Cancer Risk Assessment Benzene, Toluene, Ethylbenzene and Xylene (BTEX) in the Production of Insulation Bituminous

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Abstract

Benzene, Toluene, Ethyl Benzene and Xylene are volatile organic compounds (VOCs) with approximately similar physical and chemical characteristics. Benzene and Ethyl-benzene are carcinogen as well as they affect the circulatory, nervous, and reproductive and respiratory systems. Toluene and Xylene also damage the nervous and reproductive systems. The main purpose of this study is to determine the risk of occupational exposure to Benzene and toluene compounds among Bituminous production units in Delijan and also to calculate the quantitative rate of cancer and non-cancer risks of these compounds. In this empirical and analytical study, in ten Bituminous production units (of the suburbs and downtown) which are selected randomly. The quality of the air that the workers breathe is collected at three times; in the morning, at noon and at night in each Bituminous production unit. Air samples are gathered based on standard of NIOSH 3800 by a sampling pump manufactured by SKC Co. England with a flow rate of 0.3 liters per minute. These samples are transported to the laboratory and analyzed by gas chromatograph with Flame Ionization Detector (FID). The cancer risk for workers exposed to Benzene is calculated in the range of 8.15×10^{-7} and a quantitative non-cancer risk value for Toluene is also calculated in the range of 0.000176. Occupational exposure of workers at Bituminous production units to Benzene, Toluene compounds might increase the risk of cancer for them.

Keywords: volatile organic compounds, Human Health Risk Assessment, Bituminous industry

Introduction

The production and use of chemicals are increasing worldwide. Output of chemicals increased approximately 10-fold between 1970 and 2010, globally. Toxic chemicals are one of the main environmental factors contributing to the global burden of diseases. The potential of public health risks related to exposure to hazardous chemicals is serious, especially in developing countries. It

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is magnified by fewer resources for chemical risk management and the projected growth in the production and use of chemicals.

Urbanization and development has leaded to environmental pollutions, such as air pollution (Atash, 2007). Exposure to pollutants, such as Benzene, Toluene, Ethylbenzene and Xylene (BTEX), is considered to have abysmal health impacts, including premature mortality (Bart, 2004). BTEX compounds are categorized as non-methane volatile organic compounds (VOCs) (Lee et al., 2002). The sources of atmospheric BTEX are the combustion process, cigarette smoke, gasoline evaporations and a number of industrial activities such as petrochemical process, storage, distribution, paint, and solvent (Atkinson and Arey, 2003). Benzene as an aromatic hydrocarbon with a relatively longer lifetime is a carcinogen compound and the also is most perilous compound among BTEX (Rinsky et al., 1981). Xylenes ((m, p) -xylene plus o-xylene) are the most dominant contributor to ozone formation among BTEX (Na et al., 2005). The (m, p)-xylene/ethylbenzene concentration ratio can indicate the level of photochemical reactivity in the atmosphere and approximate the photochemical age of air mass (Nelson and Quigley, 1984; Monod et al., 2001). Kerbachi et al. (2006) studied and monitored the contribution of BTEX in the roadside and urban air pollution of Algiers, Algeria. The concentrations of BTEX in the roadside were two to three times of urban regions. The average concentrations of Benzene and Toluene in the roadside were 8.45 ppb and 10.35 ppb, respectively.

Local air quality has been an issue of social concern because of rising industrial and vehicular pollution in most cities and urban areas(Garg 2011). Outdoor air pollution has become a major concern for public health world widely. Short-term exposure to outdoor air pollution lead to increase of mortality, rates of hospital admissions and emergency department visits, exacerbation of chronic respiratory conditions (e.g., asthma) and decrease in lung function. The epidemiological studies have demonstrated that being exposed to the particulate matters (PM) concludes the occurrence of acute respiratory infections, lung cancer and chronic respiratory and cardiovascular diseases (Pope et al., 2002; Kok et al., 2006; Taus et al., 2008 , Xu et al. 2012). Most of these studies were conducted in developed countries, and only a small number of studies have been conducted in Asian developing countries (Chen et al. 2010).

