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ORIGINAL ARTICLE

The Survey of CO Distribution from the Oil Refinery Stacks Using AERMOD Dispersion Model

MOHSEN JAMSHIDI ANGAS[1], SEYED ALI JOZI [1*], ROKHSHAD HEJAZI [1], SAHAR REZAIAN [2]

[*1] *Department of Environment, North Tehran Branch, Islamic Azad University, Tehran, Iran*
[2] *Department of Environment, Shahrood Branch, Islamic Azad University, Shahrood, Iran*

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ABSTRACT

Air dispersion modeling is an important tool to improve air quality. The main objective of this research was focused on the simulation of CO emission from stacks at the Tehran Oil Refinery Complex, Iran. The AMS/EPA Regulatory Model (AERMOD) was developed to simulate the CO dispersion from stacks between the years 2018 and 2019. The results of the model on the maximum volume of CO concentration at 1hr and 8hr for hot and cold temperature were equal to 109 µg/m3, 32 µg/m3, 360 µg/m3, 254 µg/m3, respectively. Simulated values of CO emissions were compared to those obtained area measurement campaign at 4 receptors. Maximum concentration of CO in cold period of times was more than hot period of times. This can be attributed to low air turbulence. Our analysis demonstrated that the AERMOD modeling system is applicable for air quality simulation in the near future for CO. Simulation output showed that were all centered in against mountain and the middle of simulation area where the emission sources concentrated, and it is probably because the air pollutions were topography and source oriented. Finally, study results indicate that the simulated concentration of CO based on AERMOD, does not exceed concentration limit, set by the Iranian Ambient Air Quality Standard. It verified that CO release from oil refinery stacks don't have any significant impact on nearby communities.

KEYWORDS: *Air pollution, AERMOD, Monoxide carbon, Point Source, Dispersion Modeling*

INTRODUCTION

Urban air pollution has influenced human being's well-being, health, and life chances during past years. It also has become a major environmental issue in capital cities of developing countries. Levels of air pollution in Asian cities regularly exceed WHO recommended guidelines for smoke and dust particles. Fossil fuels are known as a major contributor in increasing a variety of air pollutant in urban [1].

Corresponding author: Seyed Ali Jozi
E-mail: alijozi2030@gmail.com

Urban-scale pollution estimations are a sophisticated modeling issue for computational reasons because of complexity of emission field, and wind-field effects. Also, the uncertainty analysis of emission data is challenging especially in the case of urbanized or industrial areas. To ignore the uncertainty in the modeling would lead to incorrect policy decisions, with further negative environmental and health consequences [2]. Meteorological conditions such as low wind speed, the height, and the temperature inversion especially in winter season inhibits the atmospheric dispersion of pollutant which ultimately results concentration of air pollutants or toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases.

Therefore, it is of particular importance to assess such episodes to set an efficient and effective urban air quality management [3]. The results of previous studies revealed that seasonal variability in ambient concentrations of air pollutants influenced by topography, the energy demand of power, land use, and meteorological factors [4]. Air pollutants inside cities mostly emitted from fossil fuels consumption in various daily activities such as home heating, industrial production, motor vehicle use, smelting, incineration, and process plants. The process plant consumes fossil fuels which is another source for atmospheric pollutants such as carbon monoxide [5].

In order to collect data continuously with respect to the amount of pollutant, monitoring systems analyses the status of air quality based on the existing air quality standards. So, city managers are able to have a broad perspective about the air quality data and the concentration of air pollutants at a point not only for a region. A contours spatial interpolation technique and dispersion models were used to create surface grids [6].

Therefore, environmental managers should be able to establish emission control plans alongside actual improvement in order to improve air quality. To do so, the air quality modeling may provide an effective method for simulating the dispersion of ambient concentration and the spatial allocation of outdoor air pollutants. The air modeling approach requires geographical characteristics, emission inventory, and meteorological parameters. Whereas, to collect emission data, the volume of pollutants emitted from sources such as stacks is needed. Geographical data should be collected based on the terrain data and base map. The wind speed, wind direction, rainfall, temperature, and humidity, pressure are those necessary parameters in meteorological data collection.

