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Article

Identification and Quantification of Several Contaminated Compounds in Replacement Liquids of Electronic Cigarettes by Gas Chromatography–Mass Spectrometry

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Electronic cigarettes (E-cigarettes) are devices that are refilled with replacement liquids, which normally contain propylene glycol, nicotine and the desired flavor blend. Many consumers suspect that hazardous substances are present in addition to nicotine content. In this study, eight contaminated compounds in 105 replacement liquids from 11 types of E-cigarettes sold in the Republic of Korea were identified and quantified by gas chromatography–mass spectrometry. Diethyl phthalate and diethylhexyl phthalate were detected in concentration ranges of 0.01–1745.20 mg/L (47.6% detection frequency) and 0.06–81.89 mg/L (79.1% detection frequency) in the replacement liquids. Triethylene glycol, tetraethylene glycol and pentaethylene glycol were quantified in concentration ranges of 0.1–19.3 mg/L (10.5% detection frequency), 0.1–30.1 mg/L (12.4% detection frequency) and 0.1–24.9 mg/L (6.7% detection frequency) in the same samples. *cis*-3-Hexene-1-ol, methyl cinnamate and dodecane were quantified in concentration ranges of 0.03–3267.46 mg/L (70.5% detection frequency), 4.41–637.54 mg/L (6.7% detection frequency) and 0.01–639.96 mg/L (47.6% detection frequency) in the samples.

Introduction

Electronic cigarettes (E-cigarettes) are battery powered devices that aerosolize nicotine so that it is readily delivered into the respiratory tract. The devices are also designed to be refilled with replacement liquids containing propylene glycol and/or glycerin, nicotine and the desired flavor blend, which produce aromas and flavors of tobacco, chocolate, mint, fruit and coffee (1–3). E-cigarette manufacturers claim that their products are safe alternatives to tobacco and contain little more than water vapor, nicotine and propylene glycol and/or glycerin, which is used to create artificial smoke. However, many consumers suspect that contaminated substances are present in addition to the nicotine content and have concerns regarding the safety of these products. Despite such worries, analytical data about the substances that are present in replacement liquids of E-cigarettes are very limited at present.

Several studies have provided details on the presence of compounds in the liquids or the vapors of E-cigarettes (4–9). Laugesen reported that acetaldehyde, acetone, ethanol, formaldehyde (FA), cresol, xylene, propylene and styrene exist in the vapors of E-cigarettes (4), and Hadwiger *et al.* detected amino-tadalafil and rimonabant in the liquids of E-cigarettes (5). The US FDA detected diethylene glycol in 1 of 18 cartridges tested (6). NJOY E-cigarette company identified propylene glycol, glycerin, nicotine, acetaldehyde (AA), 1-methoxy-2-propanol, 1-hydroxy-2-propanone, acetic acid, 1-menthone, 2,3-butanediol, menthol, carvone, maple lactone, benzyl alcohol, 2-methyl-2-pentanoic acid, ethyl maltol, ethyl cinnamate, myosmine, benzoic acid, 2,3-bipyridine, cotinine, hexadecanoic acid and 1′1-oxy-bis-2-propanol in the vapors of E-cigarettes (7). Ohta *et al.* published a paper on the determination of carbonyl compounds in the vapor generated from E-cigarettes (8). Our previous study reported the concentrations of tobacco-specific nitrosamines in replacement liquids of E-cigarettes (9).

This study sought to identify and to quantify glycols, phthalates, *cis*-3-hexene-1-ol, methyl cinnamate and dodecane in 105 replacement liquid brands from 11 E-cigarette companies purchased in shops in the Republic of Korea.

Material and methods

Materials

Propylene glycol (99.5%), triethylene glycol (99%; TEG), tetraethylene glycol (99%; TeEG), pentaethylene glycol (98%; PEG), diethyl phthalate (99.5%; DEP), diethylhexyl phthalate (99%; DEHP), *cis*-3-hexene-1-ol (98%; CHO), methyl cinnamate (99%; MCM), dodecane (99%; DDC) and phenanthrene-d10 (99%) were obtained from Sigma-Aldrich (St Louis, MO, USA). Analytical grades of methanol, methylene chloride and sodium sulfate were also purchased from Sigma-Aldrich. The water used in this study was purified by a Milli-Q-Reagent-Grade water system (ZD20) and had a resistivity of over 17 MΩ.

