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Original Research

Air Pollution in New Vehicles as a Result of VOC Emissions from Interior Materials

Joanna Faber*, Krzysztof Brodzik, Anna Gołda-Kopek, Damian Łomankiewicz

BOSMAL Automotive Research and Development Institute Ltd,
Sarni Stok 93, 43-300 Bielsko-Biała, Poland

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Abstract

Indoor air composition inside the cabins of five new vehicles was examined. Air pollution was assessed on the basis of determination of volatile organic compound (VOC) concentrations, which were emitted from interior materials. Air samples were collected by active method onto a Carbograph 1TD. VOCs were analyzed using the TD-GC-FID/MS method. Presented results include concentrations of identified VOCs and three main group of compounds (aliphatic, aromatic, and cycloalkanes), as well as 18 target compounds and 10 main hydrocarbons, presented in vehicle interiors. It can be stated that interior air composition depended on materials used to finish the interior.

Keywords: volatile organic compounds, vehicle interior, indoor air, interior emissions

Introduction

Volatile organic compounds (VOCs) are widely present in both outdoor and indoor air, and are considered to be an important group of air pollutants [1-4]. Numerous VOCs are reported to have a negative impact on human health, and their concentration in indoor air is higher than in outdoor air [5]. The interior of a vehicle is regarded as a specific microenvironment where the concentration of VOCs may be much higher than in public or private buildings [6-14]. VOC presence inside a new vehicle is mostly connected with interior emissions from materials used to equip the passenger compartment. The concentration of observed VOCs depends mostly on interior temperature, humidity, ventilation, age, and the general condition of the vehicle [5, 6, 15-17]. Moreover, interior trim (leather or fabric) significantly affects VOC levels inside a vehicle [6].

A mix of in-vehicle VOCs emitted from materials is responsible for the 'new car smell', which is an important pleasantness factor. Fedoruk and Kerger [16] found that the main pollutants inside two new cars tested included toluene, phenol, and e-caprolactam in one case, and methyldecanes and styrene in the second case. Total volatile organic compound emissions (TVOC) in the vehicles tested was over 5,600 and 1,999 μg/m^3 for each of the two vehicles. In that study, about 100 organic compounds were identified on the basis of mass spectra. Grabbs et al. [14] reported identifying over 60 compounds inside four types of vehicles. You et al. [15] reported that the concentration of TVOCs inside a new vehicle was about 5,000 μg/m^3, the main group of pollutants being alkanes, with decane at the highest concentration level (345 μg/m^3), along with aromatic compounds, with m,p-xylene at the highest concentration (approximately 350 μg/m^3). The total number of compounds identified in that study was 82.

Yoshida and Matsunaga [5] detected a total of 161 VOCs and SVOCs inside one new mini-van type vehicle. Total VOC emission was on the order of 14 mg/m^3, including mainly aliphatic and aromatic hydrocarbons (6,011.7 and 5,946.8 μg/m^3, respectively). The highest concentrations were found for m,p-xylene, undecane and decane (3,104.0, 1,615.8, and 1,300.6 μg/m^3, respectively). Chien [6] reported that intra-model variability in VOC concentra-

*e-mail: joanna.faber@bosmal.com.pl

tion was at an average level of 47%, while VOCs between different brands varied within 95%.

When performing analysis of VOCs it is important both to identify organic compounds and to determine them quantitatively. However, some researchers recommend determining total VOC emissions rather than individual compound concentration [1]; detailed knowledge of the chemical composition and concentration of emitted VOCs may be very useful and helpful in defining the possible source of air pollution [5]. In order to determine individual organic compounds at different concentration levels, as they are present inside a vehicle's cabin, it is necessary to apply sensitive and effective air sampling together with the preconcentration step. A combination of these parameters is possible with the use of an appropriate solid sorbent, followed by solvent extraction or thermal desorption [18-20]. Some authors suggest that solvent extraction does not permit the obtainment of a satisfactory method detection limit (MDL) [18, 19, 21-23]. Thermal desorption is an important alternative to solvent extraction, which permits: determination of VOCs at low concentration levels, avoiding the use of toxic solvents, and obtaining very good repeatability. Active sampling onto a solid sorbent enables fast and reliable VOC collection and analysis [23]. Even though multisorbent tubes have become popular in recent years, their use is limited and should be preceded by a detailed evaluation [23]. Use of a single sorbent may be limited in terms of adsorbing only select, specific, organic compounds, but the use of two complementary sorbents may provide complex information about the composition of VOCs in the air samples collected.