Availability of data is a crucial issue in modeling. The estimation of emission of industrial sources can be done for each stack as point source. The meteorological data were collected from nearby recognized meteorological station to analyze the study site considering time and indicated place [7, 8, and 9]. Air dispersion modeling is useful tools to provide concentration profile of air pollutants in spatial and temporal scale and verify the efficiency of control strategies [10, 11]. In addition, to forecast the air quality over a time period, e.g. a minimum period of 10 years' data was collected using advanced models such as CMAQ, where it can be coupled with Meteorological Forecast Models. However, to investigate the influence of the latest emission control policy, few studies simulated the near future air quality (e.g. less than 10 years) by simple AQM (e.g. AMS/EPA REGULATORY MODEL) [12].

Inaccessibility of sampling is one of the environmental assessment issues in oil refineries. In these cases, computer simulations are to estimate pollutant concentrations in the selected areas. The results of simulations should be compared with the observed data in the accessible areas. Due to the ability of computer-based dispersion models in simulating these effects. Dispersion software programs based on Gaussian plume equation have been widely used to estimate the dispersions of various pollutants [13]. However, not too many studies were assessed air quality by AERMOD in order to verify dispersion pollution. This model is preferred by EPA (Environmental Protection Agency) and it was recommended as a trusted air quality dispersion model. The Aermod View Modeling System is approved by EPA as a model for regulatory compliance applications and it is recommended for investigating the field impacts up to 50 km distance from a facility [14]. In order to simulate NO_x concentration in Chemburn, a large suburb in eastern Mumbai, India the air pollution modeling was performed by AERMOD [15]. Similarly, the amount of CO pollutants' emission and its dispersion modeling based on data derived from process plants was simulated using the Aermod View model in the Governor Eraldo [16]. Air quality assessment and the results of survey studies provide high quality data which enable to conduct an in-depth analyses and a consistent measurement record. Results of assessment enable to implement effective air quality development policies in selected regions. Consequently, based on the collected data, the air pollution resources and the air quality affecting factors can be found [17].

Due to the high contamination potential risks of oil refineries on human body and extensive damage possibilities, we seek to survey the CO distribution from an oil refinery's stacks using the air quality models. In the present study, the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) was used to indicate the oil refinery's stacks pollutants dispersion model Tehran city. Thereafter, we defined a boundary around the plant to assess the impact of pollutants on the affected areas.

MATERIALS AND METHODS

Firstly, in the current study, the AERMOD modeling system was performed to predict CO emission from TEHRAN oil refinery's stacks. Secondly, the procedures of modeling configurations, input parameters, and their applications on model simulations were presented to evaluate concentrations of total CO and their distributions.

Modeling Area (Plant Description):

Due to the importance of pollutants emission from heaters and stacks at Tehran Refinery Company, we decided to collect heaters and stacks pollutants' data. The values of stack emission data was used for each stack in air quality modeling [18]. The quantity of these emissions is a function of the type of fuel burned, the nature of the contaminants in the fuel, and the heat duty of the furnace. This petroleum refinery has vertical cylindrical fire heaters were installed to burn both oil and gas. All burners are equipped with a pilot. Tehran oil refinery is located 20 km southwest of Tehran in limestone mountain area (see Figure 1). This refinery complex has 49 stacks in total; the emission of CO can be attributed to its major pollutant source. Main emission point sources as well as four receptors around them were established according to the government documents (see Figure 1).