Purchase of replacement liquids of E-cigarettes

The samples were purchased in July and August, 2012, from 11 E-cigarette shops in various regions in Republic Korea. These shops directly imported the liquids from the manufacturer in China. All samples were analyzed within 2 months of purchase after storage in a refrigerator at 4°C.

Sample treatment procedure

Dilution method

This method was used to identify and quantify hazardous compounds in replacement liquids of E-cigarettes without an extraction procedure. In this method, 0.5 mL of E-cigarette liquid samples or standard samples spiked with analytes in propylene glycol were placed in a 50-mL volumetric flask and 50.0 μg of

Table I
Ions Selected for Quantification and Confirmation Ions of Analytes

Compounds	Quantification ion m/z	Confirmation ions m/z
DEP	149	222, 177
DEHP	149	279, 167
TEG	89	75, 58
TeEG	89	119, 102
PEG	89	133, 59
CHO	67	82, 55
MCM	131	162, 106
DDC	57	85, 71

phenanthrene-d10 as an internal standard and ~1.0 g of sodium sulfate as a water scavenger were added to the flask, which was then filled to 50 mL with methanol. The solution was shaken and used for the identification and the quantification of hazardous compounds.

Calibration curves were established by dilution with methanol as a sample treatment procedure after adding 0, 0.01, 0.2, 2.0, 10, 50.0, 125.0 and 250.0 μg of analytes in 0.5 mL of propylene glycol. The corresponding concentrations of the standards were 0.02, 0.4, 4.0, 20.0, 100, 250 and 500.0 mg/L. If the concentration in a sample was out of the calibration curve range, the sample was used after further dilution. The ions selected for the quantification and confirmation are presented in Table I. The ratios of the peak areas of the standards to that of the internal standard were used to quantify the analytes.

Liquid extraction procedure

Liquid liquid extraction (LLE) was used to quantify the analytes in the liquid samples of E-cigarettes and for comparison with the dilution method. In this method, 0.5 mL of E-cigarette liquid samples or samples spiked with analytes in propylene glycol, 50.0 μg of phenanthrene-d10 and 4.0 mL of Milli-Q water containing ascorbic acid were placed in a 15-mL test tube. The solution was extracted with 4.0 mL of methylene chloride by mechanical shaking for 10 min. The organic phase was evaporated in a rotary evaporator under vacuum and finally dried in a nitrogen stream. The residue was dissolved with 100 μL of methanol and the solution was transferred into an auto vial, and 2.0 μL of the solution was automatically injected into the gas chromatography (GC) system for quantification of the analytes.

Calibration curves were established by extraction with methylene chloride as the sample treatment procedure after adding 0, 0.01, 0.2, 2.0, 10, 50.0, 125.0 and 250.0 μg of analytes in 0.5 mL of propylene glycol. The corresponding concentrations of the standards were 0.02, 0.4, 4.0, 20.0, 100, 250 and 500.0 mg/L. The ratios of the peak areas of the standards to that of the internal standard were used to quantify the analytes.

Apparatus

All mass spectra were obtained with an Agilent 7890/5975B instrument. The ion source was operated in the electron ionization (EI; 70 eV) mode. Full-scan mass spectra (m/z 40–800) were recorded for analyte identification. Separation of all analytes was achieved with an HP fused-silica capillary column with cross-linked 5% phenyl methylsilicone (DB-5); the column has a length of ~60 m, an inner diameter of 0.25 mm and a film thickness of 0.25 μm. Samples were injected in a split mode of 10:1. The flow rate of the helium was 1.0 mL/min. The operating parameters were as follows: injector temperature, 310°C; transfer line temperature, 300°C; and oven temperature, programed from 140°C at 12°C/min to 320°C (hold for 10 min). The ions selected for the quantization and confirmation are presented in Table I.

Results

Identification of hazardous compounds

Gas chromatography–mass spectrometry (GC-MS) was used to identify compounds in replacement liquids of E-cigarettes purchased from Korean shops by comparison of EI mass spectra between diluted solutions of samples and authentic standards.

Mass spectra of DEP, DEHP, TEG, TeEG, PEG, CHO, MCM and DDC in replacement liquids were identical to those of authentic standards as obtained by electron ionization at 70 eV.