The urban areas might be viewed as dense source of enormous anthropogenic emission of pollutants, which could affect on the atmospheric composition, chemistry and life cycles in its downwind regimes, extending over several hundred kilometers (Gupta et al., 2012, Singh et al. 2013). Atmospheric particulate matter (PM) has been an environmental and health concern for decades, especially for coarse (PM_{10}) and fine ($PM_{2.5}$) particles (Li et al., 2013). Dusts on urban impervious surface have become one of the most important issues in urban environmental management. On one hand, surface dusts can be easily re-suspended under certain outside dynamic condition. Pollutants absorbed on them enter human body by the pathways of respiratory inhalation and direct skin contact and cause negative health effects (Glikson et al., 1995; Tervahattu et al., 2006; Grimm et al., 2008, Ma and Singhirunnusorn, 2012). Emissions of anthropogenic air pollutants in Asia have been increasing drastically in past decades (Lee et al., 2002; Wu et al. 2006). According to previous study PM has a potential of adverse health effect, making it necessary to control or regulate these pollutants. PM is one of six ‘criteria pollutants’ designated by the US Clean Air Act of 1971, which are measured and reviewed in the development and adjustment of environmental and health standards (Liu et al., 2005, 2010; Zhuang et al., 2009a, 2009b).

Benzene, Toluene, Ethylbenzene, and Xylenes frequently occur together. These four chemicals are volatile and have good solvent properties. Toxicokinetic studies in humans and animals indicate that these chemicals are well absorbed to lipid-rich and highly vascular tissues such as the brain, bone marrow, and body fat due to their lipophilicity, and are rapidly eliminated from the body. The available knowledge on toxic or carcinogenic responses to the whole mixtures of BTEX is insufficient. All four components can produce neurological impairment; in addition Benzene can cause hematological effects which are the reason of aplastic anemia and development of acute myelogenous leukemia. Results of different studies showed that joint neurotoxic action is expected to be additive at BTEX concentrations below approximately 20 ppm of each component.

Exposure to relatively high concentrations of BTEX is expected to increase the potential of neurotoxicity and decrease the potential of hematotoxicity/carcinogenicity due to competitive metabolic interactions among the mixture components.This study aims to evaluate the emission costs of the BTEX compounds of Bituminous production units based on the Life Cycle Assessment and Externe methodologies on human’s health.

Materials and methods

The study area

Pollutants of factories is the major reason which has made Delijan to be rated as the fourth polluted city in Markazi province in Iran (figure 1). The city is 120 kilometers far from the provincial capital (Arak city) and is located by the industrial town (7 kilometers from Delijan-Esfahan road). In Delijan city, the factories fusing history dates back to around 1372. And now more than 120 producing units of Bituminous are active in the city and produce 70% of needed insulation in the country. In this research, the mean pollution of 8 factories is studied and due to the confidentiality of the results, the factories are named using numbers instead of the names of these companies.

This analytical-descriptive study is applied to ten units of Delijan Bituminous Company in the current spring, utilizing sectional method. The case study units are selected and checked randomly among all of the units in Industrial Park of Delijan.

Field measurement

The National Institute for Occupational Safety and Health (NIOSH)'s methods was applied to monitor the concentrations of BTEX. Charcoal tubes (Supelco, Inc., Bellefonte, PA), which mounted in vertical position, were used to gather air samples. The collection tubes contained 150 mg coconut charcoal, which split into two sections of 100 mg and 50 mg. The sections were separated by glass wool and urethane foam which removed during the monitoring. The larger section was used to gather VOCs. The smaller section examined and corrected any feasible solvent breakthrough during the sampling. We used air sampling pumps (SKC-model 224-44EX, SKC Inc.) at the rate of 100 ml/min to draw air through the charcoal tubes. The pumps were calibrated to a controlled flow rate of 270 ml/min. The pressure drop across charcoal tube was controlled using a manometer, which positioned between the pumps and charcoal tube. The allowable pressure drop was 2.5 cm Hg at a flow rate of 1 l/min. The temperature and atmospheric pressure during sampling were recorded.

