Determination of The Permissible Distances in Vicinity of The Gas Station According to The Concentration of Benzene

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Abstract

Benzene is considered a toxic and hazardous pollutant in Tehran metropolis. The storage tanks of petroleum products and refueling in gas stations are among the main sources of benzene emissions. Using the software AERMOD and reviewing the benzene dispersion maps at different distances from 412 storage tanks at 148 gas stations, it was found the permissible distance of the emission source is dependent on various variables such as the number of loading times and the storage capacity. When, storage capacity in the range of 60,000 L to 96,000 L and the number of loading is in the range of 676 to 1,328 times a year, the concentration of benzene at a distance of 30 m of the emission source reaches the annual standard of $5 \mu\text{g}/\text{m}^3$. While, storage capacity in the range of 80,000 L to 128,000 L and the number of loading is in the range of 1,329 to 1,834 times a year, the concentration of benzene at a distance of 40 m of the emission source reaches the annual standard of $5 \mu\text{g}/\text{m}^3$. Also, based on the analysis of data and the linear regression equation, the permissible distance of the emission source can be predicted.

1. Introduction

Gasoline vapors, including benzene, adversely affect the environment, and large volumes of such emissions cause an increase in the greenhouse gases, which in turn leads to global warming, climate changes, acid rains, chemical reactions, smog, etc (Tsai 2016). Due to the high vapor pressure and high volatility, gasoline is easily evaporated, leading to formation of volatile organic compounds (VOCs). VOCs emitted through industrial activities have negative impacts on human health and environment (Srivastava et al 2005; Tohid et al 2019; Niu et al 2016). When decomposed in the atmosphere, VOCs react with nitrogen-containing compounds (NO_x) and form tropospheric ozone (Srivastava et al 2006; Monod et al 2001; Burghardt et al 2016). Ozone is affecting global climate changes and causes damage to the respiratory, nervous and immune systems (Xu et al 2017). These substances may reach concentrations in the air that cause undesirable health, economic, or aesthetic effects. Gasoline vapors including benzene cause damage to the constructive tissue, genetic mutation, reduced generation of bone marrow cells, severe anemia, and immunodeficiency (Neghab et al 2015; Okonkwo et al 2016). Neurological complications caused by benzene inhalation include drowsiness, dizziness, headache, anesthesia, and tremor (Merchant-Borna et al 2012; Correa et al 2012). Benzene also adversely affects organs including heart, lung, brain, liver, and kidneys (Lan et al 2004; Owagboriaye et al 2017). Benzene has been classified by US Environmental Protection Agency as a Group A carcinogen. Benzene has also been introduced as a carcinogen to humans by the International Agency for Research on Cancer (Heibati et al 2017; Hajizadeh et al 2018). The Iranian Supreme Council for Environment recommends a standard concentration of $5 \mu\text{g}/\text{m}^3$ for benzene.

Atabi et al. in 2013 studied benzene in the air of Tehran. Based on the results, the annual concentration of benzene for highways with heavy traffic 13.85 ppb, for traffic intersections 14.98 ppb, for the vicinity of

gas stations, 29.01 ppb, for Residential areas were 3.26 ppb and side streets were 9.97 ppb (Atabi et al 2013).

Researchers modeled benzene emissions using AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model) software (Mcgaughey et al 2009). Investigators Used AERMOD software to study and model concentrations of VOCs emitted from gasoline storage tanks (Ramavandi et al 2016). Researchers using TANKS 4.0.9d software (US Environmental Protection Agency) investigated the emission of VOCs from gasoline storage tanks (Khosravi and Talaei Khozani 2019). Investigators modeled atmospheric pollutants emitted from thermal power plants such as CO, NO_x, PM, SO₂, and VOCs with the help of AERMOD (Dos Santos Cerqueira et al 2019). Researchers evaluated air pollutants produced by vehicles using AERMOD model in a street in the capital of Brazil. The dispersion map showed that the pollutants were mainly concentrated around emission sources. It was also found that mathematical modeling is a useful tool for studying dispersion of atmospheric pollutants (Macêdo and Ramos 2020).