The retention times of DEP and DEHP were 21.10 and 35.50 min. The mass spectrum of DEP shows a molecular ion at m/z 222 and a base ion at m/z 149, and diagnostic ions at m/z 177, 121, 105 and 77. The spectrum of DEHP shows no molecular ion, a base ion at m/z 149 and diagnostic ions at m/z 279, 253, 207 and 167.

The retention times of TEG, TeEG and PEG were 17.20, 20.40 and 23.60 min. The mass spectra of TEG, TeEG and PEG show no molecular ion, a base ion at m/z 45 and diagnostic ions at m/z 119, 89, 75 and 58.

The retention times of CHO, DDC and MCM were 7.90, 14.60 and 19.00 min. The mass spectrum of CHO shows no molecular ion, a base ion at m/z 67 and diagnostic ions at m/z 82 and 55. That of DDC shows no molecular ion and a base ion at m/z 57, and diagnostic ions at m/z 127, 113, 99, 85 and 71. That of MCM shows a molecular ion at m/z 162 and a base ion at m/z 131, and diagnostic ions at m/z 147, 103 and 77.

As a result, DEP, DEHP, TEG, TeEG, PEG, CHO, MCM and DDC were identified in replacement liquids of E-cigarettes. Their existence in replacement liquids of E-cigarettes has not been published until now.

Validation of the analytical method

According to the manufacturer, propylene glycol and/or glycerin make up most of the liquid in the nicotine cartridge that generates the mist and vapor in E-cigarette smoke (10). Propylene glycol and glycerin are colorless, nearly odorless, clear, viscous liquid that are miscible with water, acetone, diethyl ether and chloroform; the analytes dissolve well in the solvents, and in particular TEG, TeEG and PEG are completely miscible with the solvents. Therefore, it is not easy to extract the analytes from replacement liquids of E-cigarettes.

Because the analytes in this study are present at relatively high levels in replacement liquids, preconcentration may be not necessary as a sample preparation step. Application of a dilution method and LLE are thought to be efficient for the routine analysis of analytes in these liquids. The two methods were compared with each other to select the more efficient method for a routine analysis of the analytes in the replacement liquids.

Generally, the problems encountered with dilution methods are possible interference and a high detection limit. To test the efficiency of the dilution method for sample preparation for a routine analysis of the analytes in the liquids, methanol was chosen as a dilution solvent.

For a comparison of peak interference by the LLE clean-up method with the proposed dilution method, the total ion chromatograms (TIC) of two samples having different peak patterns are shown in Figure 1. Separation of the analytes from the background compounds in the real samples was acceptable. No extraneous peaks were observed in the chromatograms of real samples near the retention times of the analytes in two sampling methods. Otherwise, the peaks of TEG, TeED, PEG, CHO and MCM disappeared in the TIC after LLE of two real samples due to the high water solubility of TEG, TeED, PEG and MCM or the high volatility of CHO.

Test samples spiked at a concentration of 100.0 μg/L in replacement liquids, where the analytes were detected at the low concentrations, were compared with standard samples spiked at the same concentration in propylene glycol. The recoveries were calculated by the percentage of the concentrations of the analyte recovered in the dilution samples to those of the spiked standard samples and were calculated to be in a range of 98–103% for the analytes.

For the LLE test, 0.5 mL of samples was diluted with 4.0 mL of Milli-Q water and then the solution was extracted with methylene chloride, which is not miscible with propylene glycol. Test samples spiked at a concentration of 100.0 μg/L in propylene glycol were used for the extraction. As a result, the recoveries were in a range of 85–89% (CV = 4.3–6.4%) for DEP and DEHP, 2.3–5.7% (CV=35–125%) for glycols (TEG, TeED and PEG), and 29–86% (CV = 15.8–46.8%) for natural products (CHO, MCM and DDC). Unsatisfactory recoveries (<30%) for TEG, TeED, PEG, CHO and MCM were observed in the LLE method due to the high water solubility of TEG, TeED, PEG and MCM or the high volatility of CHO.

A comparison of the LLE clean-up method with the proposed dilution method for 10 liquids for the phthalates was performed. The bias between the two methods was below 7%. The agreement of the dilution method with the LLE clean-up method for 10 liquids indicates that the dilution method does not present any problems related to interference and it is acceptable as a pretreatment method of the analytes from replacement liquids of E-cigarettes.

The detection limits by the LLE clean-up method were compared with those of the dilution method for the phthalates. The detection limits by the dilution method were ~10-fold higher than those by the LLE. Nevertheless, the detection limits by the dilution method were sufficient to detect at precision to 10 μg/L.