The aim of this work was to examine air composition inside five new vehicles of different brands and/or models. Interior air quality was assessed on the basis of determination of volatile organic compounds concentrations emitted from interior equipment. To our best knowledge this is the first study in Poland on air quality inside different new vehicles. The following areas were examined in the present study:

(i) qualitative analysis (identification) of VOCs
(ii) total VOC emissions
(iii) quantitative analysis of VOCs collected from new vehicles' cabins. Moreover, the precision of air sampling and the main air pollutants are described.

Methodology

Calibration

Two stock standard solutions, containing a mixture of organic compounds, were used to prepare calibration curves and confirm retention times for target compounds. One of the standard solutions contained heptane, octane, decane, undecane, and dodecane, each at 2,000 mg/L in methanol (S-19078, AccuStandard, Inc, New Haven, USA, of minimum purity 99%). The second standard solution contained benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene, 1-methylethylbenzene, propylbenzene, 1-ethyl-3-methylbenzene, 1-ethyl-2-methylbenzene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, and 1,3,5-trimethylbenzene, each at 2,000 mg/L in methanol (GRO-AK-101AA-ARO, AccuStandard, Inc, New Haven, USA, of minimum purity 99%). Target compounds were selected on the basis of their occurrence in a vehicle's interior, as presented in previous papers [24-27].

Each stock standard solution was diluted in methanol to obtain working standard solutions within the range 5.0 to 50.0 μg/mL. A volume of 2 μL of each standard solution prepared was spiked onto tubes containing Carbograph 1TD, thermally desorbed and analyzed by gas chromatography with a flame ionization detector (TD-GC-FID). The concentrations of the chemicals that were transferred to the FID detector were within the range 0.10 to 10.0 ng (but up to 100.0 ng for toluene). The validation of this analytical method for different VOC analysis has been described in detail elsewhere [24]. Calibration curves for each target compound, instrumental limit of detection (LOD), precision (repeatability), and recovery have been evaluated [19, 22, 23]. A summary of the TD-GC-FID method for all target compounds is presented in Table 1. Curves were considered acceptable with $R^2 \geq 0.99$ and Vm $\leq 3\%$. Precision (%RSD) was accepted at $\leq 10\%$.

Vehicles Under Study

The vehicles under study included five newly produced compact cars (tested less than one month from their date of production). Three of the cars studied were of the same model (brand A, cars 1-3) and two others differed in brand or model (brand B, car 4, and brand C, car 5). Accordingly, intra-brand and intra-model variations in VOC levels were examined. All vehicles, domestically produced in Poland, represented the mid-market price. The vehicles had no fuel leakages or mechanical problems. The passenger compartments were completely free of cigarette smoke and deodorizers. All vehicles differed in interior characteristics (differences in upholstery and steering wheel material and color). Details of interior equipment are presented in Table 2.

Air Sampling

Air samples were collected from the vehicles' interiors under static conditions (with the vehicle engines shut off, all doors and windows closed, air conditioning off). It has been reported several times that emissions from materials (i.e. off-gassing), and hence the concentration of total volatile organic compounds inside a vehicle, depends strongly on the interior temperature [15-17]. For this reason, each vehicle under study was conditioned for 16 hours before the sampling event, at a constant temperature in an air-conditioned space, thereby allowing the in-vehicle air conditioners to stabilize and provide similar conditions during sampling. Air samples were collected at about 50 cm above the driver's seat (approximately in the breathing zone).

VOCs emitted by interior materials were collected into glass tubes filled with 100 mg of Carbograph 1TD

Table 1. Summary of TD-GC-FID method for target compounds.

