ings and thermal degradation products), their use in the indoor environment should be restricted, consistent with current smoking bans, until and unless research documents that they will not significantly increase the risk of adverse health effects to room occupants. (pp. 22-23)

NIOSH recommends that employers "establish and maintain smoke-free workplaces that protect those in workplaces from involuntary, secondhand exposures to tobacco smoke and airborne emissions from e-cigarettes and other electronic nicotine delivery systems" (Castellan, Chosewood, Trout, et al., 2015, p. xi).

ANSI/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2015) clarify that the definition of environmental tobacco smoke (ETS) "includes smoke produced from the combustion of cannabis and controlled substances and the emissions produced by electronic smoking devices." It also recommends that "provision of acceptable indoor air quality is incompatible with the presence of ETS, including cannabis smoke and e-cigarette emissions" (p. 3).

World Health Organization (WHO, 2014) states that electronic nicotine delivery system (ENDS) users should be "requested not to use ENDS indoors, especially where smoking is banned, until exhaled vapor is proven to be not harmful to bystanders and reasonable evidence exists that smoke-free policy enforcement is not undermined" (p. 11).

Until more science is known about the potential hazards, scientific organizations recommend including e-cigarettes in existing smoke-free policies.

Conclusion

So what does all of this mean to the OSH professional? Until more science is known about the potential hazards, scientific organizations such as AIHA, NIOSH, ASHRAE and WHO recommend including e-cigarettes in existing smoke-free policies, thus limiting their use in the indoor environment. AIHA (2014) further recommends:

> For organizations and businesses that have smoking bans, especially those required by law, it would be advisable for them to update their bans to specifically include e-cigarettes in order to eliminate potential confusion among patrons as well as employees charged with enforcing those bans. (p. 19)

Knowing that e-cigarette emissions are not just water vapor can go a long way in helping OSH professionals understand the potential risks when establishing and enforcing employer smoking policies. **PS**

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