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Assessment and control of VOCs emitted from gas stations in Tehran, Iran

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ABSTRACT: In this research, gasoline vapours including Benzene, Toluene, Xylene (BTX) and Total Volatile Organic Compounds (TVOCs) emitted from vent pipes of underground storage tanks (USTs) were measured at six gas stations in Tehran. Thereafter, gas station No. 29 was selected as a pilot station and equipped with a vapour control system. The vapours were measured during the summer of 2013 and winter of 2014 in two states, before and at the time of gasoline discharge from a petrol tanker to the UST. The results reveal that the average of BTX and TVOCs are 161.22, 200.81, 229 and 647.01 ppm, respectively, higher than the World Health Organisation (WHO) guidelines. The average of TVOCs and BTX in the situation in which the control system is inactive at the pilot station, are 259.13, 55.9, 73.03 and 96.88 ppm, respectively. After activating the control system at the pilot station, the VOCs were reduced by 0.01 ppm. Almost 99.99% control was obtained for this system and 87% of the people living around the pilot station were satisfied and no longer had any complaints about the bad odour of VOCs. It can be concluded that gasoline discharge from the petrol tanker to UST, is the main reason behind the overproduction of VOCs in Tehran's gas stations ($P<0.001$). So, the most important element is to reduce VOCs at Tehran's gas stations by installing a vapour control systems in all the stations and activating the systems at the time of gasoline discharge.

Keywords: benzene, gas station, toluene, xylene, volatile organic compounds (VOCs).

INTRODUCTION

Volatile organic compounds (VOCs) are present in the urban atmosphere due to both exhaust and evaporative emissions from vehicles and fuel delivery outlets (gas stations (petrol stations) (Singh et al., 2012). VOCs from gasoline (petrol) vapours escape into the atmosphere while vehicles are being refuelled at gas stations

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(Hess, 2002). Therefore, gas stations can be considered among the main sources of VOCs emissions in urban areas. The main sources of VOCs emission at gas stations are: a) gasoline vapours emission from vent pipes of underground storage tank (UST) both at the time of discharge of petrol tanker into the UST, as well as during the day (breathing evaporation of the UST); b) gasoline vapours emission at the time of vehicle fuelling; c) gasoline vapours emission from a UST which has not been waterproofed completely (De Nevers, 2000).

VOCs associated with gasoline vapour emissions and motor vehicle exhaust, are pollutants of concern because of their toxicity (USEPA, 1990). Short-term (acute) exposure to high concentrations of many VOCs can cause nausea, dizziness, tremors or other health problems. Long term (chronic) exposure to some VOCs may cause cancer (Johnson, 2013). VOCs also play an important role in the formation of ground-level O_3 and photochemical oxidants associated with urban smog (Mohamed et al., 2002). VOCs such as Benzene, Toluene and Xylene (BTX) are considered as predominant pollutants and have adverse effects on both human health and the environment (Franco et al., 2012).