Fig.1. Location of the source and the receptor in the study area

Model Description:

The methodology of this study has been presented in Figure 2. The amounts of CO emitted from oil refinery stacks were estimated. The AMS/EPA Regulatory Model (AERMOD) was specially designed to support EPA's regulatory modeling programs. AERMOD is a regulatory steady state plume modeling system with three separate components including AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD Terrain Preprocessor), and AERMET (AERMOD Meteorological Preprocessor). The AERMOD model includes a wide range of options for modeling the impacts of pollution sources on air quality. Due to this ability, this model is a popular choice among scholars for a variety of applications [19]. The AERMOD model is an improved model for characterizing the fundamental boundary layer parameters and vertical profile of the atmosphere along with better representation of plume buoyancy. This model is composed of three parts: AERMOD Meteorological Preprocessor (AERMET), AERMOD Terrain Preprocessor (AERMAP) and AERMOD Gaussian Plume Model with the PBL modules. This model is commonly applied for assessing CO pollutant based on the hourly annual averages, maximum daily average, and maximum hourly average. All necessary data were collected at 25 × 25 km^2 diameter distances from emission points.

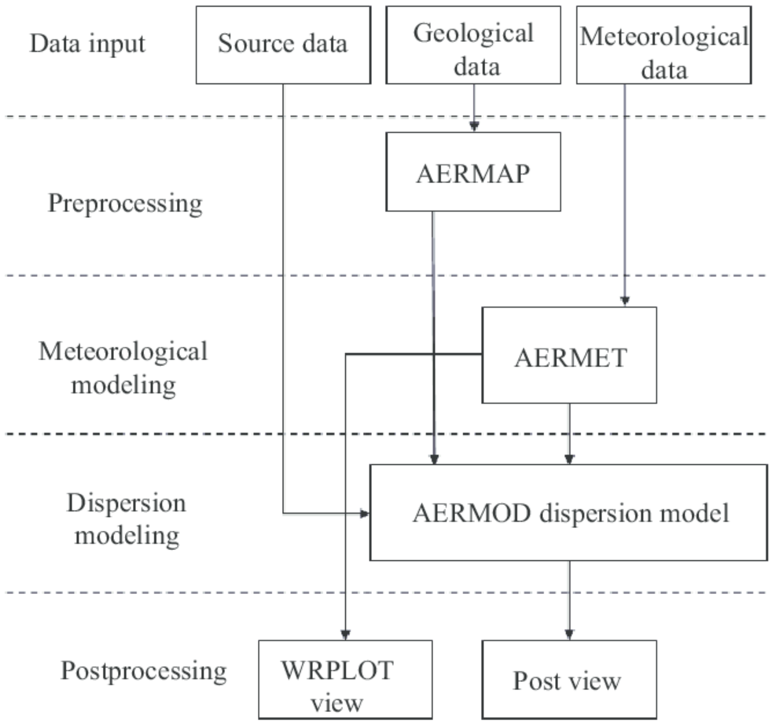

Fig 2. Schematic methodology for the study

Meteorological Measurement:

Table 1 shows the locations and details of the meteorological stations. The wind speeds and directions from Imam Khomeini's meteorological stations were 1-hr averaged data. The geographical coordinates of Tehran Imam Khomeini International Airport are 35.416 deg latitude, 51.166 deg longitude, and 990.2 m elevation. The topography within 3 km of Tehran Imam Khomeini International Airport contains only modest variations in elevation, with a maximum elevation change of 48 meters and an average elevation above sea level of 999 meters. The area within 3 km of Imam Khomeini International Airport is covered by shrubs (91%), within 16 km by shrubs (73%), and within 80 km by shrubs (50%) and bare soil (19%). Based on the meteorological data, hot-weather is from May to September and another boundary is cold weather and considered the time categorized in this study as cold and hot. The meteorological data were collected from Imam Khomeini International Airport's station. These parameters were prepared in columns and temporal resolution was prepared in rows of a spread sheet. This spread sheet was processed in AERMET which is a preprocessor of AERMOD.

