The Hazards of E-Cigarettes

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The prevalence of the use of e-cigarettes is increasing. E-cigarettes are marketed as an alternative to smoking tobacco that only produces harmless water vapor, with no adverse impact on indoor air quality. However, published literature seems to show that e-cigarettes are not harmless.[1] *Photo 1* shows an e-cigarette user exhaling a dense visible aerosol into the surrounding air. This visible aerosol consists of condensed submicron liquid droplets, which contain many chemicals including some that are carcinogenic, such as formaldehyde, metals (cadmium, lead, nickel), and nitrosamines.

Figure 1 is a schematic of typical e-cigarette components. E-cigarettes contain a liquid, typically propylene glycol and/or glycerol, that include varying amounts of nicotine (e.g., 0 to 36 mg/mL) as well as flavorants. A wicking material is used to transport the liquid by capillary action from a reservoir to the heater. When the user draws on the e-cigarette, a sensor detects the draw and a microprocessor activates the heater, which vaporizes the fluid to produce a saturated vapor at an elevated temperature (i.e., > 350°C [662°F] in the center of the heating unit[2]). Propylene glycol, glycerol, and nicotine are liquids with relatively high boiling points: propylene glycol (188°C [370°F]), glycerol (290°C [554°F]), and nicotine (247°C [477°F]). Consequently, the vaporized fluid immediately condenses upon leaving the heating element, forming an aerosol of submicron spherical liquid droplets with the visible appearance of smoke or fog.

PHOTO 1: E-cigarettes do not produce a vapor (gas), but rather a dense visible aerosol of liquid sub-micron droplets consisting of glycols, nicotine, and other chemicals, some of which are carcinogenic (e.g., formaldehyde, metals, nitrosamines).

While the word vapor is used to describe what e-cigarettes produce, and vaping is a term used to describe the process of inhaling from an e-cigarette, the emissions out of the mouthpiece are not actually a vapor, which is a gas, but rather they are primarily an aerosol. This aerosol consists of submicron particles of the condensed vapor of glycols containing the nicotine and flavorants. So users are not vaping, but rather they are aerosolizing.

What are the chemical emissions from e-cigarettes?
We searched through the published literature for information on the chemical emissions from e-cigarettes. We then used these chemical emissions to calculate the direct exposure to users and the indirect (passive) exposure to non-users, with usage and exposure assumptions selected to produce worst-case exposure scenarios. For both the direct and indirect exposures, we calculated the hazard quotients as the ratio of the calculated exposures to both cancer and non-cancer health exposure guidelines. Hazard quotients in excess of 1.0 indicate a health risk.

The paper by Goniewicz et. al.[3] contained the largest study of chemical emissions from e-cigarettes and forms the primary basis for our analyses. In this paper the chemical emissions of 11 chemicals, including carbonyl compounds, volatile organic compounds, tobacco specific nitrosamines, and heavy metals were measured from 12 different e-cigarettes. Each e-cigarette was tested three times. A total of 150 puffs (70 mL/puff) were directly vaporized into the analytical samplers from an e-cigarette attached to a mechanical smoking machine. For our exposure analyses we included seven of the 11 chemicals studied by Goniewicz

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et.al.,[3] that had both significant emission rates and relevant health-based exposure guidelines. Schripp et. al.[2] measured the emission rates of propylene glycol from three e-cigarettes.

Table 1 summarizes the minimum and maximum chemical emissions rates for nine chemicals in terms of mass (µg) of chemical per 150 puffs (70 mL/puff). The dominant chemical emitted was propylene glycol, with a range of 250,950 to 828,750 µg/150 puffs. The chemical with the next highest emission rate was nicotine, for which we assumed a concentration of 24 mg/mL of nicotine in propylene glycol, yielding 5,770 to 19,060 µg/150 puffs.

Are the chemical emissions from e-cigarettes a health risk? We used the maximum chemical emissions in *Table 1* to calculate the direct exposure to users and the indirect (passive) exposure to non-users, with the following usage and exposure assumptions, which were selected to produce worst-case exposure scenarios.