Recently, there have been many studies concerning the emission of gasoline vapours (VOCs) from gas stations in urban areas. Atabi et al. (2013) conducted the assessment of variations in benzene concentration, produced from vehicles and gas stations in Tehran, using GIS. The results of the study revealed that the benzene concentration levels in Tehran are distinctly more than its standard level. This is mainly attributed to the lack of a standard system for controlling petrol vapour at the gas stations. Singh et al. (2012) investigated the concentration of VOCs in the urban atmosphere of the national capital Delhi, India. They showed that the mean concentration of BTX at all sites especially near gasoline filling stations, were higher than the limiting value prescribed by the Central Pollution Control Board. This indicates that in the urban atmosphere, BTX does not dissipate easily in the environment. Zhang et al. (2013) investigated species profiles and normalized the reactivity of VOCs from gasoline evaporation in China. The results suggested that reducing VOC emission from the gasoline distribution sector, would particularly benefit ground-level ozone control in China. Cruz-Núñez et al. (2003) evaluated the efficiency of vapour recovery systems and personal exposure, at nine gasoline service stations in Mexico City. Each one of the nine gasoline service stations tested, reported efficiencies above 80% in the recovery of vapour losses from gasoline. Srivastava (2004) investigated the VOCs concentration at major sources like traffic junction, residential areas, commercial areas, industrial areas and petrol pumps in Mumbai City, India. The results showed that in order to control VOCs in air, the management strategy should focus on cost effective vapour recovery systems at refuelling stations and in vehicles. Yimrungruang et al. (2008) studied the characterization and health risk assessment of VOCs, in gas service station workers. The results showed that at the nine gas service stations of the research, Benzene may have been the main cause of both cancer and non-cancer risks. Jafari and Ebrahimi (2007) conducted a study on the risk assessment of Benzene, as one of the VOCs air pollution in Tehran, Iran. They concluded that the concentration of Benzene emission to air due to deficient oxidation of fuel in vehicles or evaporation of gasoline at gas stations and the gas tanks of the automobiles, at market station in Tehran shows significantly higher values compared to the EPA guidelines prescribed in Iran.

The city of Tehran, the capital of Iran, suffers from severe air pollution and is often covered by smog. About 80% of the city's pollution is due to cars (Wikipedia, 2015). Tehran has 141 gas stations for vehicles (Tehran NIOPDC, 2014). Gas stations are among the main sources of VOCs in Tehran. Thus, there was a need to assess VOCs emission from Tehran's gas stations. The goals of this study were to assess the gasoline vapours (VOCs) emitted from Tehran gas stations and develop a method in order to control and mitigate the toxic vapours.

MATERIALS AND METHODS

The study was conducted in the city of Tehran, capital of Iran. Six gas stations (petrol stations) were selected in the city based on a random method. Among the six stations, gas station No. 29 was selected as a pilot station (Satar Khan St. of Tehran) for two main reasons: i) more than 100000 litres of gasoline (petrol) are sold daily on average and ii) it is located in a populous area. At the time of discharge of gasoline from the petrol tanker to the underground storage tank (UST), nearby residents have complained about the unpleasant gasoline vapours (VOCs). In order to control and mitigate gasoline vapours at the pilot station, Stage I procedure was performed as follows:

As gasoline vapours normally escape from the UST vent pipes, a return line was installed for the transfer of vapours between the UST and petrol tanker. In addition, pressure and vacuum (P&V) valves were installed on the outlet of UST vent pipes to prevent vapours from escaping to the atmosphere. Therefore, vapours will be conducted to the petrol tanker (Powell, 2011; Zink, 2013) as shown in Figure 1.

By using a VOC multi-gas detector, gasoline vapours (TVOCs and BTX) emitted from vent pipes of USTs at the five gas stations and also the pilot station were measured both in warm and cold seasons (summer 2013 and winter 2014). Measurements were conducted in the two states, both before and at the time of discharge of gasoline from the petrol tanker to the UST. At the pilot station, measurements were carried out in situations in which the vapour control system was both active and inactive.

All measurements were taken at a distance of 30 cm from the outlet of the UST vent pipe (near the tank vent). A FirstCheck+ VOC multi-gas detector, upgradeable version 5000Ex was used to measure VOCs. The VOC multi-gas detector, detects VOCs from 1 ppb – 10,000 ppm and has been manufactured by ION SCIENCE LIMITED in UK (Ion Science, 2008).