Table 1. Meteorological data of Imam Khomeini Airport

Meteorological station	Collected data by	Meteorological parameters	Distance from reference point	Direction to reference point	Site elevation	latitude	longitude
Imam Khomeini airport- 40777	hourly weather reports	pressure, humidity/wind chill, rain, wind speed, cloud, pressure, and UV index	500 m	S.W.E.N	990.2	35.41666667	51.16666667

Emission source:

The petroleum refining industry converts crude oil into more than 2500 refined products including liquefied petroleum gas, gasoline, kerosene, aviation fuel, and diesel fuel, fuel oils, lubricating oils, and feed stocks for the petrochemical industry. Process reactions are essentially selective hydrogenation of carbon sulfur, carbon nitrogen, carbon oxygen, carbon metal and unsaturated carbon-carbon links in the fraction charged. The gases from the combustion are known as flue gas. After the flue gas leaves the firebox, most furnace designs include a convection section where more heat is recovered before venting to the atmosphere through the flue gas stack [18]. The petroleum refining industry employs a wide variety of processes units. The capacity of selected refinery is 250000 barrel per day. All 49 stacks were considered in this study having a height range 30 to 78 meters. CO emission from oil refinery stacks was contained in our emission inventories. Emission rate associated with the 49 emission sources were calculated from annual emissions.

RESULTS

Meteorological conditions play a major role in the dispersion of pollutants emitted from the refineries stacks. In the present study, Imam Khomeini Airport station's meteorological data from 2018 to 2019 were used for simulating the dispersion of CO emitted from the stacks including wind speed, wind direction, temperature, relative humidity, atmospheric pressure, solar radiation and perception. Meteorological preprocessor (AERMET) was used to process both the surface and upper meteorological data prior to model simulation. Figure 3 shows the wind rose diagram for the study period which indicates the dominant wind direction was NW to S. Maximum velocity range recorded was 11-17 m/s, and stayed 44.5 % of all the experiment period. Wind roses have some differentiation in the terms of wind speeds as well as wind directions. The variation in topography and land use may be responsible for differentiation.

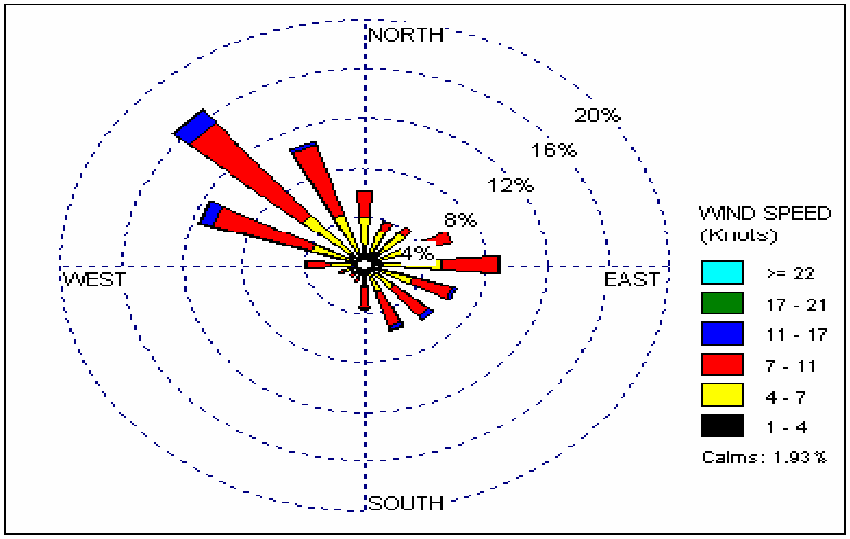

Fig 3. Wind rose diagram of study area collected from Imam Khomeini International Airport's meteorological station

