original article

Effects of vehicle ventilation system, fuel type, and in-cabin smoking on the concentration of toluene and ethylbenzene in Pride cars

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ABSTRACT

Aims: This study aimed to evaluate the concentrations of toluene and ethylbenzene inside the Pride cars and to investigate the effects of the vehicle ventilation system, fule type, and interior smoking on their concentration.

Materials and Methods: In the present study, 152 different models of Pride cars, stopped in parking [classified into three groups including: Pride KIA (Group I), Saba (Group II) 131, 141, 132, LX111, SX, and Nasim (Group III)] were sampled using activated carbon sorbent tube. The samples were analyzed using gas chromatograph-mass spectrometer. The vehicle ventilation, fuel type, and in-cabin smoking were recorded.

Results: The average concentrations of toluene and ethylbenzene were 105.4 ± 270.5 and 19.09 ± 33.97 $\mu g/m^3$, respectively. The average concentration of toluene was higher than that of ethylbenzene. The concentration differences of both toluene and ethylbenzen among the studied groups were not statistically significant.

Conclusion: The ventilation condition, fuel type, and in-cabin smoking were not significantly impressive on the toluene and ethylbenzene concentrations inside the cars. However, simultaneous usage of the vehicle ventilation system and natural ventilation (windows) could lead to little decrease in toluene concentration levels inside the car, while smoking consumption by passengers can increase them.

Key words: Ethylbenzene, fuel, in-vehicle, smoking, toluene, ventilation system

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INTRODUCTION

Volatile organic compounds (VOCs) are a different group of organic hydrocarbones released from a wide variety of sources. They can be combined with the majority of harmful air pollutants. The exposure to VOCs may cause a wide range of the health effects such as the symptoms related with neural inflammation, allergy, liver toxicity, nervousness, and cancer.[1]

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Toluene and ethylebenzene are most commonly compounds found in the urban ambient air.[2,3]

One of the most important pathogenic effects of toluene (C_7H_8) isits effect on the central nervous system (CNS) including numbness, euphoria following by impaired balance, tremor, buzzing in the ears, blurred vision, paranoia, atasia, convulsion, and ultimately coma. The acute exposure to toluene results in several short-term effects on the CNS such as headache, emotional lability, convulsion, unconsciousness, and death.[4] Ethyl benzene (C_8H_{10}) is a colorless flammable liquid with an odor similar to that found in natural products like coal and gasoline. It can be also found in several man-made products such as pesticides and paints. The high-level exposures to airborn ethylbenzene can lead to dizziness, inflammation, and the throat and eyes irritation. Damages of CNS has been atributed to its higher concentrations for both humans and animals. Higher level exposures to ethylbenzene also can cause liver problems in the human.[5]

There is a relationship between the chronic exposure to ethylbenzene and the harmful effects both on renal and respiratory systems. Ethylbenzene is classified as a potential carcinogen to humans (Group 2B) by the International Agency for Research on Cancer.[6]

Exposure to the different chemical compounds including toluene and ethylbenzene occures not only in the workplaces,[7,8] but also in residences[9,10] and urban areas.[11,12]

It was illustrated for the first time in 1980 that the indoor VOC exposures mostly exceed ambient exposures.[13] Moreover, individual exposures may strongly be dependent on indoor exposures to VOCs because the majority of people spend more than 80% of their time indoors.

Researches have shown that the monitoring of microenviroments including workplaces, public transport, and restaurants mostly provides a comprehensive view of the personal exposure to VOCs.[14]

Since people spend the majority of their time on commuting by motor vehicles, the cabin of automobiles can be considered as one of the important microenvironments.

With rapid growth of economy, using motor vehicles has dramatically become prevalent and the vehicle manufacturing companies report an increase in their products market.

The number of different models of Pride cars in Iran manufactured in 2011 was 589,000.[15] Air pollutants inside the commuting vehicles might be due to in-vehicle emissions, fuel leak, and penetrating of the ambient air into the vehicles.[16]

Studies indicate that toluene and ethylbenzene are two in-cabin pollutants that their harmful and dangerous effects have been proved.[17,18]

Chen *et al*.,[19] investigated 22 public buses in Shanghai, China to estimate in-vehicle concentrations of toluene and ethylbenzene as well as analyzing the factors affecting the target pollutants. Results showed that the concentrations of toluene and ethylbenzene were 53.3-266 μg/m^3 (microgram per cubic meters) and 19.6-95.9 μg/m^3, respectively.