Direct Exposure Assessment. The median puffs/day by e-cigarette users was assumed to be 175 puffs/day with a puff volume of 70 mL/puff. The respiratory absorption of the inhaled vapor was assumed to be 100% for all compounds. We assumed a zero exposure other than the vapor that was directly inhaled (i.e., no indirect exposure).

Indirect (Passive) Exposure Assessment. We modeled exposures for a small office space (i.e., 20.9 m^2 [225 ft], 2.4 m [7.9 ft] ceiling), with a low outdoor air ventilation rate of 0.3 h-1 (assuming openable windows closed and no mechanical ventilation, so there is only outdoor air infiltration) and no contaminant removal other than ventilation. We assumed continuous occupancy for eight hours by two occupants; one e-cigarette user (125 puffs in 8 hours, 70 mL/puff) and one non-user. For this assessment we assumed that 100% of the inhaled vapor by the user was exhaled into the indoor air and the respiratory absorption by occupants of the exhaled vapor in the indoor air was 100% for all compounds. We assumed a zero exposure when away from work.

For cancer health effects we used the California Office of Environmental Health Hazard Assessment,[4] No

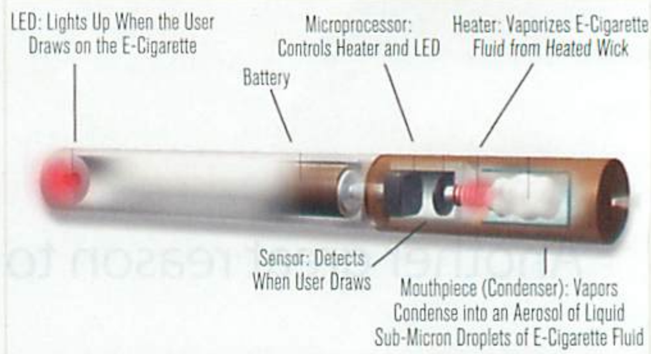

FIGURE 1: Schematic of the typical components found in an e-cigarette.

TABLE 1 Chemical emissions of selected compounds from e-cigarettes for exposure analyses.

CHEMICAL	CHEMICAL EMISSIONS (µG/150 PUFFS – 70 ML/PUFF) INDIRECT EXPOSURE	
	Minimum	Maximum
ACETALDEHYDE	2.0	13.6
ACROLEIN	<0.02	41.9
FORMALDEHYDE	3.2	56.1
CADMIUM	<0.04	0.22
LEAD	0.03	0.57
NICKEL	0.11	0.29
NICOTINE	5,770	19,060
NNK[a]	<0.0001	0.028
PROPYLENE GLYCOL	250,950	828,750

[a]NNK, 4-(n-nitrosomethylamino)-1-(3-pyridyl)1-butanone.

TABLE 2 Hazard quotients associated with the direct exposures of e-cigarette users and the indirect (passive) exposures of non-users.

CHEMICAL	EXPOSURE CRITERIA		DIRECT EXPOSURE		INDIRECT EXPOSURE	
	NSRL (µg/day)	CREL (µg/m^3)	HQ [a] NSRL	HQ [a] CREL	HQ [a] NSRL	HQ [a] CREL
ACETALDEHYDE	90	140	0.18	0.01	0.004	0.0001
ACROLEIN	N/A	0.35	N/A	**7.0**	N/A	0.17
FORMALDEHYDE	40	9	**1.64**	0.36	0.04	0.009
CADMIUM	0.05	0.02	**5.13**	0.64	0.12	0.015
LEAD	0.5	0.15	**1.33**	0.22	0.03	0.005
NICKEL	0.8	0.05	0.42	0.34	0.008	0.007
NICOTINE	N/A	5	N/A	**222**	N/A	**5.4**
NNK[b]	0.014	N/A	**2.36**	N/A	0.05	N/A
PROPYLENE GLYCOL	N/A	50	N/A	**967**	N/A	**23**

[a]Hazard quotients expressed as the ratio of the calculated exposure to the NSRL and CREL health exposure guidelines, with values above 1.0 **bolded**.
[b]NNK, 4-(n-nitrosomethylamino)-1-(3-pyridyl)1-butanone.

