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Thaer O. ROOMI, Adel S. ABED

Mustansiriyah University, College of Science

Estimating gaseous pollutants in the air near Daura Refinery, Daura Power Plant and South of Baghdad Power Plant by calculating the fuel discharge

Key words: gaseous pollutants, SO₂, CO, NO₂, power plant, refinery

Introduction

Air is polluted when there are odd substances in it, and these substances become undesirable when their presence in a concentration may cause great harm to humans, their properties and their environment. These odd materials (pollutants) may be in the form of aerosols or gases (Vallero, 2014). The environmental pollution caused by the industrial facilities has become a global concern. Part of the complexity of this problem is the conflict between the economic benefits of these facilities and their risks to public health and the surrounding environment (Al-Jahdali & Bin Bisher, 2008). The industrial facilities emits several atmospheric pollutants including SO₂, H₂S, NO_x, CO, hydrocarbons and other poisonous materials (Damian, 2014).

Many diseases such as cancer, heart disease, pneumonia and premature death can occur because of exposure to gases from refineries, power plants and other industrial facilities (Shubbar, 2019). Sulfur dioxide gas dissolves rapidly in atmospheric water vapor, thus acid rain builds up in air, soil and plants around refineries and power plants (Zhao, Li, Xiao & Li, 2019). This gas caused primarily by refineries and power plants (Liu, Yang, Zhang Xiang & Wei, 2019). Many research works confirmed that NO₂ has serious problems to humans and contributing in agriculture degrading by affection on the chlorophyll (Carmargo & Lombardi, 2018; Sheng & Zhu, 2019). Carbon monoxide resulting from incomplete combustion of carbon materials. It affects human health and plants due to its toxic nature (Cuinica, Abreu, Gomes & Esteves da Silva, 2013). One of the important factors in the dispersion and transmission of pollutants is the air stability. On diurnal to sub-diur-

nal timescales, variation in air stability can cause a comparable or greater influence on the variability of urban pollutant concentrations than the changes in source emission or advection (Wang et al., 2016). Wind speed and direction patterns play an important role in dispersion and mitigation of the high concentration of gas pollutants. However, they distribute the pollutions to cover more remote regions (Manii & Al-Jumaylii, 2012). Many research works address the pollution problem and the environmental effects of refineries and power plants in Iraq. Al-Suhaili and Al-Khafaji (2015) built a mathematical model for integrated air pollution modelling around refineries and took Daura Refinery as a study case. The model demonstrates the influence of atmospheric stability, wind speed, emission rate, exit velocity, physical height, exit temperature and rural-urban area in reducing the concentrations of pollutants. Al-Dabbas, Ali and Afaj (2012) studied the concentrations of pollutants around Kirkuk Refinery by using low volume air sampler (a sniffer) in 2010 and 2011. The results revealed that the concentrations were higher than the permissible limits of the Iraqi national determinants. Al-Hassen, Al-Qarooni, Qassim, Al-Saad and Alhello (2015) determined the gaseous pollutants concentrations of CO, NO₂, and SO₂ emitted from selected emission sources at Basra city. The results revealed that the concentrations of the above pollutants exceeded the maximum permissible limits for Iraqi National Emission Standards. Shubbar, Suadi and Al-Jiboori (2018) studied the dispersion of SO₂ from Daura Refinery by using ScreenView model and checked the effect of the wind speed and direction

on the spread of pollutants. The three pollutants (CO, SO₂ and NO₂) have been also taken up by researchers from around the world. García-Gusano, Cabal and Lechón (2015) carried out a study to ease the lack of National Emission Ceilings (NEC) Directive assessments at country level for Spain. The amount of NO_x and SO₂ emissions were analyzed using the TIMES-Spain energy optimization model. Abiye et al. (2016) provided model-based estimates of atmospheric dispersion for gaseous pollutants (SO₂ and NO_x) released from a scrap-iron recycling factory located in southwest of Nigeria. The study identified the pollutant concentrations increase by stable atmosphere, weak wind speed, low mixing height, and high relative humidity. A comprehensive Canadian study conducted by Ragothaman and Anderson (2017) presented a review of findings from different studies on air quality impacts of petroleum refining and petrochemical plants in several cities around the world. Kumar, Bhushan and Kishore (2018) applied a dispersion modeling approach to determine SO₂ and NO₂ concentrations in the surrounding air of the industrial and mining cluster in Keonjhar, India for one year 2015. Filonchyk, Hurynovich, Yan, Gusev and Shpilevskaya (2020) carried out a study focused on East China and attempted to assess comprehensively the environmental impact of the COVID-19 disease 2019 outbreak. The study analyzed satellite images of SO₂, NO₂, CO and aerosol optical depth in the period before and during the outbreak of the epidemic. The data then was compared with the data before the epidemic in 2019. The results showed that the COVID-19 lockdown improved air

quality in the short term, but as soon as power plants and refineries came back to normal work, pollution levels returned to their previous level.