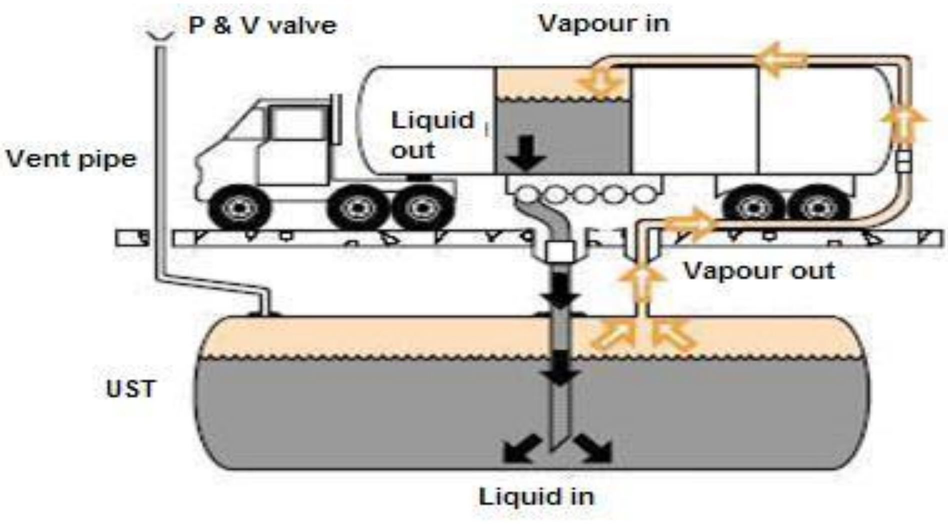

Fig. 1. Discharge of gasoline from petrol tanker to UST (Stage I) (Rankin, 2013)

After activating the vapour control system at the pilot station (station No. 29), 100 questionnaires were randomly divided among 100 local residents, on whether they are satisfied about the odour from gasoline vapours. Finally, the responses were statistically analysed.

In order to analyse the collected data (the VOCs concentrations), SPSS software version 16.0 was used. Descriptive statistics of TVOCs, Benzene, Toluene and Xylene were analyzed by the software. Moreover, Paired-Sample T Tests for emission of TVOCs, Benzene, Toluene and Xylene between two states of the VOCs i.e. before and at the time of discharge of gasoline from the petrol tanker to UST, were performed in the SPSS software medium.

RESULTS AND DISCUSSION

Descriptive statistics of the VOCs including Benzene, Toluene and Xylene (BTX) and Total Volatile Organic Compounds (TVOCs) at the six gas stations of Tehran are as shown in Table 1.

Mean values of the VOCs emissions in summer and winter at the six gas stations of Tehran are shown in Table 2.

Results of the VOCs measurements (in summer and winter) including BTX and TVOCs at the pilot station (gas station No. 29) are given in Table 3. Table 3 indicates the concentrations of VOCs in a situation in which the vapour control system is active at the pilot station.

Table 1. Descriptive statistics of VOCs concentrations (ppm)

VOCs	Minimum	Maximum	Mean	SD
TVOCs (ppm)	1.30	2700	647.01	785.62
Benzene (ppm)	0.10	790	161.22	208.38
Toluene (ppm)	0.30	850	200.81	248.17
Xylene (ppm)	0.50	955	229	274.27

Table 2. Mean values of VOCs concentrations in summer and winter (ppm)

VOCs	Season	Mean
TVOCs (ppm)	Summer	859.78
	Winter	434.23
Benzene (ppm)	Summer	212.62
	Winter	109.83
Toluene (ppm)	Summer	269.63
	Winter	132
Xylene (ppm)	Summer	299.11
	Winter	158.82

Table 3. A situation in which the vapour control system is active at the pilot station

Station No.	Season	Condition	TVOCs (ppm)	Benzene (ppm)	Toluene (ppm)	Xylene (ppm)
29 (pilot)	Summer	Before discharge	<0.01	<0.01	<0.01	<0.01
		At the time of discharge	<0.01	<0.01	<0.01	<0.01
	Winter	Before discharge	<0.01	<0.01	<0.01	<0.01
		At the time of discharge	<0.01	<0.01	<0.01	<0.01

Paired-Samples T Tests for emission of TVOCs and BTX under the two conditions of the VOCs i.e. before and at the time of discharge of gasoline from the petrol tanker to UST, show that $P<0.001$.