Significant Risk Levels (NSRLs). The NSRL is the 70 year average daily intake level calculated to result in one excess case of cancer in an exposed population of 100,000. For non-cancer health effects, we used the California Office of Environmental Health Hazard Assessment[5] Chronic Reference Exposure Guidelines (CRELs).

For propylene glycol and nicotine, which do not have established CRELs, we used 1% of the California OSHA[6] occupational eight-hour Permissible Exposure Guideline, and for lead we used the Environmental Protection Agency[7] National Ambient Air Quality Standards (NAAQS), three-month average requirement.

For both the direct and indirect exposures, we calculated the hazard quotients as the ratio of the calculated exposures to the cancer (NSRL) and non-cancer (CREL) health exposure guidelines. Hazard quotients in excess of 1.0 indicate a health risk.

Table 2 summarizes the hazard quotients associated with the direct exposures of e-cigarette users and the indirect (passive) exposures of non-users.

With respect to the NSRL hazard quotients for cancer related health effects, four of the nine chemicals analyzed exceeded 1.0 for the direct exposure to users; lead (1.33), formaldehyde (1.64), NNK (2.36), and cadmium (5.13). For the indirect exposure to non-users, the NSRL hazard quotients were all less than 1.0, with the highest, cadmium (0.12). With respect to the CREL hazard quotients for non-cancer related health effects, three of the nine chemicals analyzed exceeded 1.0 for the direct exposure to users; acrolein (7.0), nicotine (222), and propylene glycol (967). For the indirect exposure to non-users, the CREL hazard quotients also exceeded 1.0 for nicotine (5.4) and propylene glycol (23).

If we use the minimum rather than the maximum chemical emissions in *Table 1*, the modeled direct and indirect CREL hazard quotients still exceed 1.0 for propylene glycol (293 direct and 7.0 indirect) and nicotine (65 direct and 1.6 indirect).

With respect to the modeled indirect exposures, we note that while this was a worst-case exposure scenario with a low ventilation rate of 0.3 h-1, even if ventilation rates are tripled to 0.9 h-1, which exceeds ASHRAE Standard 62.1[8] default minimum ventilation of 0.78 h-1 for the modeled office space, the indirect exposures still present a significant health risk. Ventilation rates would have to be increased by a factor of 23 to mitigate the health risks for each of the nine chemicals modeled. Clearly, ventilation is not a solution and e-cigarette use will have to be regulated indoors in the same manner as is done for tobacco smoking, which is prohibited indoors.

We also note that there has been little research into the emissions of the flavorants that are added into the e-cigarette fluids. Some flavorant chemicals, such as diacetal, while having no apparent adverse effects when ingested, when aerosolized and inhaled can cause lung irritation.

Like the flavorants, the propylene glycol carrier, while used as a preservative in food products without apparent adverse health effects, are themselves a potential airborne respiratory irritant. Wieslander et.al.[9] conducted experimental studies of 27 individuals exposed to propylene glycol aerosol for a one-minute period with airborne concentrations ranging from 176 to 851 mg/m^3 (geometric mean of 309 mg/m^3). Results of post-exposure measurements of tear film stability and forced expiratory respiratory volume indicated that short-term exposures to propylene glycol aerosol can cause acute eye and upper respiratory irritation in non-asthmatic patients.

Conclusions

We conclude that e-cigarettes emit harmful chemicals into the air and need to be regulated in the same manner as tobacco smoking. There is evidence that nitrosamines, a group of carcinogens found specifically in tobacco, are carried over into the e-cigarette fluid from the nicotine extraction process.[10] There is also evidence that the glycol carriers can by oxidized by the heating elements used in e-cigarettes to vaporize the liquids, creating aldehydes such as formaldehyde.[11] Consumers should be warned that, while the health risks associated with the usage of e-cigarettes are less than those associated with tobacco smoking, there remain substantial health risks associated with the use of e-cigarettes.

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