Comp. No.	Target VOC	CAS	t_R [a] (min)	R^2 [b]	V_m [c] (%)	Precision [d] (%)	LOD [e] (μg/m³)	Recovery [f] (%)
1	n-heptane	142-82-5	12.05	0.9998	1.67	2.4	0.9	97.0
2	n-octane	111-65-9	17.82	1.0000	0.65	2.7	0.3	96.9
3	n-decane	124-18-5	28.82	0.9996	2.56	1.5	1.3	98.2
4	n-undecane	1120-21-4	33.11	0.9997	2.65	1.4	1.3	99.3
5	n-dodecane	112-40-3	36.48	0.9996	2.55	0.77	1.3	99.4
6	benzene	71-43-2	10.43	0.9996	2.95	3.3	1.6	94.8
7	toluene	108-88-3	16.12	0.9999	1.43	1.6	0.5	95.8
8	ethylbenzene	100-41-4	21.93	1.0000	0.99	2.2	0.5	94.0
9	m-xylene	108-38-3	22.43	0.9999	1.21	2.0	0.6	90.8
10	p-xylene	106-42-3	22.52	0.9999	1.42	5.1	0.7	91.6
11	o-xylene	95-47-6	23.79	1.0000	0.61	1.0	0.3	91.2
12	1-methylethylbenzene	98-82-8	25.42	1.0000	0.72	6.1	0.4	95.6
13	propylbenzene	103-65-1	26.99	0.9998	1.78	10.8	0.9	86.5
14	1-ethyl-3-methylbenzene	620-14-4	27.32	0.9998	2.21	10.3	1.1	90.0
15	1,3,5-trimethylbenzene	108-67-8	27.72	0.9998	2.07	10.9	1.0	95.5
16	1-ethyl-2-methylbenzene	611-14-3	28.23	0.9998	1.48	12.3	0.7	92.5
17	1,2,4-trimethylbenzene	95-63-6	28.99	0.9998	1.78	3.6	0.9	96.0
18	1,2,3-trimethylbenzene	526-73-8	30.33	0.9999	1.70	4.5	0.9	86.3

[a] retention time for target compound, [b] calibration square coefficient, [c] method variation coefficient, [d] RSD (n=5), [e] instrumental limit of detection, [f] desorption efficiency (n=3)

Table 2. Interior characteristics of vehicles under study and indoor atmospheric conditions.

Vehicle No.	Brand	Upholstery	Steering wheel	Interior temperature (ºC)	RH (%)
1	A	red fabric/white leather	white leather	23.6	44.6
2	A	white-red fabric	white leather	22.4	40.6
3	A	fabric/synthetic leather	black synthetic leather	19.8	44.3
4	B	brown alcantara	black leather	22.8	33.3
5	C	black-grey fabric	black rubber	25.6	36.3

(graphitized carbon black, 40/60 mesh, medium/weak sorption strength). Carbograph 1TD is an appropriate sorbent for collecting and analyzing a wide range of organic compounds present in indoor air within vehicles [26, 27]. The tubes were conditioned before use at 300ºC for 60 min with a helium flow of 20 mL/min. Air samples from the vehicles' cabins were collected by active sampling, using air pumps (PCM TX-8, SKC, UK) with calibrated and controlled air flow at a rate of 100 mL/min, for 20 minutes. The influence of outdoor air was reduced to a minimum since the vehicle's doors were open not longer than 10 sec during installation of duplicate sorbents connected to the air pump [6]. The sampling device was switched on manually. The total sampled air volume was 2 L in each case.

Duplicate samples were collected during each sampling event [28]. Tubes with air samples were sealed with Swagelok brass end caps fitted with PTFE ferrules, transported to the laboratory in a sealed plastic box and stored at 4ºC until analysis was performed (within max 1 week).

Indoor temperature and relative humidity (%RH) were measured using a thermohygrometer (LB-702, LAB-EL, Poland), and the average atmospheric conditions during the sampling event are presented in Table 2.

Table 3. Parameters of chromatographic analysis and equipment used.

Equipment	Type	Program
Thermal desorber	Unity 2, Markes	tube: 300ºC/15 min He purge 20 ml/min cryotrap: -30ºC
Cryotrap	U-T11GPC-2S	desorption: 320ºC/15 min split ratio: 5:1
Gas chromatograph	Agilent 7890A	Capillary column DB-5msUI (60 m × 320 μm × 1 μm) carrier gas: He 6.0 temperature program: from 40ºC (2 min) at 3ºC/min to 92ºC, then 160ºC at 5ºC/min, then 290ºC (12 min) at 10ºC/min, total runtime: 60 min
FID detector		350ºC constant helium flow: 3 mL/min injector volume 2.5 μL
Mass detector	Agilent MSD 5975C	Transfer line to MS: 300ºC ion source: electron impact (EI) ion source temperature: 230ºC scan mode: SCAN m/z: 35-260 amu NIST 08 library

Gas Chromatographic Analysis and VOC Identification

Analytes from collected air samples were removed from the sorbent by thermal desorption (Unity2, Markes, UK) and analyzed using a gas chromatograph equipped with a flame ionization detector coupled with a mass detector (TD-GC-FID/MS). The gas chromatograph was equipped with a column splitter that permitted simultaneous analysis on both the FID and MS detectors. The parameters of thermal desorption and chromatography analysis, as well as the equipment used, are presented in Table 3.