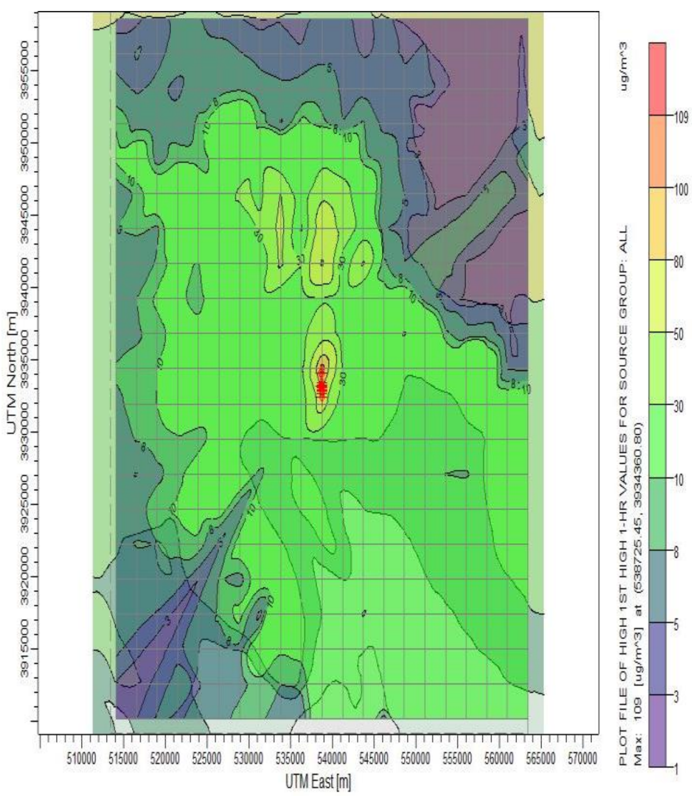

Fig 4. Contour plots of 1-hr CO for hot season

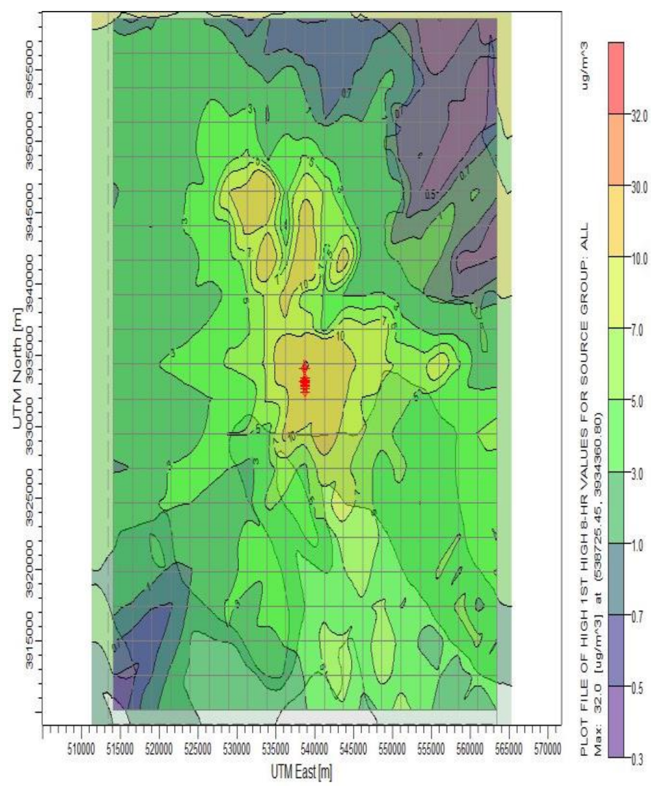

Fig 5. *Contour plots of 8-hr CO for hot season*

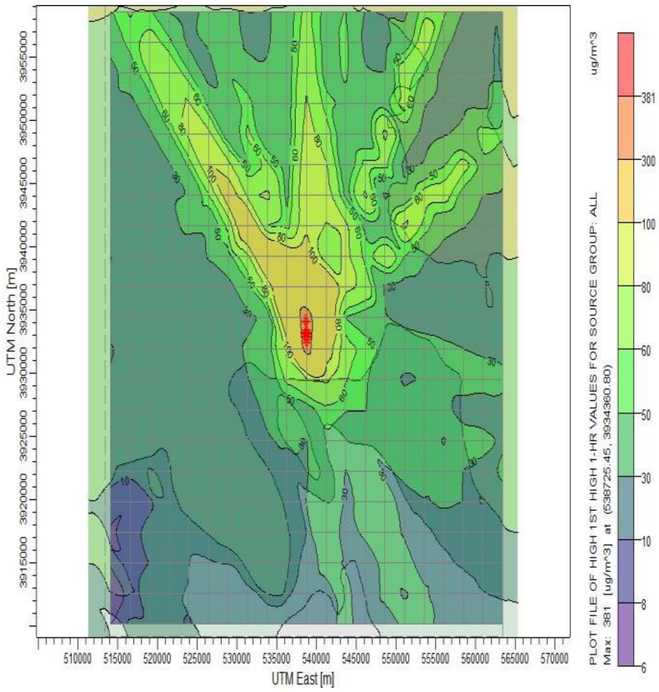

Fig 6. Contour plots of 1-hr CO for cold season

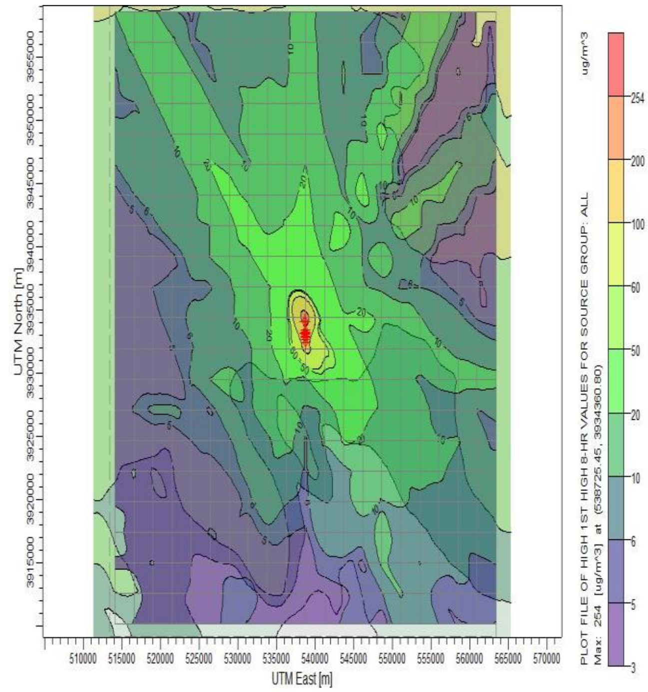

Fig 7. CO Contour plots of 8-hr CO for cold season

In our study, meteorological data from Imam Khomeini International Airport's meteorological station was used. In order to process meteorological data, AERMET as one of the most important modules in AERMOD was used prior to model simulation. The values of the land use parameters such as albedo, Bowen ratio, surface roughness that were used during meteorological data processing are provided in table 2.

Wind class frequency distributions have been presented in Figure 8. Based on the obtained data, wind speed varied between 3.6-5.7 (m/s) 31%, for 16.8 % of time 5.7-8.8(m/s), for 5.6 % of time 8.8-11.1 (m/s) and for 1.2% of time was above 11.1 (m/s).

Table 2. Land use parameters

Sector. No	**Albedo**	**Bowen Ratio**	**Surface Roughness**
1	1	1.6	0.2
2	0.07	0.7	0.2
3	0.2	4.7	0.32

