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ORIGINAL ARTICLE

Evaluation of Air Pollutants Caused by Benzene, Toluene, and Xylene at Kazakhstan Petrochemical Industries Inc. LLP in 2022

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ABSTRACT: Volatile organic compounds (VOCs) such as benzene, toluene, and xylene are toxic air pollutants which are released into the atmosphere by various human activities such as gasoline production and use, chemical manufacturing and incineration of certain waste. These pollutants are also harmful to the environment, causing harm to plants, aquatic life, and soil quality. Therefore, it is important to implement measures to reduce emissions from these substances. The purpose of this paper is to evaluate the air pollutants caused by benzene, toluene, and xylene at Kazakhstan Petrochemical Industries Inc. LLP in 2021–2022. In order to calculate the sample size for this cross-sectional study, the preliminary evaluation findings from a related study that measured the concentration of hydrocarbons in petrochemical facilities were employed. 281 samples were gathered between the winter and summer of 2022. The national institute for occupational safety and health (NIOSH) methods of 1501 was applied to conduct the sampling and analysis of pollutants. The air was sampled using a charcoal tube sampler that was attached to a pump. The chemicals were then extracted using the solvent carbon disulfide (CS_2), and samples were then analyzed using a capillary-equipped gas chromatography-mass spectrometer. The collected data were analyzed by SPSS software version 23.0. The findings demonstrated that benzene concentrations in the sampling areas throughout the winter and summer were higher than the recommended value advised by the American conference of governmental industrial hygienists (ACGIH).

INTRODUCTION

Air pollution is a major environmental issue that affects the health and well-being of people and the planet. Technology and industry have contributed significantly to air pollution through various sources of emissions. These emissions include [1, 2]:

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- Fossil fuel combustion: The burning of fossil fuels, such as coal, oil, and gas, in power plants, factories, and vehicles, releases carbon dioxide, nitrogen oxides, and sulfur dioxide into the air. These pollutants contribute to the formation of smog, acid rain, and respiratory problems.
- Industrial processes: Industrial processes, such as chemical manufacturing, oil refining, and metal production, release a variety of pollutants into the air, including volatile organic compounds (VOCs), particulate matter, and greenhouse gases.
- Transportation: Cars, trucks, buses, and airplanes release exhaust fumes that contain pollutants like nitrogen oxides, carbon monoxide, and particulate matter.
- Agricultural practices: Agricultural practices such as livestock farming, use of fertilizers and pesticides, and burning of agricultural waste release pollutants such as methane, ammonia, and nitrogen oxides.

The impact of air pollution from technology and industry on human health can be severe, leading to respiratory problems, cardiovascular disease, and even premature death [3–5]. It also has negative effects on the environment, including acid rain, smog, and global warming [6].

The petrochemical industry is a major contributor to air pollution due to the release of various pollutants during the production process [7]. Despite the increasing benefits it has provided to humanity, this industry contributes significantly to the generation of industrial effluents and aerosol gas pollutants, which can have negative direct and indirect consequences on the environment and human life.

One of the primary pollutants from the petrochemical industry is VOCs, which are emitted during various stages of the production process, including the refining of crude oil, processing of natural gas, and production of chemicals and plastics [8–10]. They include chemicals like benzene, toluene, and xylene (BTX), which are hazardous to human health and contribute to the formation of ground-level ozone and smog. Ozone and smog can cause respiratory problems, including coughing, shortness of breath, and aggravate asthma and other lung conditions [9].

Another significant pollutant from the petrochemical industry is particulate matter (PM), which is generated during combustion and other processes that involve high temperatures [11]. PM is a mixture of tiny particles, including dust, soot, and other microscopic substances, which are generated during combustion and other high-temperature processes in the petrochemical industry [12]. These particles can be inhaled and cause respiratory problems and aggravate cardiovascular disease [13]. PM can also contribute to reduced visibility and damage to vegetation, leading to negative environmental impacts [14].

The petrochemical industry also produces greenhouse gas emissions, primarily in the form of carbon dioxide (CO_2), which contribute to climate change. The industry contributes to emissions in various ways, including the extraction, processing, and transportation of fossil fuels, as well as the production of chemicals and plastics [15,16]. Climate change can have significant impacts on human health, including increased incidence of respiratory and cardiovascular diseases, and environmental impacts such as sea-level rise, extreme weather events, and loss of biodiversity [17].