Different programs are used to calculate emissions from organic liquids stored in petroleum tanks at gas stations. The TANKS 4.0.9d program can estimate VOCs and hazardous pollutants emitted from various types of storage tanks, including horizontal tanks. This software can be used to estimate emissions from tanks during storage and loading operations. The tanks studied of this project are horizontal and release vapors during storage, charge and discharge. Accordingly, in this study, the TANKS 4.09d program was used. The raw input data for this software include tank specifications, location, and the properties of stored liquids (USEPA 1999). Direct measurement of concentration of pollutants and experimental analysis are usually impossible at all points and times due to topographical conditions and the lack of necessary equipment. Accordingly, the use of air pollution dispersion models can be the simplest and most useful method for monitoring and evaluating the concentration of pollutants and the effect of emission sources on the air quality (Hanna et al 2007; Gurjar et al 2010; Truong et al 2016). As a continuous plume dispersion model, AERMOD software can be applied to rural and urban areas and both flat and uneven terrains. AERMOD is composed of a meteorological pre-processor called AERMET and a geological pre-processor known as AERMAP (USEPA 2018).

Due to the high concentration of benzene in the air of Tehran (Atabi et al 2013) and health problems and the destructive effects of benzene on the environment have caused, in this study attempts were made for the first time to evaluate all gas stations in Tehran city to determine benzene emissions and the determination permissible distance of gas station from sensitive and residential areas.

2. Data And Methods

In this study, 148 gas stations in 22 districts in Tehran city (Fig. 1) were examined.

First, the factors affecting the emission of gasoline vapors, including the number of gas stations, number of gasoline fuel storage tanks, maximum operating capacity of storage tanks, gasoline sales rate,

number of loading and the number of active nozzles at gas station in Tehran was investigated. In the next step, to evaluate benzene emissions, data on the following parameters for 412 storage tanks were used as inputs to TANKS 4.0.9d Software:

Physical specifications of the storage tank (length and diameter), the number of loading times, the maximum operating capacity of the tank, weather parameters, the average daily and annual ambient temperatures, the maximum and minimum daily and annual temperatures, the average wind speed, specifications of petroleum products stored in the tank, type of chemical compounds in the petroleum product, the weight percentage of compounds, pressure, and the vent vacuum of the storage tank. Based on information from the National Iranian oil products Distribution Company Fixed-roof horizontal underground tanks with a nominal capacity of 45,000 L and 24,000 L were considered. Due to the presence of gasoline vapors over the surface of the liquid stored in the tanks, the maximum operating capacity of the tanks is respectively 32,000 and 20,000 L.

Climatic information was obtained from the Meteorological Organization of Iran and related sites for MEHRABAD station in Tehran, which is the closest station to the study area for 12 months of 2018. Based on the software outputs, the volume of gasoline vapors emitted from storage and the annual loading operations of underground tanks from 148 gas stations is about 2,037,660 gallons per year.

$$2,037,660.28 \text{ gal/year} \times 3.78 = 7,702,355.85 \text{ lit/year (1)}$$

Assuming a density of 0.72 g/cm^3 for the liquid gasoline, the rate of gasoline vapor emissions equals 12,242,997.14 pounds per year.

$$12,242,997.14 \text{ lb. /year} \times 453.59 = 5,553,301,072.73 \text{ gr/year (2)}$$

$$5,553,301,072.73 \text{ gr/year} / (365 \times 24 \times 3,600) = 176.094 \text{ gr/sec (3)}$$

According to the above calculations (Eq. (1), Eq. (2) & Eq. (3)) and considering 1vol% of benzene concentration in gasoline accordance with the standards EN228 and ASTM D1319, the rate of benzene emitted from storage and the annual loading operations of underground tanks from 148 gas stations in Tehran is about 1.76 g/s. Eventually Using the dispersion model AERMOD view 8.9 software, benzene concentrations in Tehran with a grid distance of 20-30-40-50 m were determined in a 12-month statistical period (in 2018) at an elevation of 1.5 m above the ground surface (respiratory height) (Correa et al 2012) and benzene dispersion in the region was simulated.