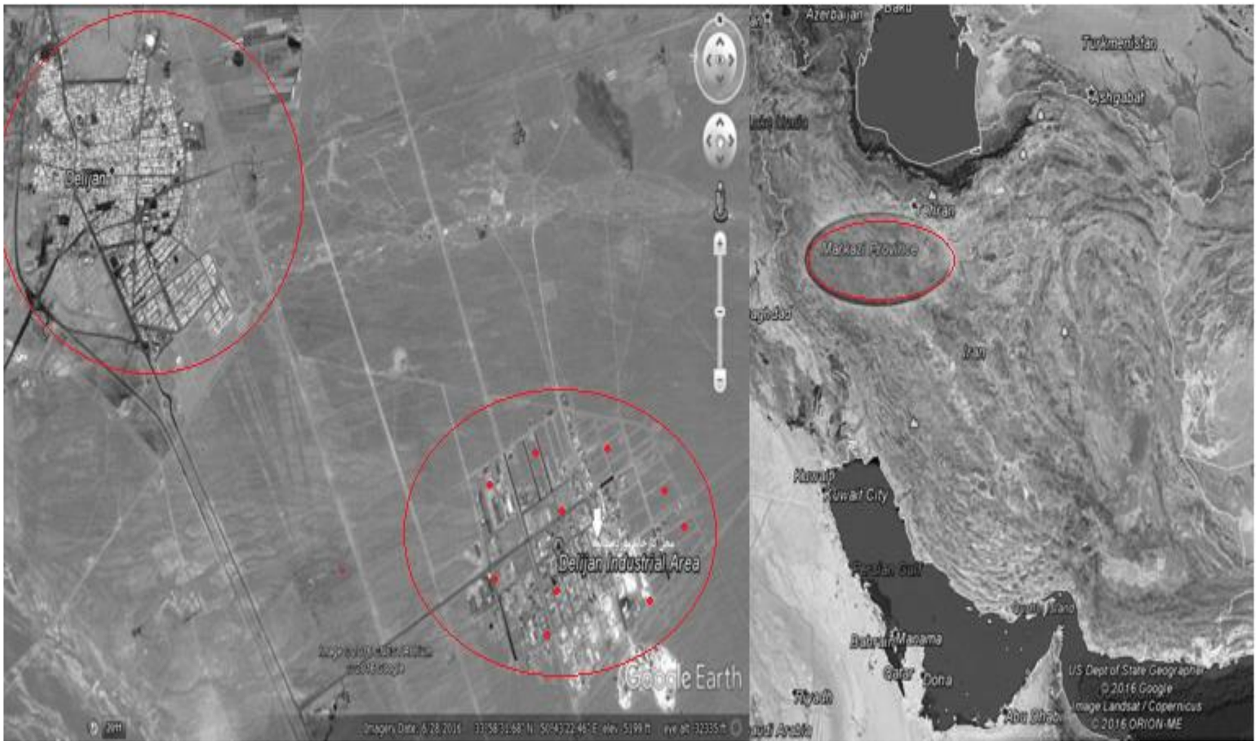

Figure 1. Location of in Industrial Town Delijan, Delijan city, Markazi province

To measure the concentrations of BTEX, the charcoal was placed in a septum sealed vial. Then 1 ml carbon disulphide (CS_2) was added. The sample was agitated ultrasonically for 3 min to 5 min. Afterwards 2 µl of the sample was injected into a Gas Chromatography with FID detector (Perkin-Elmer model sigma 3B). To assess the correctness of sampling, we treated similarly to the smaller section.