Therefore, assessing air pollutants like BTX is crucial in petrochemical complexes due to their potential harmful effects on both human health and the environment. Firstly, exposure to these pollutants can cause a range of negative health effects. Benzene (C_6H_6), for instance, is a known carcinogen that can cause leukemia and other blood disorders, as well as damage to the immune system and other organs [18,19]. Toluene ($C_6H_5CH_3$) can cause central nervous system effects like headaches, dizziness, and confusion [20], while xylene (C_8H_{10}) exposure can cause similar effects as well as respiratory and skin irritation [21]. In addition to the health effects, BTX pollutants can also have negative impacts on the environment. Benzene, for example, can contaminate soil and groundwater, and can also contribute to the formation of ground-level ozone, a harmful air pollutant. Toluene and xylene can also contribute to the formation of ground-level ozone and can harm aquatic life if they enter waterways [22].

The measurement and analysis of pollutants is unquestionably the first step in regulating them since, without thorough knowledge of the quantity and quality of pollutants, it will not be feasible to compare them with the permitted limits and, eventually, regulate them. Studies carried out by the west coast of South Korea petrochemical and oil refinery industry in the summer and winter revealed that the overall amount of hydrocarbons in the complex is more than the allowable limit in all areas [23–25]. Also, it was discovered in a study that measured VOCs and trace gases near the tall towers in Guangzhou, China that there was a strong correlation between the city's high petrochemical activity, particularly in the summer, and the compounds' high emission [26]. Furthermore, a study conducted in an oil refinery in in southern Taiwan discovered that the dispersion of volatile organic compound pollution in the air and its emission from nearby petrochemical complexes were significantly influenced by the direction and speed of the prevailing winds in the area [27]. This study aims to assess the air pollutants BTX at Kazakhstan Petrochemical Industries Inc. LLP. Systematic recognition of the qualitative and quantitative characteristics of petrochemical complex air pollutants and how they are distributed in different areas is the first task that can provide the necessary information for realistic planning.

MATERIAL AND METHODS

The present cross-sectional study was conducted in 2021-2022. Sampling was done at Kazakhstan Petrochemical Industries Inc. LLP, and pollutant analysis was done in Kh. Dosmukhamedov Atyrau State University (Figure 1). Kazakhstan Petrochemical Industries Inc. LLP is a petrochemical company based in Atyrau, Kazakhstan. The company was established in 2011 as a joint venture between United Chemical Company LLP (UCC) and Saudi Basic Industries Corporation (SABIC), two major petrochemical companies. It is primarily engaged in the production of polyethylene and polypropylene, two widely used thermoplastic polymers. The company's plant in Atyrau has a production capacity of 500,000 tons per year of polyethylene and 400,000 tons per year of polypropylene [2].

Figure 1. Location of study area of Kazakhstan Petrochemical Industries Inc. LLP (Source: Google Maps).

The minimal number of samples in each season were collected with an active charcoal tube sampler in order to sample pollutants based on $n = \frac{\left(Z_{1-\alpha/2}\right)^2 \delta^2}{d^2}$ with a confidence level of 95% and the extent of petrochemical production units [28]. Here, α is the selected level of significance, $Z_{1-\alpha/2}$ is the value from the standard normal distribution, δ is the standard deviation and d is the tolerated margin of error. The outcomes of the preliminary assessment that was carried out in a comparable study were utilized to determine the volume of the sample in order to be indicative of the uniformity of pollution in the production units [29].