AERMOD is capable of defining point, surface and volume sources. To model benzene dispersion, data such as emission rate of volume sources (g/s), pollutant release height, volume source center relative to the ground surface (m), the initial side dimension of the volume source (m), the initial vertical dimension of the volume source (m), and x and y coordinates of the center of the volume source relative to the origin selected for the volume source were entered into the model. AERMOD is composed of a meteorological pre-processor called AERMET and a geological pre-processor known as AERMAP. For the pre-processor

AERMET, the raw surface and upper air meteorological data (a total of 8,760 hourly data) including wind speed (FF), wind direction (DD), humidity (U), temperature (t) and cloud cover (n) for a 1-year (2018) were taken from Iran Meteorological Organization for MEHRABAD Station as the closest station to the study area. The collected data were then converted to format acceptable by AERMET.

For the pre-processor AERMAP, the digital elevation model (DEM) of Tehran was prepared to examine the effect of terrains on the concentration of pollutants and to process the topographical data of the region. This pre-processor has been designed based on the USGS topographical maps and analyzes topographical information of the region. Using the results of these two pre-processors and additional data on the emission sources and the receiving grid, AERMOD performs calculations and outputs the final results.

In order to evaluate the results of a dispersion model, statistical parameters are used (Haq et al 2019; Pandey and Sharan 2019). The AERMOD air dispersion model was investigated for its performance in predicting concentration of pollution emitted from petroleum refinery. A set of statistical parameters was employed to evaluate model performance. Results indicated that AERMOD can provide good results (Thepanondh et al 2016).

In this study to determine which variables are most influential on benzene concentration and in order to find the corresponding equation, data related to variables (number of loading times, tank capacity and permissible distance of the emission sources) were inserted into SPSS 20 software as primary data. Multivariate regression was used for the parameters of number of loading times and tank capacity as an independent variable and permissible distance as a dependent variable. The data obtained from modeling were analyzed using the above software and ANOVA test.

The ANOVA determines whether a regression model can significantly and appropriately predict the variations in dependent variables. To evaluate the statistical significance of the regression model, the last column of the table (sig) will be examined in the ANOVA test. If the value obtained in the (sig) part of the ANOVA was less than 0.05, it would mean that the regression model was significant.

3. Results & Discussion

3.1. Investigation of benzene concentration results and determination permissible distance of gas station from sensitive and residential areas.

According to the software output and calculations performed, emissions of benzene vapor emitted from 412 storage tanks in 148 gas stations in Tehran city was investigated. The lowest emission rate of benzene is about 0.0023 g/s and the maximum emission rate is 0.0314 g/s. In order to determine the permissible distance of emission source from sensitive and residential areas, using AERMOD dispersion

model, the dispersion rate of benzene concentration with a grid distance of 20-30-40-50 meters was determined and their distribution in the area was simulated.

When the emission rate of benzene vapors is in the range of 0.0023 to 0.012 g/s, storage capacity in the range of 20,000 L to 64,000 L and the maximum number of loading is 675 times a year, the concentration of benzene at a distance of 20 m of the emission source reaches the annual standard of $5 \mu\text{g}/\text{m}^3$. Therefore, it can be concluded that in order to construct a gas station with similar conditions, it should be at least 20 meters away from residential and sensitive areas.

While the emission rate of benzene vapors is in the range of 0.013 to 0.0218 g/s, storage capacity in the range of 60,000 L to 96,000 L and the number of loading is in the range of 676 to 1,328 times a year, the concentration of benzene at a distance of 30 m of the emission source reaches the annual standard of $5 \mu\text{g}/\text{m}^3$. So, it can be concluded that in order to construct a gas station with similar conditions, it should be at least 30 meters away from residential and sensitive areas.