According to Table 1, the mean values of TVOCs and BTX are 647.01, 161.22, 200.81 and 229 ppm, respectively, higher than the WHO outdoor environmental air guidelines. WHO guidelines for TVOCs and BTX are 0.24, 6.1, 38.77 and 33.65 ppm, respectively. Mean values of TVOCs and BTX before discharge of gasoline were 18.02, 3.28, 4.63 and 6.59 ppm, respectively, at the six gas stations. Also, mean values of TVOCs and BTX at the time of discharge of gasoline were1276, 319.17, 397 and 451.33 ppm, respectively, at the six gas stations. The VOCs at the time of discharge of gasoline from petrol tanker to UST, have concentrations which are greater than the WHO guidelines. Such concentrations of the VOCs can cause serious health problems for the local residents in the vicinity of the six gas stations in Tehran megacity.

According to the results of Paired-Samples T Tests for emission of TVOCs and BTX, there is a significant difference between the two states of the VOCs including before and at the time of discharge of gasoline from petrol tanker to UST; since significant levels show at $P<0.001$. As mentioned above, the emission of VOCs at the time of gasoline discharge, are greater than before its discharge.

According to Table 2, mean values of TVOCs and BTX at the six gas stations of Tehran in the summer are bigger than values measured in the winter. This is due to the summer’s high temperature which causes greater evaporation compared with less evaporation in winter, due to lower temperature.

Table 3 indicates the concentrations of VOCs, in a situation in which the vapour control system is active at the pilot station. The VOCs emissions in summer and winter at the pilot station, before and at the time of discharge of gasoline, are less than 0.01 ppm as shown in Table 3 which reports concentrations of less than 10 ppb, the lower limit of detection by the instrument. These are remarkably low values as the gasoline vapours (VOCs) at the pilot station, were controlled and mitigated. As a matter of fact, gasoline vapours in the UST of the pilot station escaped from vent pipes. Therefore, by installing a return line for the transfer of vapours between UST and petrol tanker and installing the P&V valves on the outlet of the UST vent pipes, it is possible to prevent vapours from escaping to the atmosphere. So, the vapours will be conducted to the petrol tanker and unable to escape from P&V valves of the UST vent pipes, as illustrated in Figure 1. That is why the VOCs concentrations of pilot station are less than 10 ppb which are low values. The measurements reported in Table 3 were taken at a distance of 30 cm from the P&V valve of the UST vent pipe. Another point is that, at the pilot station (station No. 29), in the case of inactive vapour control system, the mean values of TVOCs and BTX were 259.13, 55.9, 73.03 and 96.88 ppm, respectively. If the VOCs concentrations of pilot station in Table 3 are compared with those of the pilot station in inactive situation (inactivated vapour control system), it will be inferred that the vapour control system has been far too effective to reduce the VOCs emissions. Almost 99.99% control was achieved for this system.

The questionnaires show that, 87% of the local residents living near gas station No. 29, were satisfied with the vapour control system of this station and no longer complained of unpleasant odours from the release of VOCs.

Vapour control technology dates back to the 1970s and was common in California. More than 40 years later, its application in Tehran is significantly different as only

Stage I, was implemented at the pilot station. Stage II was not performed due to some technical and economic restrictions including: a) implementation of Stage II requires the site of the gas station to be excavated for piping (Figs. 2 and 3). b) special nozzles and dispensers are required to perform Stage II, which are also very expensive (Fig. 2). c) in order to perform Stage II, a special door has to be designed for the vehicle tank and manufactured by automobile factories, as it is a long-term and expensive project. On the whole, Stage II can be described as follows:

At the time of vehicle fuelling at the gas station, liquid gasoline flows into the vehicle's tank, during which gasoline vapours are emitted from the vehicle's tank to the atmosphere. In order to prevent the vapours from emitting to the atmosphere at the time of vehicle fuelling, a coaxial nozzle is used. As a result of pressure difference at the time of vehicle fuelling, vapours in the vehicle tank will be conducted to the UST by a return line. By installing the pressure and vacuum (P&V) valves on the outlet of UST vent pipes, it is possible to prevent UST vapours from escaping to the atmosphere (Fung and Maxwell, 2011; Powell, 2011; Zink, 2013) (Fig. 2).