According to Balanay and Lungu[20] study, the exposure levels of 15 Jeepney drivers to toluene and ethylbenzene were 196.6 and 17.9 μg/m^3, respectively.

Guang-Shan Zhang *et al*.,[16] sampled 822 cars parked in a parking lot using the activeted carbon. The measured concentrations of toluene, xylene, and formaldehyde were 1220, 170, 80 μg/m^3, respectively.

In another study, Esteve-Turrillas *et al*.,[21] reportedthat the passengers inside the cars were exposed to the elevated levels of benzene, toluene, ethylbenzene and xylenes (BTEX). The concentrations included toluene with 33-258 μg/m^3 and xylene isomers with 20-169 μ/m^3.

Fedoruk and Kerger[22] evaluated the effect of ventilation condition on the in-vehicle concentrations of VOCs. The results showed that all three different ventilation conditions including the air-conditioner, the air vent only, and the open windows were able to reduce the concentration of the compounds under standard levels.

Manini *et al*.,[23] in Italy, investigated the BTEX concentrations inside the taxis, taxi drivers' exposure, and the effect of the interior tobacco smoke on the concentrations of the substances. The in-cabin concentrations of toluene and ethylbenzene were reported as 35.2 and 6.2 μg/m^3, respectively.

The results extracted from the previous studies indicate the necessity of the consideration to the VOCs concentrations inside the cars as well as the factors affecting the concentration changes.

According to the literature review, however, there is no study conducted on different models of Pride cars in Iran. The aim of this study, therefore, was to detectthe target compounds concentration with an interior source in Pride cars manufactured in Iran as well as evaluating the impact of vehicle ventilation condition and in-cabin tobacco smoke on the interior concentrations of toluene and ethylbenzene in the vehicles which have allocated a major portion of the automobiles manufactured and used in Iran.

MATERIALS AND METHODS

Study plan

The purpose of the present study was to evaluate the in-vehicle concentration of toluene and ethylbenzene with an interior source in the Pride cars produced in Iran and to investigate the effect of the vehicle ventilation condition, fuel type, and interior smoking on the target compounds concentration.

As the presenceof the target compounds can be due to inside emission of the materials, fuel leakage, and penetration of the polluted ambient air into the vehicle, to eliminate the influence of fuel leakage on the results, all samples were taken from turned off cars parked in a covered parking lot. Moreover, to control the effect of the polluted ambient air on in-vehicle concentrations of the target compounds, one environmental sample was taken from the parking space surrounding air per each sample taken from in-cabin air.

Stratified random sampling method was used to determine the number of samples.

The public vehicles were eliminated in the present study to control the vehicle application effect on the current research desired results. Different models of car Pride were investigated in the present study included: Pride KIA (Group I), Saba (Group II) 131, 141, 132, LX111, SX, and Nasim (Group III).

A varity models of Pride cars were under the current study and to better evaluation, the tested cars were classified into three specified groups. The sampling then carried out on 50 Pride model KIA, 52 cars Pride model SABA, and 50 cars Pride with other models.

Several samples were taken from fabric cars and at the market office to determine the initial concentrations of the compounds inside the car at the time of being manufactured and before being utilized. Other necessary information such as manufacturing years, the vehicle ventilation condition, fuel type, and smoking inside the car was collected usinga check list.

Measurement method

The sampling was conducted based on National Institute for Occupational Safety and Health sampling method No. 1500-1501.[16,24]

The samples were collected using low-flow rate sampling pump (Model 222-3) SKC Inc-England) drawing air through an active carbon tube (SKC. No 226-01).

Temperature and humidity were also mearsured by temperature humidity meter (model sinometer CTH-609).

The sampling pump was calibrated by a digital soap bubble flowmeter (Defender, Model 570 made in Bios company, England) prior to each sampling event. The vehicles under investigation had different manufacturing years, from 0 year (2012) to 17 years (1995) that were classified into three groups to meet the desired results.

A covered parking lot in Isfahan was selected to eliminate the effect of solar radiation on the car and intense sunlight-induced heat.

After the vehicle entered the parking garage and parked in the specified parking space, the car was turned off and all the windows were rolled up. After 10 min, the suspended absorbant tube containing activated carbon inserted to the calibrated pumpwas sent into the back part of vehicle cabin. Based on the pretest, then, the sampling took about 20 min at an air flow rate of 200 mL/min.[16]

The samples were sealed and kept in the refrigerator until analysis. To prepare the samples, the target compounds absorbed by the active carbon tube were moved to a vial followed by adding 1 mL carbon disulfide to desorb the tested VOCs.