The national institute for occupational safety and health (NIOSH) methods of 1501 was applied to conduct the sampling and analysis of pollutants. An activated coconut shell charcoal tube sampler was utilized for sampling air. At the sampling location, the sampler tube was split on both sides and linked with a connecting tube to a calibrated low-flow individual sampling pump. The production units underwent sampling throughout the whole work shift at a flow rate of 200 ml per minute. To prevent the sampler from becoming saturated and invalidating the sample at each location, the sampling time was set to 3±1 hours [30]. Sampling locations included inside production units, outside production units, and personal sampling. The samples were examined using a gas chromatography coupled to mass spectrometry (GC/MS) (Varian model 3200). The equation v = m/p was used to prepare the standard solution, which included compounds such as BTX in CS_2, with a concentration of 1000 g ml^{-1}. In this equation, v represents the volume of the solution to be prepared (ml), m represents the mass of the solute (the substance being dissolved) needed to make the solution (g), and p represents the density of the solute (g ml^{-1}). Then using the relation C1V1 = C2V2, where C1 represents the initial concentration of the solution being diluted, and V1 represents the initial volume of that solution. C2 represents the final concentration of the solution after dilution, and V2 represents the final volume of the solution, the diluted standard solutions with various concentrations were also prepared from the standard solution. The peak level values of each substance were determined by injecting 1 ml of each of the diluted standard solutions into the GC/MS instrument, which produced a chromatogram similar to Figure 2.

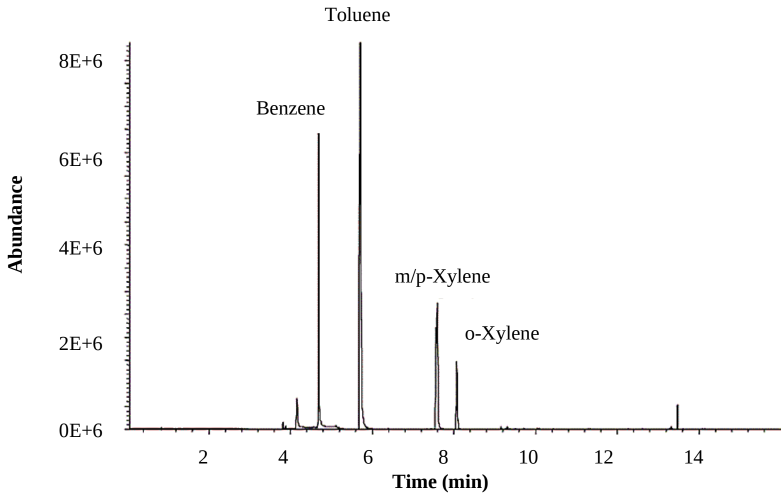

Figure 2. Chromatogram of concentration of benzene, toluene, and ortho-, Meta- and para-xylene injected into GC/MS device.

After gathering 210 samples in two different seasons—winter and summer—and transporting them to the lab, the samples were processed by emptying the contents of the absorbent tubes into vials, adding one milliliter of the carbon disulfide solvent, and stirring the mixture for 30 minutes. 1 ml of the vial solution was injected into the GC/MS device for analysis. The concentration of the aforementioned compounds was calculated according to Ref. [30].

To evaluate the data gathered from this research, t-test and on-way ANOVA were employed using SPSS software version 23.0.

RESULTS

The findings demonstrate that the concentration of pollutants is often higher in summer than in winter across most samples. After comparing the concentration values of each pollutant with the advised allowable concentration limits, it was found that the level of benzene exceeds the recommended limits in two locations. In the summer, the concentration of benzene was higher than the advised limit in the indoor ambient air sampling locations with a mean value of 0.51 ± 1.18. Additionally, in the winter, the mean level of benzene in the inhaled air of employees was 1.74 ± 7.65, and in the summer, it was 2.14 ± 8.88, both of which were above the recommended limits. Out of all the benzene samples collected, the air sample from the loading the loading and unloading site of benzene-containing products such as gasoline or crude oil had the highest concentration. The findings indicate that the levels of toluene and all three isomers of xylene (m/p-xylene and o-xylene) were below the permissible density limits set by the standards (Table 1). Permissible pollutant concentration limit values (ppm) based on the guidelines of American Conference of Governmental Industrial Hygienists (ACGIH) for benzene, toluene, and xylene are 0.5, 20 and 50, respectively

Table 1. Comparison of the average pollutant content (ppm) in the surrounding air inside and outside the unit, as well as in the air that personnel of the Kazakhstan Petrochemical Industries Inc. LLP breathed in the winter and the summer of 2021-2022.