Compounds were confirmed by their retention time (t_R) and mass spectra (NIST08 library). All compounds at concentrations above 1 μg/m^3, with scores above 80% [6, 14], were regarded as identified compounds (VOC_{id}). Identification was confirmed for benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene, 1-methylethylbenzene, propylbenzene, 1-ethyl-3-methylbenzene, 1-ethyl-2-methylbenzene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene, heptane, octane, decane, undecane, and dodecane from their chromatographic retention times (t_R, min).

The concentrations of total emission of volatile organic compounds (TVOC) included all compounds emitted from interior materials into the vehicle's interior, which were possible to adsorb onto Carbograph 1TD. In general, total VOC emissions and concentrations of all VOC_{id} was calculated in toluene equivalent (TE, μg/m^3), which means that they were calculated against the standard toluene curve [15, 29]. Additionally, concentrations of identified and confirmed volatile organic compounds were calculated against proper calibration curves, while unconfirmed compounds were calculated in toluene equivalent. The aliphatic hydrocarbons included alkanes and alkenes, while cycloalkanes were regarded as a separate class of compounds.

Quality Control

Quality control included sampling of duplicate air samples, field blanks and analysis of an internal standard (deuterated toluene). Five pairs of duplicate air samples were collected from the five different vehicles' cabins. Sampling of duplicate samples was performed simultaneously onto two solid sorbents of the same type, connected in parallel to an air pump. The precision of the sampling method was designated as percent relative standard deviation (%RSD) for each pair of duplicate samples, and was considered acceptable where RSD was <20% [30, 31].

Results and Discussion

Total VOC (TVOC) emissions included all compounds collected from the vehicles' interiors onto Carbograph 1TD, and ranged from 1,259.9 to 8,612.4 μg/m^3. The average TVOC emission in three vehicles of the same model (vehicles 1-3) was on the order of 3,423.8 μg/m^3. The resulting average RSD value for TVOC emissions for all five vehicles was 14.7%.

In the present study, all results were related to identified VOCs (with quality score above 80% and concentrations above 1 μg/m^3), which ranged from 797.0 to 6,711.1 μg/m^3 in the vehicles tested. In vehicles 1-3, the VOCs identified were determined at an average level of 1,991.6 μg/m^3, with a minimum of 1,053.0 μg/m^3 and a maximum of 2,616.3 μg/m^3. For each vehicle tested, the sum of identified VOCs constituted from 44.0 to 77.9% of TVOC emissions. The resulting RSD value for VOC_{id} emissions ranged from 5.4 to 14.3%, with an average of 9.5%, while the average RSD value for the target compounds was 7.3%. Both RSD values fulfilled the acceptance criteria (RSD<20%).

The number of identified compounds depended on vehicle model and equipment, and ranged between 57 and 103 compounds (82 on average). The data obtained are in accordance with data presented by Grabbs et al. [14].

The results for measurements of identified VOC emissions and the three main groups of compounds (aliphatic, aromatic, and cycloalkanes), detected in air sampled from vehicles, are presented in Table 4. The distribution of the three main groups of compounds, together with error bars (in reference to the identified VOCs) is presented in Fig. 1.

The concentration of each target compound, calculated on the basis of the proper calibration curve and in TE together with precision (%RSD) for duplicate samples, are presented in Table 5. Chemical composition of air samples differed, depending on vehicle model and interior equipment. Aliphatic compounds, with concentrations ranging

Table 4. Air sampling precision for VOC_{id} and the three main groups of compounds in the vehicles tested.