Chemical analysis

A gas chromatography (GC) (Agilent: 7890A: USA) with a mass spectrometer (MS) (Agilent: 5975C: USA) and split sample distribution (1:10) was used to analyze the samples.

The column used in the system was HP-5 ms (5% phenyl-95% dimethyl polysiloxane; 30 m length. 25 mm ID, 0.25 μm film tickness).

To analyze the samples, the column oven temprature was programmed at 40°C for 5 min with an increase of 5°C per minute to the point where the temprature reaches 150°C and remains for 2 min.

To calibrate GC-MS, the known concentrations of the target compounds were made and injected to GC as the standard materials.

After preparation, the samples were injected to the GC through an automated injection system (CTC PAL-combi PAL). The concentrations of the pollutants were determined based on the standard curve related to each sample and the sampling size and reported in $\mu g/m^3$.

The calibration curves of toluene and ethylbenzen are represented in Figure 1.

Nonparametric Kruskal-Wallis test was applied to compare the inside concentrations of target compounds among tested vehicles and the parameters under investigation.

RESULTS

The exposure to VOCs can be caused by leaking vehicle fuel or the interior emitted sources including the cabin components or deodorizers. Toluene and ethylbenzene are selected as two tested VOCs because they have the potential of affecting the public health.[25,26]

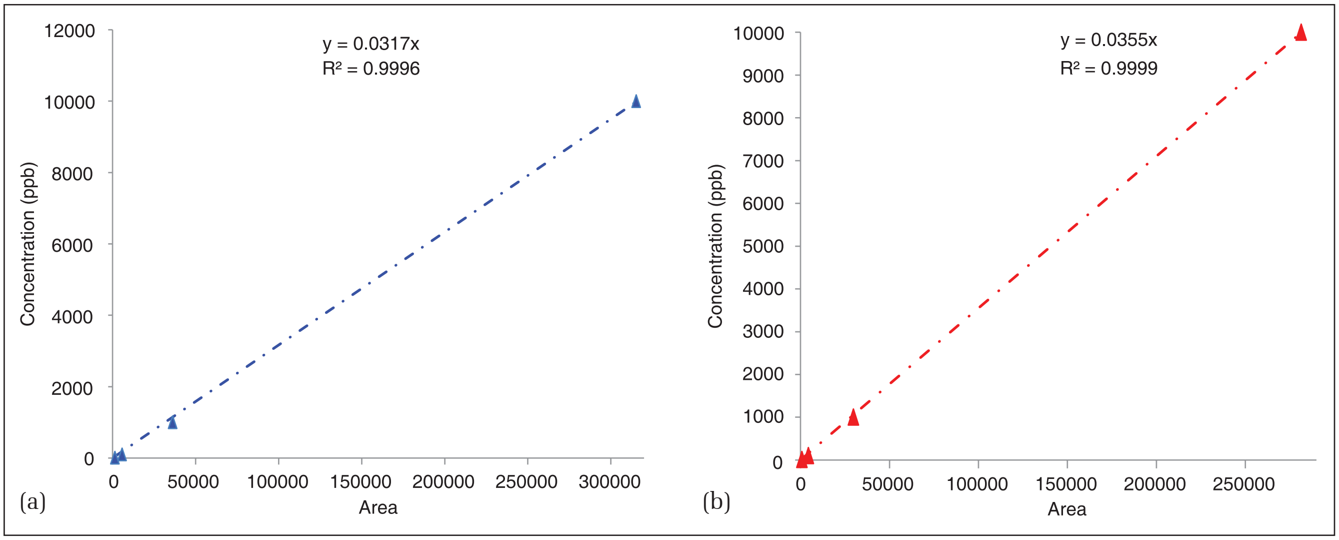

Figure 1: The standard curves of (a) toluene and (b) ethylbenzene

Table 1: Toluene and ethylbenzene concentrations (average standard deviation) in terms of the vehicle model and age