Because the proposed dilution method is simple and showed good agreement with the LLE clean-up method for phthalates, and it was thereafter used to quantify the analytes in the replacement liquids.

In the GC separation of the analytes, the nonpolar stationary phase was used. As can be seen from the chromatograms shown in Figure 2, separation of the analytes from the background compounds in the real samples was very good.

The lowest limit of detection (LOD) and the limits of quantification (LOQs) (10) were defined as 3.14 and 10 times the standard deviation for replicate determinations ($n = 7$) from samples spiked at a concentration of 0.002 or 0.020 mg/L and the LODs of the analytes were in a range of 0.002–0.037 mg/L, and the LOQs of the analytes were in a range of 0.007–0.111 mg/L, respectively, as shown in Table II. Calibration curves of the analytes were constructed by dilution of the spiked samples. Examination of the typical standard curve by computing a regression line of peak area ratios for the analytes to the internal standard on concentrations using a least-squares fit revealed a linear relationship with correlation coefficients >0.994. The linear equations and linearity of analytes are presented in Table II.

The accuracy can be assessed by determining the recovery in spiked samples: intra-day accuracy was evaluated using five spiked samples at a concentration range of 5.0–100 mg/L for analytes. The inter-day accuracy was determined using the sample recovery on five different days. The accuracy was in the range of ~83–108% and the precision of the assay was <9%, as shown in Table II.

Quantification of hazardous compounds in replacement liquids of E-cigarettes

Eight compounds (DEP, DEHP, TEG, TeEG, PEG, CHO, MCM and DDC) found in the identification procedure were quantified in the 105 replacement liquids of E-cigarettes.

DEP and DEHP were quantified in the replacement liquids and were detected in concentration ranges of 0.01–1745.20 mg/L (47.6% detection frequency) and 0.06–81.89 mg/L (79.1% detection frequency), respectively, as shown in Table III. The mean concentrations and the standard deviations of detected phthalates were 33.70 ± 74.08 mg/L for DEP and 1.13 ± 2.09 mg/L for DEHP.

TEG, TeEG and PEG were quantified in concentration ranges of 0.1–19.3 mg/L (10.5% detection frequency), 0.1–30.1 mg/L (12.4% detection frequency) and 0.1–24.9 mg/L (6.7% detection frequency) as shown in Table IV. The mean concentrations and the standard deviations of detected glycols were 0.35 ± 0.79 mg/L for TEG, 0.60 ± 1.38 mg/L for TeEG and 0.53 ± 1.26 mg/L for PEG.

CHO, MCM and DDC were quantified in concentration ranges of 0.03–3267.46 mg/L (70.5% detection frequency), 4.41–637.54 mg/L (6.7% detection frequency) and 0.01–639.96 mg/L (47.6% detection frequency) as shown in Table V. The mean concentration and standard deviation of CHO, MCM and DDC were 107.27 ± 211.88 mg/L, 10.97 ± 31.68 mg/L and 7.52 ± 21.27 mg/L, respectively.

Discussion

DEP, DEHP, TEG, TeEG, PEG, CHO, MCM and DDC were identified and quantified in E-cigarettes replacement liquids. DEP and DEHP were detected in concentration ranges of 0.01–1745.20 mg/L (47.6% detection frequency) and 0.06–81.89 mg/L (79.1% detection frequency) in replacement liquids. DEP is used as a solvent to bind cosmetics and fragrances, and in industrial applications including plasticizers, detergent bases and aerosol sprays (11). DEHP is meanwhile widely used as a plasticizer in the manufacture of articles made of polyvinylchloride (12). They have estrogenic and antiandrogenic activity and cause premature breast development in girls (12). Research on cancer (13) classified DEHP as "a possible carcinogen to humans" in Group 2B. Committee for Risk Assessment (RAC) under REACH proposed the derived no-effect level (DNEL) of 0.035 mg/kg bodyweight/day for DEHP and 0.75 mg/kg bw/d for DEP (14, 15). This amount corresponds to ~30 mL of each