Vehicle No.	Identified VOC			Aliphatic compounds		Aromatic compounds		Cycloalkanes	
	No.	Conc.[a]	RSD [b]	Conc.[a]	RSD [b]	Conc.[a]	RSD [b]	Conc.[a]	RSD [b]
1	57	1053.0	10.9	497.8	11.1	259.9	7.8	89.7	6.8
2	103	2616.3	7.0	1105.3	4.8	596.4	6.4	684.3	4.1
3	83	2305.6	14.3	874.6	11.9	758.5	7.6	402.0	22.0
4	97	6711.0	9.9	4026.6	7.5	783.3	4.8	1340.7	12.1
5	68	797.0	5.4	313.0	4.7	207.7	2.4	150.7	10.0
Average	82	2696.6	9.5	1363.5	8.0	521.2	5.8	533.5	11.0

[a] concentration in toluene equivalent (µg/m^3), [b] air sampling repeatability (%, n=2)

from 313.0 to 4,026.6 µg/m^3, were the group of hydrocarbons with the maximum share of VOC emissions in each vehicle (37.9-60.0%). The sum of the concentrations of the target compounds (Table 5) differed by ca. 0.3% in the case of vehicle 5 with the lowest TVOC, to ca. 8.7% in the case of vehicle 4 with the highest TVOC. The distribution of the various compounds denoting aliphatic and aromatic hydrocarbons is presented in Figs. 2 and 3, respectively.

Aliphatic compounds were sampled onto Carbograph 1TD with a precision of 4.7-11.9%. The best sampling repeatability was achieved for aromatic compounds (average RSD 5.8%); the worst results were observed for cycloalkanes (average RSD 11.0%). Among aliphatic hydrocarbons, the best repeatability was observed for heptane, heptane derivatives, octane, and octane derivatives. Sampling precision decreased with increasing hydrocarbon chain length. Determination of the compounds' concentrations, based on toluene equivalent, led to lower values than the application of single compound curves. The difference between the calculated concentrations was especially important in the case of aliphatic compounds (Table 5). The influence of the calibration curve used increases with total VOC concentrations.

Benzene, which is a recognized carcinogenic compound [32, 33], was found in vehicles 3 and 5. Heptane, octane, and decane, together with the methyl derivatives, methylcyclohexane and methyldecahydronaphtalene were found in all vehicles tested (Table 6). Moreover, toluene, xylene (sum of isomers), 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, and ethylbenzene were present in all cases. The ten main organic compounds, identified in the vehicles, constituted 52.9-74.0% of identified VOCs. Several esters, alcohols, and carbonyl compounds also were detected in the air samples taken from the test vehicles.

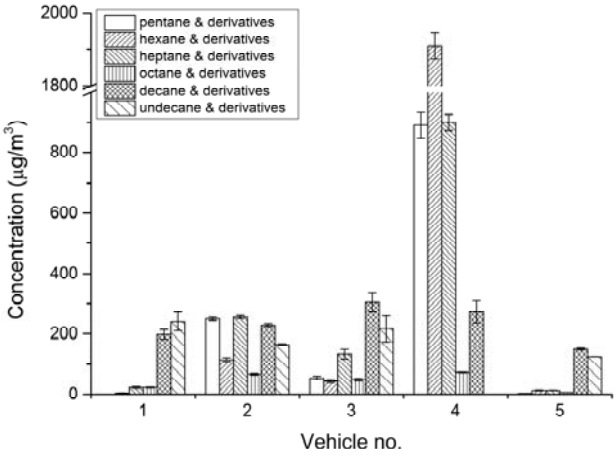

Fig. 2. Distribution of compounds in the aliphatic hydrocarbon group.

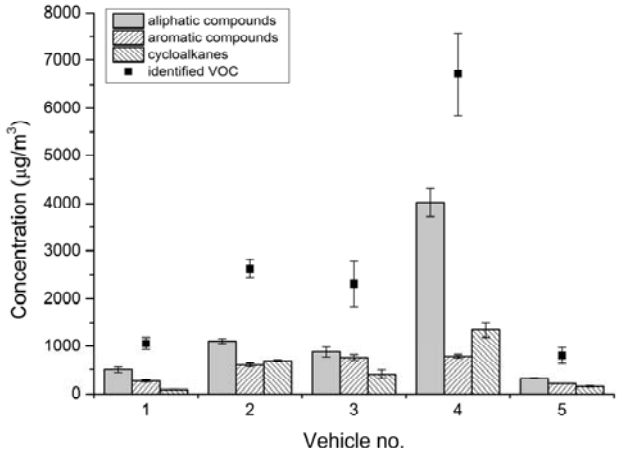

Fig. 1. Distribution of select group of hydrocarbons in tested vehicles in the reference to identified VOC emissions.