The complete vapour control technology (including Stage I and Stage II), is illustrated in Figure 3.

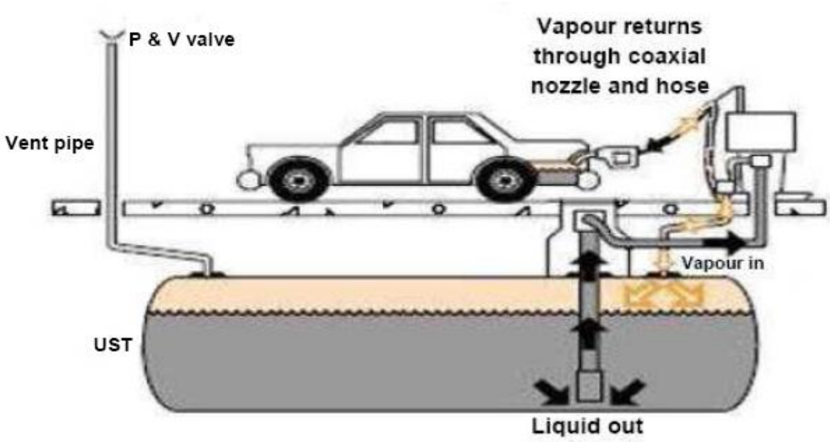

Fig. 2. Discharge of gasoline from UST to vehicle tank (Stage II) (Rankin, 2013)

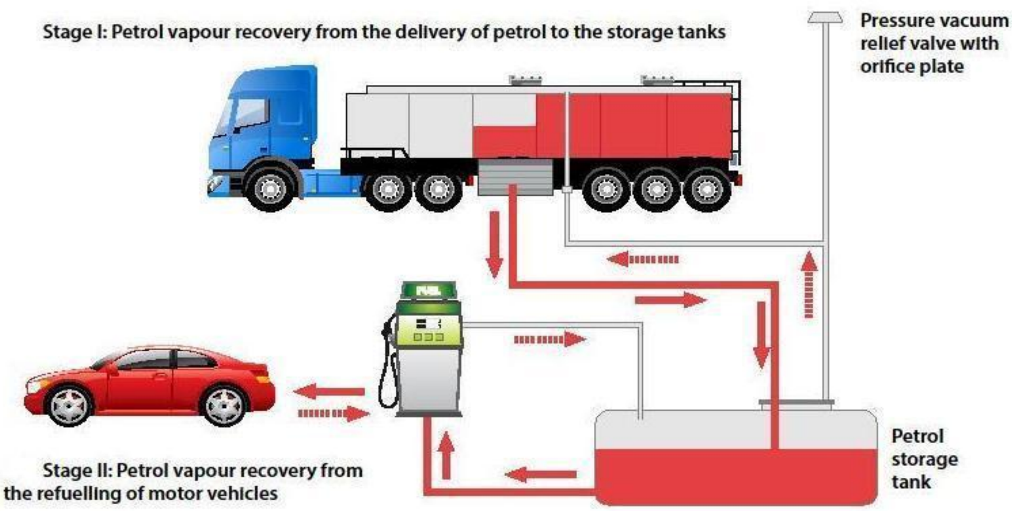

Fig. 3. The vapour control technology including Stage I and Stage II (SEPA, 2015)