The efficiency and precision of the monitoring were examined. First, we added specified quantities of CS_2 to 5 tubes of 100 mg charcoal. To complete absorption of the CS_2 to charcoal, the sealed vials were maintained overnight. Another tube of 100 mg charcoal, in which CS_2 was not added, (blank media) would be treated similarly. Afterwards, the charcoals were analyzed. Contrasting the specimen with the standard solution, the desorption efficiency could be computed. For the standard solution, we added various amounts of charcoals to 1 ml of CS_2. The desorption efficiency was computed using areas of the peaks on the gas chromatograms while adsorbed samples were compared to standard solutions:

desorption efficiency = (area of sample- area of blank media)/ (area of standard):

$$\text{desorption efficiency} = \frac{\text{area of sample} - \text{area of blank media}}{\text{area of standard}} \tag{1}$$

Risk assessment method

In the process of risk assessment, there are four steps: Hazard Identification, Dose Response assessment, Exposure Assessment, Risk Characterization. Risk assessment method includes identification of any substance or process that may have destructive effect on public health. A wide variety of studies and researches are used to support a hazard identification analysis. Toxicokinetics considers how the body absorbs, distributes, metabolizes, and eliminates specific chemicals. Toxicodynamics focus on the effects of chemicals on the human body. Models based on these studies can describe mechanisms which indicate how each chemical may impact on human health. Then, the responses human body to the certain amount of each one of the BTEX compounds are investigated and described. Which is said to determine the contact-response and finally exposure assessment along with risk Characterization.

Upon determination of concentration for each of Benzene, Toluene, Ethylbenzene and Xylene (BTEX) in the production of insulation bituminous, the instruction defined by the United States Environmental Protection Agency (EPA) was used which was published during Integrated Risk Information System (IRIS, 2005). This action was aimed to identify the rate of concentration of each individual's confronted with the contacting materials in the studied region. Following determination of individual's contact with contaminators, Acute Reference Dose (RfD), Acute Reference Concentrations (RfC), Slope Factor, Unit Risk presented by the Integrated Risk Information System (IRIS) were employed. It was aimed to measure and assess the increase in cancer death rate due to being in contact with mentioned metals.

$$CDI_{air-inhalation}\left(\frac{\mu g}{m^3}\right) = \frac{C_{air}\left(\frac{\mu g}{m^3}\right) * \mathrm{EF}\left(\frac{\mathrm{days}}{year}\right) * \mathrm{ED}(\mathrm{years}) * \mathrm{ET}\left(\frac{hours}{day}\right) * \left(\frac{1day}{24hours}\right)}{\mathrm{AT}\left(\frac{\mathrm{days}}{year} * \mathrm{LT}(\mathrm{years})\right)} \quad (2)$$

CDI_{inhal} - Concentration Daily Intake by inhalation.
C_{air} - Concentration of heavy metals in air (ng/m^3).
EF- The number of contact days.
ED- The number of years during which the possibility for sickness exist.
ET- The number of hours with contaminators during day and night.
AT- The human longevity which is assumed 70 years (the mean longevity) for cancer diseases. It equals to contact duration for non-cancer diseases.
Furthermore Hazard Index (HI) was calculated for volatile organic compounds, with other non-cancer, anti-hygienic side-effects. The Hazard Index (HI) based on the following equation via respiratory contact for each of the BTEX compounds is observed in the region.

$$HQ_{\ inhalation} = CDI_{\ inhalation} / RfD_{\ inhalation} \quad (3)$$

Table 1. Summary of USEPA standard default exposure factors

Parameter	Default Value
EF (exposure frequency) d/yr	175
ED (exposure duration) years	25
ET (exposure time) hours/day	8
LT (lifetime) year	70

Table 2. Reference Dose for BTEX

Chemical	Reference	Chronic RfC (mg/m^3)	Reference	Air Concentration (ug/m^3)
Benzene	ASTDR	0.03	U.S EPA	7.8×10^{-6}
Toluene	IRIS	5	U.S EPA	0
Ethylbenzene	ASTDR	1	U.S EPA	2.5×10^{-6}
Xylene	IRIS	0.1	U.S EPA	0