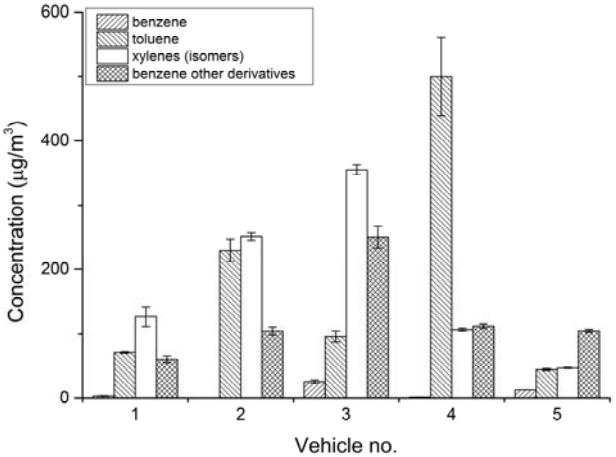

Fig. 3. Distribution of compounds in the aromatic hydrocarbon group.

Table 5. Concentrations and sampling precision for confirmed compounds measured inside vehicles.

Target VOC	Vehicle 1			Vehicle 2			Vehicle 3			Vehicle 4			Vehicle 5		
	Conc.[a] (µg/m³)	Conc.[b] (µg/m³)	RSD (%)	Conc.[a] (µg/m³)	Conc.[b] (µg/m³)	RSD (%)	Conc.[a] (µg/m³)	Conc.[b] (µg/m³)	RSD (%)	Conc.[a] (µg/m³)	Conc.[b] (µg/m³)	RSD (%)	Conc.[a] (µg/m³)	Conc.[b] (µg/m³)	RSD (%)
n-heptane	7.5	6.6	3.4	97.5	81.9	1.0	26.3	22.3	12.5	918.1	768.0	1.5	8.9	7.8	11.0
n-octane	3.8	3.6	10.7	29.5	26.4	0.4	15.4	13.7	13.6	58.0	51.6	0.8	5.2	4.9	1.0
n-decane	32.3	37.7	10.3	74.4	93.6	2.8	82.8	104.8	7.3	85.6	108.5	8.8	46.7	56.8	2.1
n-undecane	100.7	93.9	5.9	154.1	143.8	1.4	274.7	256.5	9.4	200.5	187.2	24.6	18.4	17.0	2.2
n-dodecane	ND[c]	ND[c]	-	16.8	15.4	7.9	ND[c]	ND[c]	-	15.1	13.8	18.0	ND[c]	ND[c]	-
benzene	ND[c]	ND[c]	-	ND[c]	ND[c]	-	31.0	31.5	11.3	ND[c]	ND[c]	-	12.3	12.8	0.5
toluene	35.7	35.7	11.4	140.7	140.7	11.2	240.9	240.9	8.1	59.0	59.0	2.9	20.8	20.8	1.6
ethylbenzene	43.9	42.1	2.2	262.7	252.6	20.0	124.7	119.8	8.9	519.7	500.0	12.1	45.6	43.8	3.7
m-xylene	15.4	15.0	20.7	51.5	50.1	11.1	91.7	89.3	8.0	18.1	17.6	3.4	10.6	10.3	1.3
p-xylene	25.2	25.0	15.0	87.2	86.3	10.5	114.5	113.2	7.7	30.3	30.0	0.2	15.3	15.1	1.6
o-xylene	15.2	15.3	7.9	61.6	61.6	4.1	81.2	81.1	8.4	22.7	22.8	1.9	8.9	9.1	6.1
1-methylethylbenzene	3.7	3.0	26.0	8.9	7.6	5.0	11.6	10.0	9.4	9.7	8.3	0.4	2.0	1.5	2.1
propylbenzene	ND[c]	ND[c]	-	ND[c]	ND[c]	-	18.5	16.8	5.0	ND[c]	ND[c]	-	8.6	7.7	1.4
1-ethyl-3-methyl benzene	ND[c]	ND[c]	-	ND[c]	ND[c]	-	37.2	35.1	6.8	ND[c]	ND[c]	-	13.7	12.9	1.1
1,3,5-trimethylbenzene	2.4	2.3	15.6	7.1	7.0	7.2	11.3	11.1	7.4	7.6	7.5	15.6	5.2	5.1	0.4
1-ethyl-2-methyl benzene	ND[c]	ND[c]	-	ND[c]	ND[c]	-	21.8	20.6	4.3	ND[c]	ND[c]	-	24.1	22.8	3.6
1,2,4-trimethylbenzene	8.8	8.5	15.2	23.2	22.4	9.2	43.1	41.6	7.0	24.9	24.0	6.0	22.3	21.6	0.5
1,2,3-trimethylbenzene	8.6	7.2	18.9	ND[c]	ND[c]	-	ND[c]	ND[c]	-	ND[c]	ND[c]	-	14.1	12.1	1.8
sum	353.6	341.8	-	1015.2	989.2	-	1266.5	1208.6	-	1969.5	1798.1	-	282.9	282.1	-