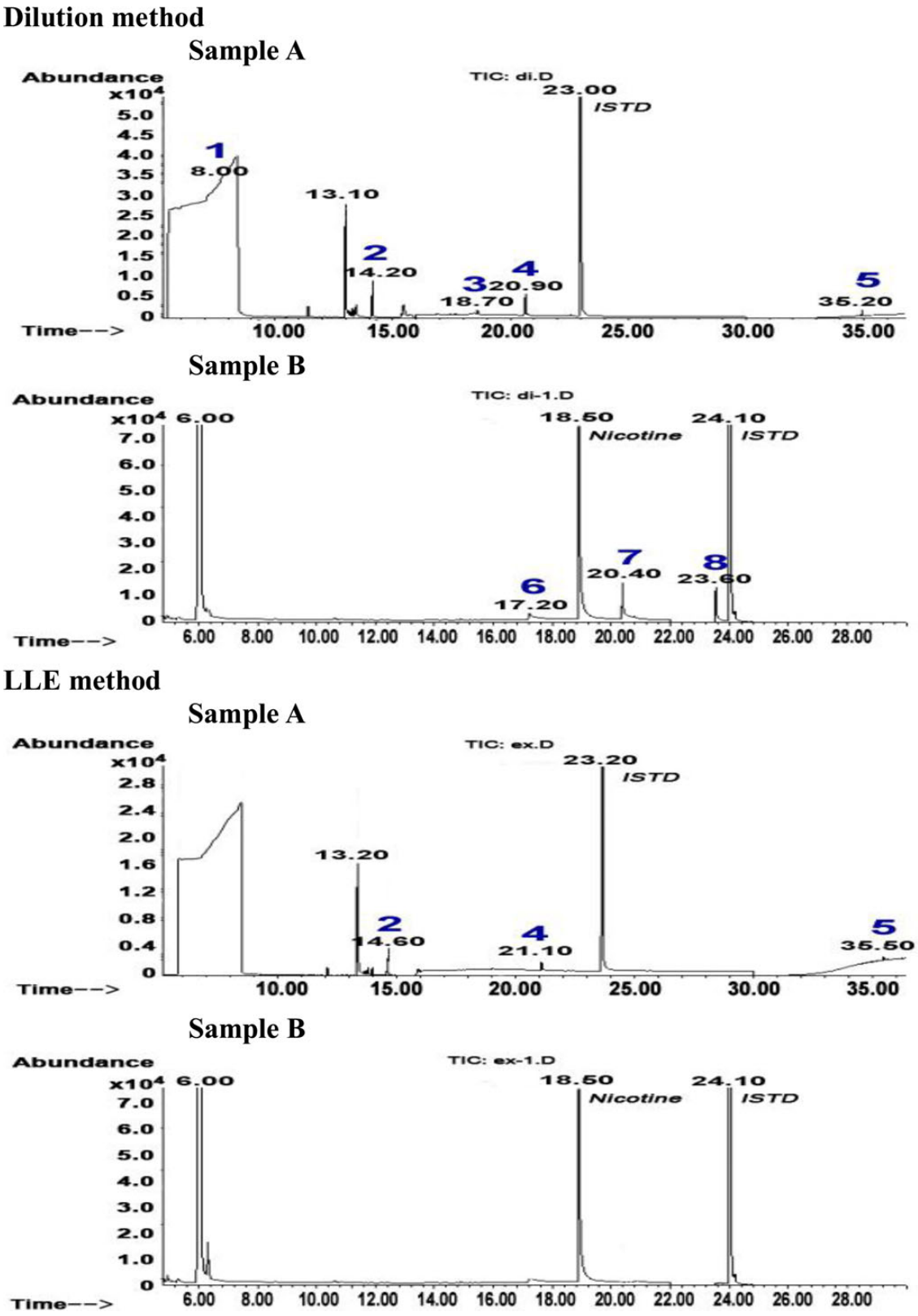

Figure 1. Comparison of GC-MS total ion chromatograms of analytes by dilution and LLE from two real samples. 1, CHO; 2, DDC; 3, MCM; 4, DEP; 5, DEHP; 6, TEG; 7, TeEG; 8, PEG.

DEHP 81.89 mg/L or DEP 1745 mg/L in the replacement liquids, in which the analytes were detected in the highest concentration. Although 30 mL of the replacement liquids cannot be achieved for a day by normal consumption of E-cigarettes, the detected concentrations cannot be overlooked considering their ubiquity in the environment.