Vehicle (Pride) model	Vehicle age	Toluene (μg/m³)			Ethylbenzene (μg/m³)	
		N	Mean	SD	Mean	SD
Group I	Non-used[a]	—	—	—	—	—
	1-2	2	30.78	28.53	11.67	5.76
	2-4	7	19.78	18.91	9.01	3.74
	>4	41	121.9	311.2	23.06	43.52
	Total	50	103.95	283.94	20.63	39.7
Group II	Non-used	2	10.56	—	7.6	—
	1-2	2	50.07	55.87	7.6	—
	2-4	23	34.73	48.52	11.47	9.37
	>4	25	112.85	207.68	17.38	23.35
	Total	52	71.95	151.6	14.02	17.5
Group III	Non-used	12	323.96	615.36	32.55	55.56
	1-2	15	121.8	184.34	27.93	38.66
	2-4	14	16.53	12.68	8.16	2.12
	>4	9	126.25	258.19	24.16	49.7
	Total	50	141.64	344.12	22.83	28.14

[a]These vehicles (Pride, KIA, Group I) have not been manufactured recently and their non-used vehicles were not available.

The average concentrations of toluene and ethylbenzene among 152 tested Pride vehicles were 105.4 ± 270.4 and 19.09 ± 33.97 μg/m³, respectively.

The average temprature and humidity during the study were 17.2°C ± 5.9 and 26.16% ± 8.7, respectively.

The in-vehicle detected concentrations of toluene and ethyl benzene are presented in Table 1 in terms of the vehicle model and age.

The effects of the utilized ventilation condition of the car, the fuel type, and smoking inside the car on the target VOCs were investigated. The sum of results related to these parameters are presented in the Table 2.

DISCUSSION

There was not any significant difference between three studied groups according to nonparametric Kruskal-Wallis test.

The outside concentrations of toluene and ethylbenzene were below the GC-MS detecton limit, so that measuring toluene and ethylbenzene concentrations simultaneously both inside and outside the car could resulted in eliminating the influence of environmental concentrations of the target compounds on interpreting the results related to both in-cabin concentrations and outside concentrations of toluene and ethylbenzene.

The concentration of toluene inside Pride vehicles was higher compared with the concentration of ethylbenzene. It can be

Table 2: Toluene and ethylbenzene concentrations under different ventilation condition, fule types, and driver smoking habit

Variable		Toluene (μg/m³)			Ethylbenzene (μg/m³)	
		N	Mean	SD	Mean	SD
Ventilation condition	Vehicle ventilation	15	129.02	335.98	17.22	25.2
	Window	49	94.13	249.5	17.25	36.5
	Both ventilation	74	75.2	149.9	18.82	29.79
Fuel type	General gasoline	86	63.44	171.6	17	31.51
	General and super gasoline	25	139.55	302.2	15.37	23.91
	Gasoline and CNG	27	117.32	233.11	24.11	38.4
Smoking inside the car	Yes	26	122.52	210.31	22.7	34.02
	No	112	79.71	214.46	17.02	31.2

due to the fact that toluene is the most important component of the solvents used in painting and coating the surface of decoration inside the car.[16]

The results is consistent with Fedoruk and Kerger[22] study which measured the concentrations of toluene and ethelbenzene in Chevrolt, Ford, and Toyota cars.

Geiss *et al*.,[27] reported the toluene and ethylbenzene concentrations inside cars as 98.8 and 11.7 μg/m³, respectively.

The cars in Group I (Saipa) showed higher levels of toluene and ethylebenzene in-vehicle concentration in comparison with the other studied groups (Group I, Kia; Group II, Saba); however, based on Krus kal-Wallis test results, the difference between the groups were not statistically significant for both toluene and ethylbenzene. In the present study, the average concentrations of toluene and ethylebenzene in the car Kia were 103.95 and 20.63 μg/m³, respectively, that showed lower levels of target compounds in comparison with the Jo and Park[28] study in the South Korea which reported the concentrations of toluene and ethylbenzene as: 3331 and 42.8, respectvely, in car Kia. This inconsistancy may be due to the usage to tenax sorbent in Jo and Park's[28] study as the sorbent with high ability to absorb low-level concentration compounds.

To compare the concentrations of the target compounds both before and after using the car, some samples were taken from fabriccars parked in the market offices.

Although the concentrations of the target compounds in fabriccars were slightly higher than other cars, using Kruskal-Wallis test, the difference between the cars with different age (manufacturing year) was not statistically significant.