Pollutant		Number	Mean ± SD		p-value
			Winter	Summer	
Benzene	Inside unit	19	0.16 ± 0.15	0.51 ± 1.18	0.174
	Outside unit	18	0.06 ± 0.17	0.18 ± 0.25	0.261
	Personal	29	1.74 ± 7.65	2.14 ± 8.88	0.928
Toluene	Inside unit	22	0.12 ± 0.30	0.29 ± 0.54	0.110
	Outside unit	18	0.02 ± 0.01	0.24 ± 0.13	0.001
	Personal	31	0.14 ± 0.36	0.20 ± 0.37	0.854
m/p-Xylene	Inside unit	22	0.04 ± 0.09	0.29 ± 0.70	0.004
	Outside unit	22	0.01 ± 0.02	0.07 ± 0.13	0.004
	Personal	32	0.67 ± 2.91	0.58 ± 2.55	0.339
o-Xylene	Inside unit	19	0.02 ± 0.03	0.12 ± 0.27	0.014
	Outside unit	18	0.01 ± 0.01	0.01 ± 0.02	0.001
	Personal	31	0.21 ± 0.87	0.20 ± 0.77	0.856

The findings demonstrate that personal exposure to the targeted chemicals is significantly greater than ambient air concentration inside the unit and they both are significantly higher than ambient air outside the unit during each season (Table 1).

According to the results of a sampling conducted in petrochemical units, para-xylene and meta-xylene were detected in 84% of the samples, toluene in 73%, ortho-xylene in 68%, and benzene in 63%. The specific percentages may be influenced by a variety of factors such as location, type of process, time of day, and weather conditions. According to an analysis of pollutant emission, the northeast side of the complex has the highest concentrations of toluene, para-meta-ortho xylene pollutants in the winter and summer, while the southwest and south sides of the area have the highest concentrations of benzene.

DISCUSSION

As per the aims of the regional organization dedicated to environmental protection, regular assessments are carried out within the petrochemical complex to monitor the levels of pollutants. Occupational health experts also conduct inspections to determine if the concentrations of pollutants meet the allowable limits.

The results of these evaluations indicate that the pollution levels are low. Specifically, measurements of toluene, para-meta, and ortho-xylene pollutants are compared to established standards in both the ambient air inside and outside the complex, as well as in the breathing zones of the employees working within the complex's units.

Our results demonstrate that the generation of VOCs remained within acceptable limits, as shown by the low incidence of exceedances. We observed significantly higher concentrations of toluene and xylene pollution during the summer months than in the winter across most of the samples.

These findings are consistent with earlier studies conducted in Ref. [31,32], as well as in a typical petrochemical company in the Beijing-Tianjin-Hebei Region of China [33], indicating that VOC levels are seasonally dependent, with higher concentrations observed during the summer. A study conducted in the Sinopec Maoming Petrochemical Company in southern China during the summer, fall, and winter of 2022 [34] showed a significant correlation between seasonal variation and the concentration of volatile hydrocarbons, excluding benzene and toluene. Our study found no significant difference in the average concentration of benzene between three sampling locations during the winter and summer seasons. This result is consistent with earlier studies conducted in the in the Sinopec Maoming Petrochemical Company in southern China during the summer, autumn, and winter of 2021-2022, which also found no significant relationship between seasonal variation and the concentration of benzene and other volatile hydrocarbons. Our study further reveals that personal exposure to the targeted chemicals is substantially higher than ambient air concentrations both inside and outside the production unit throughout all seasons. This finding is consistent with a previous investigation conducted in Ref. [31]. As the sources of pollution are primarily located inside the production units, pollutant concentrations gradually decrease with distance from the source and are typically higher in ambient air samples taken inside the unit than outside, due to pollutant emissions and wind flow.

CONCLUSIONS

Given the findings of the current study and the significance of maintaining the health, safety, and human capital of the country, methods of limiting the spread of hydrocarbons have been proposed in an effort to possibly serve as a starting point for more extensive research and the presentation of practical and workable solutions in the country to prevent the occurrence of negative effects brought on by exposure to organic hydrocarbons. Three techniques for the treatment of hydrocarbon pollutants are commonly used in the industry: 1) Carbon recycling, which involves the physical removal of pollutants through recycling on coal grains. 2) Burning with an open flame, which uses an auxiliary fuel gas flow and vapor to burn hydrocarbon compounds. 3) Burning in a furnace, which can be achieved through thermal or catalytic methods. Thermal burning is used to remove halogen and sulfur hydrocarbon compounds, whereas the catalytic method is employed to purify VOCs.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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