[a] concentrations calculated for each compound by calibration curve, [b] concentration in toluene equivalent, [c] ND – below the limit of detection

Table 6. List of 10 main compounds determined in vehicles.

Vehicle 1	(μg/m^3)	Vehicle 2	(μg/m^3)	Vehicle 3	(μg/m^3)	Vehicle 4	(μg/m^3)	Vehicle 5	(μg/m^3)
VOC_{id}	1,053.0	VOC_{id}	2,616.3	VOC_{id}	2,305.6	VOC_{id}	6,711.1	VOC_{id}	797.0
undecane	157.4	xylene (isomers)	251.1	xylene (isomers)	354.7	methylhexane	1,803.6	undecane	118.4
methyldecane	134.9	toluene	229.4	undecane	205.2	heptane	768.0	methyldecane	83.9
xylene (isomers)	126.4	undecane	143.8	methyldecane	197.2	toluene	499.8	decane	56.8
methylundecane	83.3	methyldecane	134.9	3,7-dimethyldecane	105.9	dimethylpentane	471.6	xylene (isomers)	46.3
toluene	70.5	cyclohexane	121.0	methyl-decahydronaphthalene	100.1	methylpentane	413.3	toluene	43.8
decane	63.0	ethyl-methyl pentane	110.0	toluene	95.9	methylcyclohexane	351.4	decahydronaphthalene	39.9
2-ethyl-1-hexanol	44.6	2,2,4,6,6-pentamethyl heptane	105.8	decahydronaphthalene	89.3	dimethylcyclopentane	249.7	trimethylbenzene	38.8
methyl-decahydronaphthalene	37.9	methylcyclohexane	100.0	decane	83.8	methyldecane	147.0	trimethylcyclohexane	17.9
trimethylbenzene	30.1	dimethyl cyclohexane	93.7	2,2,4,6,6-pentamethyl heptane	55.9	dimethylcyclohexane	133.1	2-methyl-decahydronaphthalene	14.7
ethylbenzene	25.6	decane	93.6	dimethylheptane	55.5	methylheptane	130.0	benzene	12.8
total	773.8	total	1,383.4	total	1,343.7	total	4,967.5	total	473.2
10 main VOC/VOC_{id} (%)	73.0	10 main VOC/VOC_{id} (%)	52.9	10 main VOC/VOC_{id} (%)	58.3	10 main VOC/VOC_{id} (%)	74.0	10 main VOC/VOC_{id} (%)	59.4

Conclusions

The present study concentrated on examining air composition inside five new vehicles. The vehicles under study were of different models or/and brands. The main reason for the observed differences may be divergences in car cabin equipment and the materials used to finish the interior.

The concentrations of target compounds in all vehicles varied between 1.5 and 918.1 μg/m^3. Aliphatic compounds were the main group of collected VOCs in each case. The main aliphatic pollutants inside the test vehicles were undecane and methyldecane for vehicles 1-3 and 5, and methylhexane and heptane for vehicle 4, while toluene and ethylbenzene were the main aromatic compounds present inside each vehicle. The sum of aliphatic, aromatic, and cyclic compounds accounted for ca. 80.5 to 91.5% of identified VOCs, while the 10 main compounds constituted 52.9-74.0% of identified VOCs. The concentrations calculated were influenced by the calibration curves applied, especially in the case of samples collected from vehicles with relatively high total volatile organic compound concentrations.

Taking into account the fact that new vehicles were examined, it can be stated that all compounds identified originated from off-gassing of interior materials. The concentrations of in-vehicle organic compounds were at a rather high level, for that reason a vehicle's interior should be well ventilated before use. Johansson [34] claimed that within weeks or months the VOC concentration inside a car cabin decreases to a low level, but complete elimination of those compounds is impossible. Therefore, it is appropriate to make all efforts to minimize the presence of VOCs and their concentrations in vehicular passenger compartments in order to reduce possible negative health effects.

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