Result and discussion

To achieve the aim of this regard, a cross-sectional study was performed in 2017. Sampling was carried out by active pump sampler using the NIOSH method. A total of 10 samples of BTEX were analyzed by Gas Chromatography-Flame Ionization Detector (GC-FID). Finally, estimated terms of Chronic Daily Intake (CDI) was performed for cancer risk and Exposed Concentration (EC) for non-cancer. Table 4. The measured mean concentration of benzene, toluene, ethylbenzene, and xylene was 0.575(1.831), 0.294(1.104), 0.182(0.787), and 0.262 (1.133) $\mu gr/m^3$, respectively. Among the BTEX compounds, benzene had the most skewed distribution. Jafari and Ebrahimi (2007) reported that the average concentration of benzene in Tehran fluctuated between 3.2 ppb (0.011 mg/m^3) to 156 ppb (0.536 mg/m^3). Atabi et al (2013) investigated the contribution of benzene in air pollution of Tehran. The annual concentrations of benzene were as follows: in paths with heavy traffic 13.85 ppb; in the intersections 14.98 ppb; in the vicinity of gas stations 29.01 ppb, in residential area 3.26 ppb and roadsides 9.97 ppb. Consequently, the development of public transportation, including subway and bus rapid transit (BRT) and limitations for private cars entering to traffic zones was effective in ameliorating of air quality. Hassani and Hosseini (2016) reported the total hydrocarbon (THC) emission factor for motorcycles and cars in Tehran were 0.492 g/km and 0.36 g/km, respectively. Shafiepour and Kamalan (2005) studied the non-methane volatile organic compounds (NMVOCs) emission factor of motorcycles and mentioned as much as 8.831g/km. Hosseinloo and Ghaemi (2014) studied vehicular emission rate in the district 7 in 2010. They reported that the car VOCs emission factor was 6.73 g/km. Bahrami (2001) demonstrated the BTEX as the major VOCs in Tehran air pollution. Considerations of pollutants Benzene, Toluene, Ethyl-Benzene and Xylene (BTEX) are analysed in 54-employee factory of Delijan, utilizing gas chromatography. The results show that the maximum level of pollutant consideration is lower than the standard limit.

Figure 2 indicate the concentrations of BTEX in Bituminous production units of Delijan in 2017. The prevailing wind of Delijan is western. The density of population and consequently business and official centers were concentrated lesser in the western and northern areas of Delijan city. The inhalation hazard quotient (HQ) for each volatile pollutant, depicts that Benzene has the most deteriorative impact on the human health.

Table 3. Volume of measured values of exhaust gas concentration (PPb)

Bituminous production units	Benzene	Toluene	Ethylbenzene	Xylene
1	0.63	0.26	0.048	0.037
2	0.096	0.23	0.057	0.32
3	0.21	0.087	0.054	0.261
4	0.91	0.71	0.118	0.074
5	1.27	0.65	0.114	0.059
6	0.051	0.042	0.086	0.052
7	0.056	0.074	0.063	0.054
8	0.65	0.079	0.601	1.26
9	1.83	0.12	0.531	0.093
10	0.047	0.69	0.151	0.41

Table 4. Average total volume of measuring the concentration of Bituminous production units

Measured parameters of the air	Average total volume (µgr/m^3)	Average total volume (ppb)
Benzene	1.831	0.575
Toluene	1.104	0.294
Ethylbenzene	0.787	0.182
Xylene	1.133	0.262

Table 5. Inhalation Noncarcinogenic (HQ)

Chemical	Chronic RfC (mg/m^3)	Air Concentration (ug/m^3)	Inhalation Noncarcinogenic CDI	Inhalation HQ
Benzene	0.03	1.831	0.000293	0.00975
Ethylbenzene	1	0.787	0.000126	0.000126
Toluene	5	1.104	0.000176	0.0000353
Xylenes	0.1	1.133	0.000181	0.00181
*Total Risk/HI	-	-	-	0.0117