In this study, the emitted pollutants of CO, SO₂ and NO₂ emerged from each of Daura Refinery (DR), South of Baghdad Power Plant (SBPP) and Daura Power Plant (DPP) was addressed. These three facilities uses the crude oil and are situated in a region of less than 3 km in diameter. Two of them (DR and BSPP) was established in 1950s, while DPP was established in 1981. In 1950s, these facilities where outside the city and no houses in around (Murtadah, Al-Sharify & Hasan, 2020). However, nowadays, these facilities are surrounded by inhabited cities, which are affected by the pollution of undesired gases. Therefore, the Iraqi committee of health and environment in the Iraqi parliament called for a decision to transfer DR to another place according to environmental and international regulations (Murtadah et al., 2020). However, due to the economic difficulties the country is going through, this option is no longer on the table now.

Gaussian plume model of dispersion

Gaussian dispersion models are extensively used to calculate local pollution levels. The accuracy of such models depends on stability determination (Awasthi, Khare & Gargava, 2006). This model utilizes an emissions rates, meteorological elements, and equations, which describe mathematically the physical process of turbulent transport of air

pollutants in the boundary layer to calculate concentrations. Gaussian plume equation tells mathematically how to compute the concentration of a gas or any comparable in size, solid or liquid pollutant being emitted continuously from a single source (Weber, 1982), the equation can be written simply by (Leelőssy et al., 2014):

$$C(X,Y,Z,H) = \frac{Q}{2\pi\sigma_y\sigma_zU} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left[\exp\left(-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right) \right]$$

where:

- C – concentration [ppm of kg],
- X – horizontal distance in downwind direction [m],
- Y – central line of pollutants dispersion [m],
- Z – vertical altitude above surface [m],
- H – effective height of chimney ($H = h + \Delta h$, in which h is chimney height and Δh is plume height) [m],
- Q – emission rate [$\text{kg}\cdot\text{s}^{-1}$],
- σ_y, σ_z – Gaussian plume standard deviations in horizontal (crosswind) and vertical directions,
- U – wind speed at the effective height of chimney [$\text{m}\cdot\text{s}^{-1}$].

Our current study estimated the concentrations of by using the consumed fuel in three facilities: Daura Refinery (DR), Daura Power Plant (DPP) and South of Baghdad Power Plant (SBPP). The calculation implemented by using Gaussian dispersion model. The effects of the stability, wind speed and direction, chimneys height and diameter were also investigated. The most affected cities were determined, as well.

Material and methods

Location

Daura Refinery, Daura Power Plant are located in Daura District, south of Baghdad, while South of Baghdad Power Plant is located to the east of the refinery, 2 km away on the other side of the Tigris river. The area surrounding these facilities is urban areas of flat nature devoid of complex terrain as well as of tall buildings (Fig. 1).

on SBPP was obtained from the power plant. Data about DPP was obtained from the Environment Unit in the Department of Planning and Studies, Iraqi Ministry of Electricity. The meteorological data of 10 m wind speed and hourly 1.5 m air temperatures of year 2017 of Daura District were obtained from the European Center for Medium Weather Forecast (ECMWF) website. DR contains 12 units that have 35 chimneys, DPP has four units connected to four chimneys, while SBPP

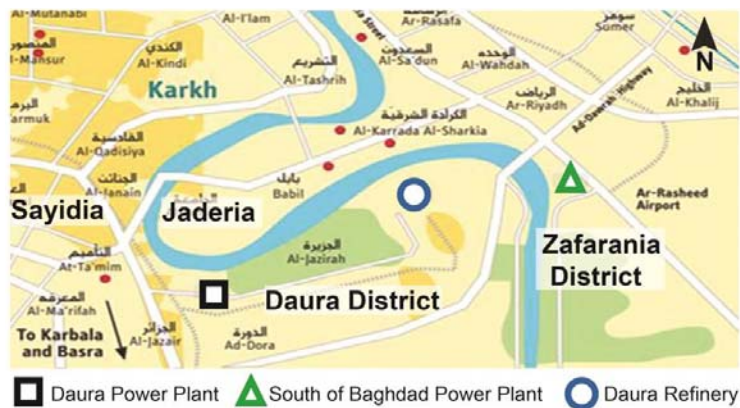


FIGURE 1. Location of examined emitters of air pollution

Data

The data were used for the monthly quantities of fuel discharged in each unit of DR for year 2017, and the data for the height, diameter, and temperature of the outgoing gas were used. These data were obtained from DR. Likewise, the data

has six units, three of which only are in operation, and each of the plant's units is connected to one chimney. To consider these units as a single point source, the height and diameter of the chimney and the temperature of the gas exiting from it were calculated as rates. Table 1 lists the information of the chimneys.

TABLE 1. Chimney characteristics of the pollutions sources

Specification	Daura Refinery (DR)	South of Baghdad Power Plant (SBPP)	Daura Power Plant (DPP)
Chimney average height [m]	29	54	100
Chimney average diameter [m]	1.5	2	2.5
Chimney exit gas temperature [K]	615	460	433

Concentrations of SO₂, CO and NO₂

Concentrations of SO₂, CO and NO₂ gases emitted from DR, DPP and SBPP were calculated for four months representing the seasons of 2017 (January, April, July and October) for a distance of 10 km from the source. The concentrations were calculated by using Gaussian plume model of dispersion, which requires gas emission rate, chimney's gas exit velocity in addition to the height, diameter, and gas exit temperature of the chimney. The method uses the data of consumed fuel. To calculate gas emission rates, the monthly fuel quantities data converted into hourly rates and then to convert volume units to mass units. Calculation of emission rates and gas exit velocity were computed by FORTRAN script.