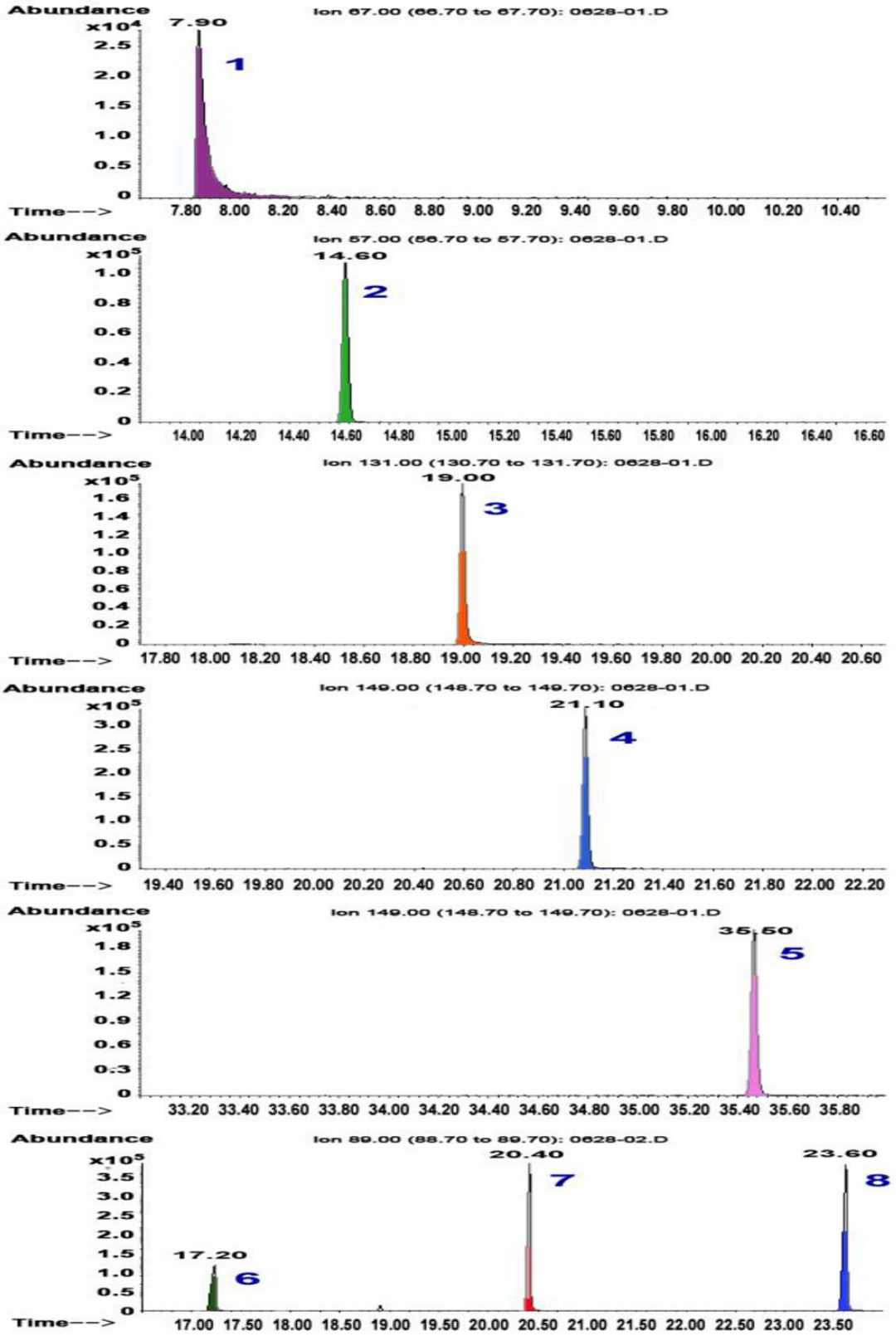

Figure 2. GC-MS selected ion chromatogram of analytes from the liquid samples of E-cigarettes. 1, CHO; 2, DDC; 3, MCM; 4, DEP; 5, DEHP; 6, TEG; 7, TeEG; 8, PEG.