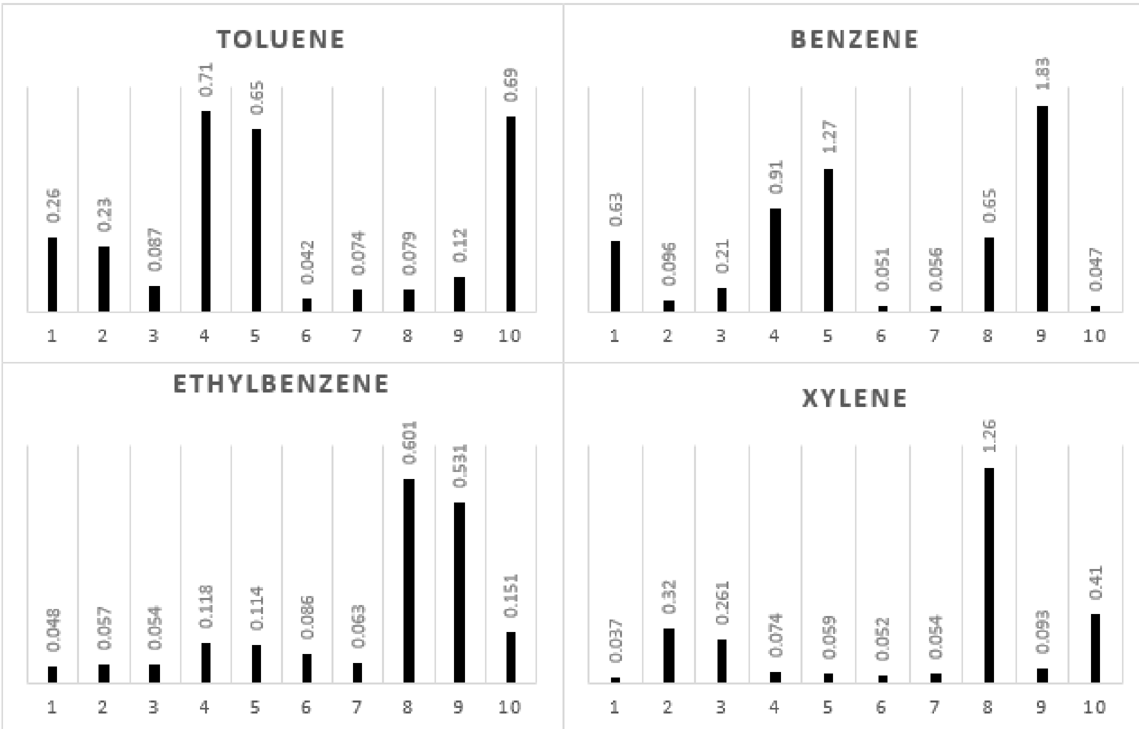

Figure 2. BTEX concentrations in Bituminous production units

Table 6. Inhalation carcinogenic (Risk)

Chemical	Chronic RfC (mg/m^3)	Air Concentration (ug/m^3)	Inhalation Carcinogenic CDI	Inhalation Risk
Benzene	0.03	1.831	0.105	8.15×10^{-7}
Ethylbenzene	1	0.787	0.0449	1.12×10^{-7}
Toluene	5	1.104	0.063	-
Xylenes	0.1	1.133	0.0647	-
*Total Risk/HI	-	-	-	9.27×10^{-7}

Conclusion

The BTEX pollutions of Bituminous production units met the allowable concentrations. It should be noted that risk assessment is an iterative process having a number of assumptions. Health risks may have been overestimated due to the fact that the risks calculated based on the chemical concentrations measured in a short time were compared to specified risks developed based on the toxicological data established for exposures over a lifespan.

Since inhalation HQ is lower than one, it is concluded that deteriorative effects of bituminous production derived from BTEX presence is not significant in closed areas.

The achieved results for CDI demonstrates that the 54 employees of the probed ten units aren't threated by BTEX Inhalation during the assumed span of 70 years. Although the level of pollutants would be increased in other seasons.

The evaluated sanitary risk depicts that air conditioning system has induced consideration of organic volatile compounds. Thus the staff are not exposed to danger of cancer.

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