When the emission rate of benzene vapors is in the range of 0.0219 to 0.0314 g/s, storage capacity in the range of 80,000 L to 128,000 L and the number of loading is in the range of 1,329 to 1,834 times a year, the concentration of benzene at a distance of 40 m of the emission source reaches the annual standard of $5 \mu\text{g}/\text{m}^3$. Therefore, it can be concluded that in order to construct a gas station with similar conditions, it should be at least 40 meters away from residential and sensitive areas.

Based on the results, number of loading times and storage capacity are the main factors affecting benzene emissions from gas stations.

Figure 2 displays benzene dispersion of gas station (no.134) with benzene emissions 0.009 g/s, Storage Capacity 64,000 L and Number of loading 675 times per year, benzene dispersion of gas station (no.255) with Benzene emissions 0.016 g/s, Storage Capacity 96,000 L and Number of loading 1,328 times per year and benzene dispersion of gas station (no.148) with Benzene emissions 0.022 g/s, Storage Capacity 128,000 L and Number of loading 1,834 times per year.

In Figures 3 Benzene concentration dispersion maps at different distances from emission source are shown. A gas station with a storage capacity of 64,000 L and a loading number of 675 times per year at a grid distance of 20, 30, 40, and 50 m (Fig. 3a), a gas station with a storage capacity of 96,000 L and the loading number of 1,328 times per year at a grid distance of 20, 30, 40, and 50 m (Fig. 3b), a gas station with a storage capacity of 128,000 L and the loading number of 1,834 times per year at a grid distance of 20, 30, 40, and 50 m (Fig. 3c).

The permissible distance of the emission sources from each gas station is determined based on the factors mentioned in Table 1.

Table 1
Compare permissible distance of the emission sources

Maximum storage capacity of tanks	Maximum number of loading	Minimum permissible distance of residential areas
64,000 L	675 times per year	20 m
96,000 L	1,328 times per year	30 m
128,000 L	1,834 times per year	40 m

According to studies conducted in Brazil on the emission of pollutants from gas stations, even regions at a distance of 150 m from gas stations contain high BTEX concentrations (Correa et al 2012).

Researchers studied the relative location of gas stations and public centers in Kano metropolis in Nigeria in accordance with the guidelines of Department of Petroleum Resources and Urban Development and Planning Agency. According to their results, the minimum distance of gas stations from public centers should be 100 m (Mohammed et al 2014). Scientists investigated the emission rate of pollutants from gas stations in Umuahia and came to the conclusion that the minimum safe distance of the gas stations and residential areas should be 80 m (Okonkwo et al 2014). Researchers studied emissions of pollutants and their effects in the vicinity of gas stations in Portugal. They found that the limit to protect human health for living or working around a gas station should be at least 150 m (Fontes et al 2016). Scientists through measuring vapors from vent pipes in two large gas stations in the US and comparing them with estimates by the California Air Pollution Control Officers Association and considering the 91 m distance of large gas stations specified by the California Air Resources Board, found that evaporative losses are larger than estimates. In some cases, even at distances larger than 91 m, people are exposed to benzene emissions, and authorities must revise regulations based on these data (Hilpert et al 2019).

According to the above studies and considering benzene emissions and dispersion at different distances of the emission sources and comparing the results with the annual standard limit of benzene $5 \mu\text{g}/\text{m}^3$, it was determined that the permissible distance from the emission sources is dependent on various variables. The first factor is the number of annual loading times and the second factor is the storage capacity of tanks in each gas station. As a result a fixed number cannot be declared for the permissible distance. For a storage tank with a capacity of 64,000 L and the maximum loading of 675 times per year, the minimum permissible distance between the gas station and the residential areas equals 20 m. For a storage tank with a capacity of 96,000 L and the maximum loading of 1,328 times per year, the minimum permissible distance between the gas station and the residential areas equals 30 m. For a storage tank with a capacity of 128,000 L and the maximum loading of 1,834 times per year, the minimum permissible distance between the gas station and the residential areas equals 40 m. Accordingly, by increasing the capacity of storage tanks and the number of annual loads of the above declared values, permissible distance from residential areas more than 40 meters.