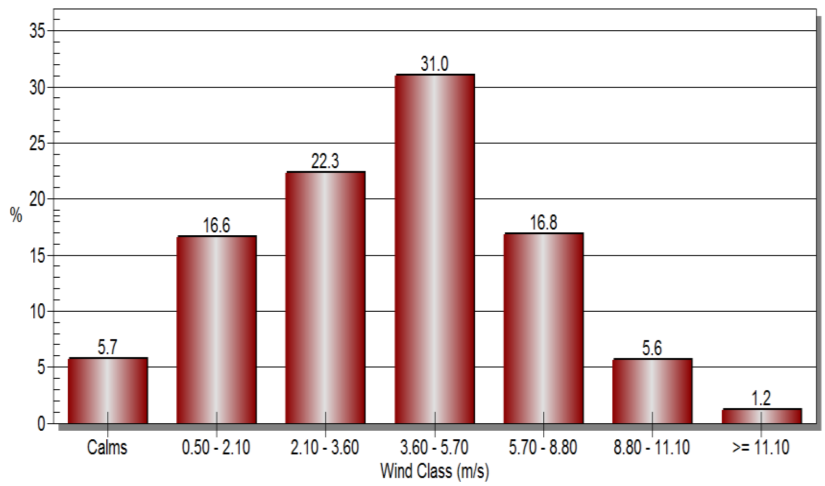

Fig 8. Wind class frequency distributions

The existing emission rate of CO from oil refinery stacks as a point source was modeled. Thus, emissions from all stacks in the study domain were considered for CO modeling. The seasonal average concentration distributions of CO emission from given area were presented in Figures 4, 5, 6 and 7. Modeling was run for 1 hour and 8 hours during the survey collection period in the study area and discrete receptors.

In order to describe the pollution dispersion model in different periods of time, the CO concentration emission at Tehran Oil refinery based on model running time for 1 hour and 8 hours in cold and hot seasons in 2018 and 2019 has been shown in Figures 4, 5, 6 and 7. The pattern of CO concentration transferred from stacks in the southeast direction. For hot time, CO concentration in many regions were below 6.0 mg/m3 and polluted area were mostly located near the oil refinery stacks boundary where surrounded by the main pollutant emission points 109 m/m3 for 1hr contour and 32 mg/m3 for 8hr contour. Based on the results of Figure 6 and 7, it can be concluded that the highest CO concentration level were 381 and 254 mg/m3 in north of stacks.

However, the dispersion of CO was significantly affected by the slightly change of wind direction and air turbulence, such as the crosswise distribution caused by the drastic air turbulence in hot period. The CO maximum concentration for both 1 hour and 8 hours did not exceed the Iranian air quality standard from environment protection organization. The maximum concentrations of CO emission were predicted for the mean of 1 hour (381 μg/m3) and 8 hours (254 μg/m^3) for cold period and 1hour (109 μg/m3) and 32 (μg/m3) for hot period were below both standard levels (primary and secondary) which should not be exceeded more than once per year.

Based on the refinery documents, averaged concentration level of CO monitored at four receptors varied from 145 – 186 μg/m3. Results of simulation by AERMOD software compared with monitored values. The model evaluation was carried out as shown in Table 4. Validation and accuracies of model were examined by three statistical indexes through USEPA guidelines included fractional bias (FB), normalized mean square error (NMSE), and correlation coefficient. FB is a dimensionless value used to evaluate the biasness of data sets and ranges from +2 to -2. The positive and negative FB values indicate under predictions and over predictions, respectively [21]. Also, NMSE measures variance and scattering values between modeled and measured data. Thus, a perfect model will have the FB and NMSE values to be zero [22].