In the studies carried out separately by Zhang *et al*.,[16] and Fedoruk and Kerger,[22] the VOCs concentrations inside the newer cars were also higher. The higher concentrations of the target compounds in newer cars may be due to the higher potential of the materials used in decoration of the surfaces inside the car inemitting more VOCs at the early stages of installment.[16]

The effects of the utilized ventilation system, fuel type, and smoking consumption inside the car were also evaluated in this study. The ventilation mechanisms used in the studied cars included: Open windows, vehicle ventilation system, and the simultaneous usage of both mentioned ventilation systems.

Based on Krusal-Wallis test, the effect of ventilation system on toluene and ethylbenzene concentrations was not statistically significant.

In Ongwandee and Chavalparit[29] study also the effects of open and close windows on toluene and ethylebenzene concentrations were investigated; however, Wilcoxon test showed no significant difference.

In the study performed by Jo and Park,[28] there were no significant differences between the ventilation systems under investigation (the ventilation system, windows open, and turned on fan).

The results indicated a remarkable decrease in toluene concentration when using the two ventilation systems at the same time. It is recommended, therefore, to apply two ventilation systems simultaneously instead of using each one separately.

The concentration levels of ethylbenzene in terms of ventilation systems showed the greater pollution in the vehicles using natural ventilation (open windows) that can be due to the penetration of the polluted ambient air into the car.

The average concentrations of toluene and ethylebenzene were relatively higher in the cars with either smoker drivers or passangers; however, based on the Kruskal-Wallis test, the effect of in-vehicle smoking consumption on toluene and ethylebenzene was not statistically significant in this study.

In a study carried out by Balanay and Lungu[20] on Japanese drivers, smoking consumption was not also significantly effective on the concentration of the target compounds.

Table 3: Comparison of the mean concentrations of toluene and ethylebenzene in different studies

Study	Location	Average concentration of toluene inside the car (μg/m^3)	Average concentration of ethylebenzene inside the car (μg/m^3)
Current study	Isfahan, Iran	105.04	19.09
Geiss *et al*.[27]	Italy	98.8	11.7
Som *et al*.[18]	Kolkata, India	186.7±118.2	130.5±76.4
Lau and Chan[32]	Hong Kong, China	43.5±12.6	4.4±1.6
Fedoruk and Kerger[22]	California, USA	169.6±67.2	15.7±11.7
Chan *et al*.[17]	Guangzhou, China	108.5±30.6	20.3±6.9
Jo and Yu[33]	Taegu, Korea	175	15.1

Manini *et al*.,[23] also found no significant relationship between in-vehicle sampling and the individual sampling of either smoker or nonsmoker drivers.

The concentrations results of the target compounds investigated both for smoker and nonsmoker drivers were 34.2 and 36.5 (μg/m^3) for toluene and 6.1 and 6.3 for ethylebenzene, respectively.

Although Jo and Park[28] found the fuel type can be one reason for in-vehicle toluene and ethylbenzene concentrations to be different, there was no considerable difference in the current study between the fuel type and target compounds concentration.

There was no standard for the quality of in-vehicle air in Iran; but in the present study, the average concentrations of toluene and ethylebenzene were both lower compared to the Hong Kong indoor Air Quality Objective[30] standard that is useful for both toluene and ethylbenzene and the National Indoor Air Quality Standards[31] that can be practical only for toluene.

The average concentrations of the target compounds were varied in the present study that can be due to the sampling stuation, different vehicle models, the drivers condition, fuel type, local climatic conditions, and so on. The results of several studies have been illustrated in Table 3.

Regarding the fact that Environmental Protection Agency (EPA) methods and the environmental absorbants have the ability of detecting low-level concentrations, so their application can be attributed to more complete results.[3,34]

CONCLUSION

In the current study, the in-vehicle concentrations of toluene and ethylbenzene with an interior emission sources were investigated under static conditions.

The samples were taken from turned off cars and the results showed that the concentrations of the target compounds in surrounding ambient air were below the GC detection limit; it is possible, therefore, to claim that the detected concentrations are related to the in-cabin emitted compounds. The average concentration of toluene was higher than that of ethylbenzene in all samples.

Although the average concentrations of toluene and ethylbenzene in the interior of the cars were different in terms of ventilation condition, fuel type, and smoking inside the cars, the differences were not statistically significant.

The results also indicated a relative impression of two ventilation conditions applied simultaneously inside the car as well as in-vehicle smoking consumption.

Nevertheless, the findings illustrated the in-vehicle concentrations of the compounds under study to be present and the necessity of a standard development specialized for the interior air of the vehicles.

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