TEG, TeEG and PEG were detected in concentration ranges of 0.1–19.3, 0.1–30.1 and 0.1–24.9 mg/L, respectively. Glycols are used as solvents for a wide range of products such as paints, lacquers, varnishes, plastics, waxes, resins, fats, oils and ethers. They are also used in cosmetics, automotive brake fluids, textile processing, stains, dye baths and printing (16). Replacement

Table II
Calibration Curve, Detection limit, Precision and Accuracy of Analytes in a Control Sample

Analytes	Calibration curve ($y = ax + b$)				Detection limit (mg/L)		Precision and accuracy (%)				
	Linear range (mg/L)	a	b	r^2	LOD	LOQ	Spiked concentration (mg/L)	Intra-day		Inter-day	
								Accuracy	Precision	Accuracy	Precision
DEP	0.01–2,000	0.1312	0.0218	0.998	0.003	0.009	5.0	104	2.43	108	4.28
							10.0	105	2.05	107	3.98
DEHP	0.01–2,000	0.0526	0.0450	0.997	0.004	0.011	5.0	86.8	4.57	83.7	5.29
							10.0	96.4	3.29	97.2	5.48
TEG	0.1–100	0.0977	0.0018	0.995	0.037	0.111	10.0	94.2	4.86	95.4	6.74
							100.0	93.4	8.32	95.1	8.39
TeEG	0.1–100	0.9043	0.0256	0.995	0.021	0.063	10.0	85.6	8.44	83.4	8.87
							100.0	98.3	6.63	96.2	7.77
PEG	0.1–100	0.1850	0.0036	0.994	0.035	0.105	10.0	95.6	8.83	93.3	8.61
							100.0	103.2	4.87	104.6	5.48
CHO	0.01–5,000	0.0188	0.0170	1.000	0.003	0.009	10	95.3	8.25	93.2	8.98
							100	98.7	7.23	95.9	8.24
MCM	0.01–1,000	0.0586	0.0067	0.999	0.002	0.007	10	94.3	7.36	96.7	8.39
							100	97.3	4.98	94.2	5.24
DDC	001–100	0.0412	0.0014	1.000	0.003	0.010	1.0	97.3	5.26	93.4	6.74
							10.0	100.4	2.07	101.2	4.61

Table III
Analytical Results of Phthalates in the Liquid Samples of E-cigarettes Purchased from Korean Shops (mg/L)

Compound	Blend	Number of samples	Detected concentration range	Mean	Frequency detected (%)
DEP	A	7	0–0.13	0.03	43
	B	15	0–12.12	0.96	80
	C	10	0–1745.20	174.67	90
	D	7	0–1341.09	191.99	57
	E	19	0–42.16	2.25	11
	F	2	0	0	0
	G	6	0.22–0.80	0.44	100
	H	4	0	0	0
	I	16	0–0.18	0.04	31
	J	5	0–0.38	0.08	20
	K	14	0–0.94	0.22	57
DEHP	A	7	0.17–0.41	0.29	100
	B	15	0.34–8.34	1.63	100
	C	10	0–2.42	0.43	30
	D	7	0–0.6	0.1	14
	E	19	0–1.16	0.25	95
	F	2	0.24–0.66	0.45	100
	G	6	0.15–0.45	0.28	100
	H	4	0.16–0.66	1.49	100
	I	16	0–0.58	0.23	81
	J	5	0–0.37	0.07	20
	K	14	0–81.89	7.24	93

Table IV
Analytical Results of Glycols in the Liquid Samples of E-cigarettes Purchased from Korean Shops (mg/L)

Compound	Company	Number of samples	Detection range	Mean	Frequency detected (%)
TEG	A	7	0	0	0
	B	15	0–19.3	2.5	53
	C	10	0–10.5	1.1	10
	D	7	0–0.4	0.1	14
	E	19	0	0	0
	F	2	0	0	0
	G	6	0	0	0
	H	4	0	0	0
	I	16	0–1.9	0.1	6
	J	5	0	0	0
	K	14	0	0	0
TeEG	A	7	0	0	0
	B	15	0–30.1	4.2	67
	C	10	0–20.3	2.3	20
	D	7	0–0.6	0.1	14
	E	19	0	0	0
	F	2	0	0	0
	G	6	0	0	0
	H	4	0	0	0
	I	16	0	0	0
	J	5	0	0	0
	K	14	0	0	0
PEG	A	7	0	0	0
	B	15	0–24.9	3.0	33
	C	10	0–17.1	1.9	20
	D	7	0	0	0
	E	19	0	0	0
	F	2	0	0	0
	G	6	0	0	0
	H	4	0	0	0
	I	16	0	0	0
	J	5	0	0	0
	K	14	0	0	0

liquids of E-cigarettes are using by dissolving nicotine in propylene glycols, and TEG, TeEG and PEG are considered as impurities in propylene glycol. A toxicological review of glycols revealed that they may cause irritation of the eyes, skin and mucous membranes (16, 17). Ohta *et al.* identified that toxic carbonyl compounds were generated from glycols during heating of the electronic cigarette (8). Because aldehydes can be produced from the glycols under heating conditions, the continued use of tainted propylene glycol including TEG, TeEG and PEG should be reconsidered from the viewpoint of consumer safety.