3.2. Equation for determining permissible setback distance for gas stations

By examining statistical analysis it was found that there is a significant relationship between the variables of number of loading times and tank capacity with the permissible distance variable of the emission source ($P < 0.05$). As a result, the model used is a good predictor for determining the permissible distance from the emission source. Also, the constant value and the variables of number of loading times and tank capacity of all three are significant in the model. The standardized regression coefficient (beta) shows the share of the effect of independent variables on the dependent variable. Analysis of the enter regression method indicates that the share of the impact of the number of loading times ($BETA = 0.576$) is greater than the share of the impact of the storage capacity ($BETA = 0.433$) in determining the permissible distance of the emission source.

R Squared (R^2 or coefficient of determination) is the square of the correlation coefficient. The closer the output is to one, the more accurate the predictive model is, and vice versa. According to regression model analysis, $R^2 = 0.679$.

To create a regression equation, we use the unstandardized regression coefficient (B). With the values obtained from the regression model and placing the data in the linear regression & Eq. (4), the permissible distance of the emission source can be predicted (Table 2).

Table 2
Values of linear regression equation

Subject		Values
a	Constant	16.68
b_1	Unstandardized Coefficients for number of loading times	0.008
b_2	Unstandardized Coefficients for storage capacity of tanks	0.063
X_1	Independent variable: number of loading times	variable
X_2	Independent variable: storage capacity of tanks (m^3)	variable
Y	Dependent variable: permissible distance of the emission source	can be predicted

$$Y = 16.68 + 0.008(X_1) + 0.063(X_2) \quad (4)$$

Where

Y - the predicted benzene concentration (Benzene emitted from storage and the annual loading operations of underground tanks),

X_1 - the number of loading times and

X_{max} - is the storage capacity of the underground storage tank.

For example, for a storage tank with a capacity of 128 m³ and a loading of 1,834 times per year, the minimum distance to residential areas is about 39.4 m.

4. Conclusions

Based on software output and calculations, the amount of benzene emitted from storage and the annual loading operations of underground tanks (charge and discharge) were obtained. Then, using the AERMOD program, benzene concentration in the environment surrounding the emission source was predicted. By comparing the predicted benzene concentration with the annual standard limit of benzene (5 µg/m³), the minimum permissible distance of gas stations from residential and sensitive areas was determined.

On the other hand, In order to determine which variables (storage capacity and number of loading times) are most influential on benzene concentration and to find the equation for the permissible distance from the emission source, the parameter data (loading times, tank capacity, and permissible distance from the emission sources) were inserted into SPSS 20 as primary data. Multivariate regression was calculated for the parameters of loading times and tank capacity (independent variables) and permissible distance (dependent variable).

In the presence of additional factors affecting the emission of benzene vapors in the environment (such as vehicle refueling, liquid gasoline spills, and evaporation from leaking hoses and connections), that this will be an underestimation of total gasoline vapor emissions from gas stations. Therefore, setback distances might even need to be larger than suggested in this study.

According to the results of this study, construction of new gas stations should be supervised by the authorities and supervisory organizations to take into account the minimum permissible distance of residential areas and critical points based on the storage capacity and the number of loading times.

Declarations

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Author Contributions

M.CH (Ph.D. student) conducted all the modeling, reported the results and wrote the manuscript. A.MH. (Dr. Assistant Professor) assisted in data interpretation and supported manuscript writing. N.M. (Dr. Professor) was responsibility overall direction, planning and final approval. M.H.B. (Associate Professor) supported statistical data analysis. Y.R. (Assistant Professor) supported the modeling.

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Figures

Figure 1

The location of 148 gas stations in 22 districts in Tehran

Figure 2

Comparison of benzene emissions from gas stations selective with annual standard

Figure 3

Benzene concentration dispersion maps at different distances from emission sources

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