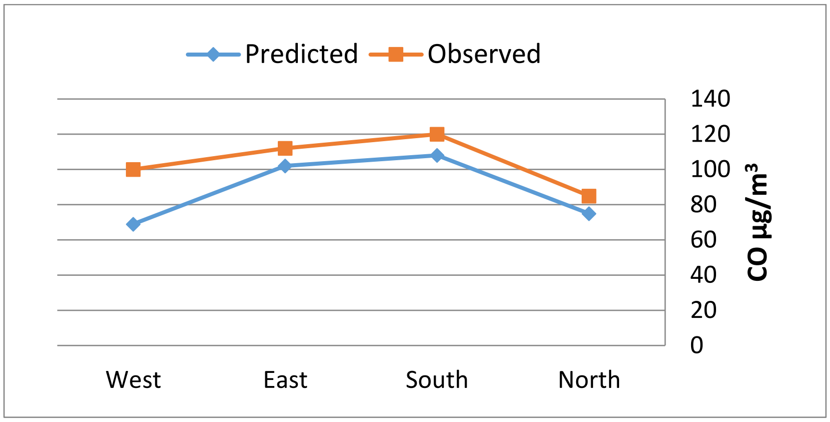

Fig 9. Field-measured values vs. simulated values by AERMOD for CO in Hot time

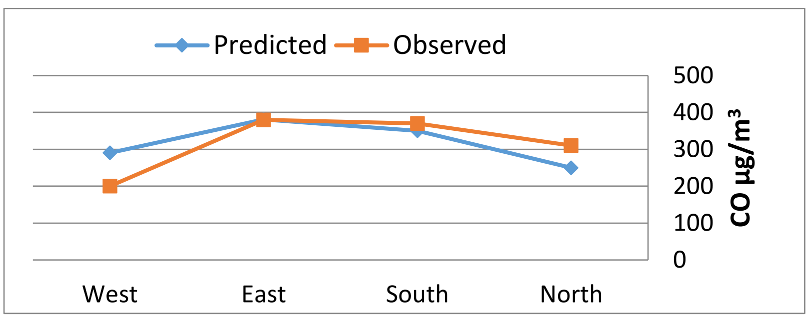

Fig 10. Field-measured values vs. simulated values by AERMOD for CO in cold time

Table 4. Indices performance AERMOD validations

Statistical index	2017	2018
FB	0.38	0.28
NMSE	0.45	0.52
CCOF	0.79	0.85

DISCUSSION

Based on the statistical indexes in Table 1, FB values for two periods were positive 0.38 for hot time and 0.28 for cold time, respectively. Therefore, other statistical indexes such as NMSE and coefficient were within satisfactory range [7]. Thus, it shows the ability of Aermod software in assessing CO emission from oil refinery stacks.

Simulation of CO dispersion modeling from oil refinery stacks in 2018 and 2019 at Tehran was presented in Figures 4, 5, 6, and 7. Although the CO concentration emitted from stacks were below standard levels but significant amount of pollution accumulated in the north of the refinery against of BIBISHAHRBANO Mountain. According to the modeling results, CO concentration was significantly affected by wind direction and disperses to prevailing wind WS. In cold season, values of CO concentration accumulated around the domain area more than hot season in this study. Air turbulence, wind direction and temperature had an impact on the level of CO pollution in hot time [3]. In cold time, CO concentrations were increased by a change of air temperature. The maximum concentration of CO recorded in simulation detected in cold time when using the Aermod View model, in the simulation of the dispersion of pollutants emitted from process plant [16]. It can be concluded that the dispersion of pollutants is greatly affected by the local meteorological factors and land surface features [21].

However, two factors of peak production time and process type leads to produce more CO concentration. So, this situation should be considered to set up emission control policy to reach normal operations in accordance with the operating and analytical manual of the oil refinery. From testing point of view, it would be interesting to perform various streams of the process units in order to control process and increase combustion efficiency and reduce CO concentration release from stacks and this finding has also been observed by others [20].

CONCLUSION

The meteorological information in the modeling domain showed that prevailing wind direction was from NW and 31% of wind class frequency distribution varied range 3.6 to 5.7 m/s. The assessment of model performance using statistical index showed a significant correlation between predicted and observed CO concentration in 1-hour contour for 2018 and 2019 (hot and cold times). In the current study, the AERMOD slightly underestimate the 1-hour contour. The CO underestimate occurs probably due to life plant, maintenance situation, and potential modeling issues related to the modeling such as differences between values at domain site that pollutants emission and observation site although meteorological parameters applying in software [23].

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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