CHO, MCM and DDC detected in the concentration of 0.03–3267.46, 4.41–637.54 and 0.01–639.96 mg/L in the liquid samples, respectively. CHO is a colorless liquid with a powerful, grassy-green odor and has low toxicity of LD_{50} 7–10 g/kg for rats and 0.4–0.6 mg/kg for mice (18). MCM is found naturally in a variety of plants. It is used in the flavor and perfume industries and is moderately toxic with an LD_{50} of 2610 mg/kg for rats (19). DDC is used and produced as a solvent in organic synthesis, distillation chasers, jet fuel research and the manufacture of paraffin products and as a component of gasoline and its release to

Table V
Analytical Results of CHO, MCM and DDC in the Liquid Samples of E-cigarettes Purchased from Korean Shops (mg/L)

Compound	Company	Number of samples	Detection range	Mean	Frequency detected (%)
CHO	A	7	0–113.97	21.80	57
	B	15	0–106.28	22.52	87
	C	10	0–152.06	34.83	40
	D	7	0.05–107.83	28.19	100
	E	19	0.05–103.35	17.20	100
	F	2	0.10–71.08	35.59	100
	G	6	0–832.79 5	139.15	83
	H	4	0.05–0.15	0.09	100
	I	16	0–1664.39	112.35	25
	J	5	0–3267.46	733.32	100
	K	14	0–255.32	34.92	50
MCM	A	7	0	0	0
	B	15	0–8.31	0.55	7
	C	10	0–42.34	4.23	10
	D	7	0	0	0
	E	19	0–20.85	1.33	11
	F	2	0	0	0
	G	6	0–637.54	106.26	17
	H	4	0	0	0
	I	16	0	0	0
	J	5	0–9.09	1.82	20
	K	14	0–90.33	6.45	7
DDC	A	7	0	0	0
	B	15	0–2.87	0.19	7
	C	10	0–639.96	71.58	60
	D	7	0	0	0
	E	19	0–11.72	2.87	95
	F	2	0.80–2.69	1.75	100
	G	6	0.92–5.49	2.38	100
	H	4	0–3.37	1.31	75
	I	16	0–0.01	0	6
	J	5	0–1.55	0.53	80
	K	14	0–12.39	2.11	64

the environment may occur through various waste streams. It is only slightly hazardous to human health with an acute oral LD_{50} of >5 g/kg and only breathing protection is needed (20). DNEL of CHO, MCM and DDC are not available, thus, it cannot discuss a health effect for CHO, MCM and DDC found in the E-cigarette replacement liquids. Although these compounds have not a high toxicity, the impurity compounds must not be ignored considering being in their high concentration in E-cigarette replacement liquids.

Conclusion

The proposed analytical methods have been successfully applied to E-cigarette replacement liquids to determine the compounds of interest and the results revealed that the proposed method makes it possible to determine the levels of individual analytes in commercial E-cigarette replacement liquids. The precision of this method, as indicated by the relative standard deviations (RSDs), was within the range of 2.05–8.98%. The detection limits obtained from calculations by using GC–MS results were within the range of 0.007–0.111 mg/L. Excellent linearity was obtained in the concentration range of 0.01–2,000 mg/L with R^2 in the range of 0.9994–1.000.

DEP, DEHP, TEG, TeEG, PEG, CHO, MCM and DDC were identified and quantified in 105 replacement liquids from 11 types of E-cigarettes sold in the Republic of Korea by using GC-MS. The chemical analyses have revealed a great variation in the chemical composition of the analyzed E-cigarette replacement liquids as well as in the concentration of the chemical substances detected in the analyzed E-cigarette replacement liquids. Phthalates may have originated from package materials and the production procedure of replacement liquids and CHO, MCM and DDC may be existed naturally in the plant extract. The eight contaminated compounds in replacement liquids should be controlled to the lowest concentrations in raw materials and the production procedure considering their toxicity, their high concentration in E-cigarette replacement liquids and their ubiquity in the environment.

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