By comparison, Zheng et al. (2011) studied the characterization of gas station emissions, during the 2008 Beijing Olympic games. Their results indicated a successful implementation of vapour recovery system in the gas stations of Beijing. On average, about 18 ppb of Benzene was detected at each gas station, twice as much as the US Environmental Protection Agency recommended safe chronic exposure level. The average concentration of Benzene in the situation in which the vapour control system was active at the pilot station of Tehran, was 0.01 ppm (10 ppb) at most; less than 18 ppb of Beijing. Moreover, Majumdar et al. (2008) studied source apportionment of VOCs at the petrol pumps in Kolkata, India. They found that among the measured volatile organic compounds, Toluene was the most abundant; whereas among the measured BTX at the six gas stations of Tehran, the mean value of Xylene was the most abundant. In addition, Correa et al. (2012) studied the impact of BTEX (benzene, toluene, ethyl benzene and xylenes) emissions from gas stations of Rio de Janeiro, Brazil into the atmosphere. Results indicated that among the measured BTEX, Toluene was the most abundant.

Also, Heitner (1973) released a status report on the control of gasoline vapour losses from station and vehicle filling in California. This report states that San Diego implemented vapour control technology at its gas stations on January 17, 1972 in two steps. The first step consisted of the use of a line that returned the UST displaced vapours to the truck. The incoming gasoline was piped into the UST via a "submerged" fill line, which reduced the vapour losses about 40% over "splash" fill by minimizing the vapour-liquid interface area. Almost 100% control was claimed for this system, especially when no venting to the atmosphere was allowed during the filling operation. A pressure-activated valve was used to close the vent during the filling operation. The second step of gasoline vapour control in California was vehicle tank filling control. At the pilot gas station of Tehran the incoming gasoline was piped into the UST via a submerged fill line; almost 99.99% control was obtained for this system, similar to the same situations in California in 1972. A P&V valve was permanently used to close the UST vent pipe of the Tehran pilot station, whereas in California a pressure-activated valve was used just during the filling operation. As mentioned above, Stage II was implemented in California but not at the Tehran pilot station.

Furthermore, in 1975, the Air District Board of Directors in California began the use of a new radio communications system, involving two transmitters and a computer linkup, to accelerate the dispatch of air pollution complaints (such as bad odours of gasoline vapours from gas stations) to inspectors in the field for investigation (Bay Area Air Quality Management District, 2011). Forty-five years later, local residents in the vicinity of the Tehran gas station had to attend to an Oil Company to make their complaints, due to bad odours of gasoline vapours. Actually, there were no systems at Tehran gas stations for accelerating the dispatch of air pollution complaints. Therefore, there is need to establish a legal framework to deal with complaints.

CONCLUSION

Considering the WHO outdoor environmental air guidelines, mean values of BTX and TVOCs are much more than the guidelines at the six gas stations of Tehran. Thus, local residents are confronted with the bad odours of the VOCs, which also endangers their health. There is a need to establish a legal framework to formally deal with complaints. It can be concluded that discharge of gasoline from petrol tankers to

UST, is the main reason for the over production of VOCs at the gas stations of Tehran. Because there is a significant difference between the two states of the VOCs, including before and at the time of discharge of gasoline ($P<0.001$). Therefore, the most important way of reducing the emission of VOCs in Tehran's gas stations, is to install the vapour control system at the gas stations and activate the system at the time of discharge of gasoline, as mentioned in Stage I. This vapour control system has an efficiency of approximately 99.99%. Furthermore, in order to prevent the gasoline vapour in the vehicle tank from being emitted to the atmosphere at the time of vehicle fuelling, a coaxial nozzle should be used in Tehran's gas stations. Moreover, in the petrol bulk storages of Tehran gas stations, vapour recovery units (VRUs) must be installed to recover gathered gasoline vapour from the USTs. Transferring gasoline vapour from the vapour control system to the VRU, not only prevents vapour emission to the environment, but also enables vapour recovery and recycling. Due to the high costs of production and importation of gasoline and overconsumption of this strategic product in Tehran, recovery of gasoline vapour will have economic benefits for Tehran's gas stations. The study of the benefits should be considered in further researches.

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