Effect of stability and wind on pollutants concentrations

The concentrations were calculated for slightly stable (E) and moderately unstable air classes (B) for four months in 2017: January, April, July, October. Finally, a comparison among the three sources (DR, DPP, SBPP) of the emission rates and concentrations of pollutants was made to quantify the contribution of each source of the three pollutant gases (SO₂, CO, NO₂).

Results and discussion

Emission rates

The results of emission rates and gas exit speed were shown in Table 2. It is clear that DPP consumed more fuel and emitted more pollutants than the other sources.

TABLE 2. Emission rates and gas exit speed of Daura Refinery (DR), South of Baghdad Power Plant (SBPP) and Daura Power Plant (DPP)

Specification	Facility	January	April	July	October
Consumed fuel mass [kg·h ⁻¹]	DR	41 428	45 056	51 997	47 964
	SBPP	25 629	24 189	25 164	20 680
	DPP	57 980	77 184	94 321	64 505
SO ₂ emission rate [g·s ⁻¹]	DR	904	1037	1 123	1 017
	SBPP	598	564	587	482
	DPP	1 352	1 800	2 200	1 505
CO emission rate [g·s ⁻¹]	DR	862	863	1 023	930
	SBPP	660	623	648	533
	DPP	1 495	1 990	2 432	1 663
NO ₂ emission rate [g·s ⁻¹]	DR	84	89	97	84
	SBPP	61	58	60	49
	DPP	139	185	226	154
Gas exit speed [m·s ⁻¹]	DR	5.5	6.1	7.2	6.9
	SBPP	18.8	17.7	18.4	15
	DPP	19.3	25.7	31.4	21.5

Concentrations of the pollutants at four months of slightly stable condition (E)

Figure 2 shows the pollutant concentrations emitted from DR for the four months when the atmosphere is slightly stable (E). The figures showed that the pollutant concentrations change with distance, as the pollutants concentrations at the surface level increase in the beginning with moving away from the point source and then decrease after that. It was observed that the highest concentration of pollutants is approximately at distance of 1,000 m. This high value can be justified due to the fact that the gas leaving the chimney is at a higher temperature than the surrounding temperature and therefore its density is lower than the surroundings' density. The gas rises higher due to the force of buoyancy and turbulence enhancing pollutants dispersion and reducing the concentrations. With increasing distance from

the source, the plume mixes with the surrounding air. The temperature decreases gradually and the buoyancy force will be diminished and the vertical movement will be inhibited. Therefore, the concentrations of pollutants increase gradually in the distance less than 1,000 m. After this distance, pollutants concentrations begin to decrease gradually due to their departure from the source. Although the lowest emission rates of pollutants were during January, concentrations of pollutants at the surface level were the highest during this month. This may be due to the lower wind speed in addition to the stratification of stable weather and inversion during this month. It was also noted that the concentration of SO₂ is slightly higher than CO and that the ratio of SO₂ to CO is greater in April. This may be due to the fact that the consumption of gaseous fuel is greater than that of liquid fuels in April when the need to electricity is the lowest. It is well known that the gaseous fuel releases more quantities of

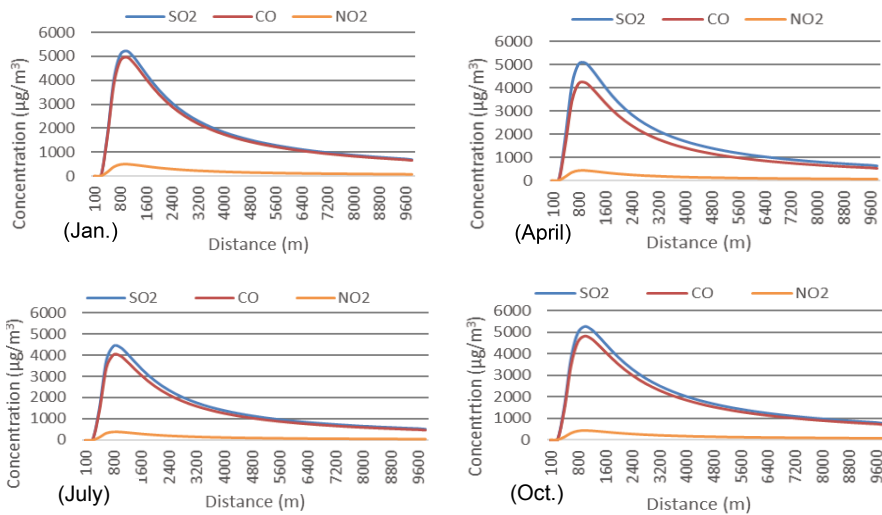


FIGURE 2. Pollutants concentration at stable conditions, at Daura Refinery

SO₂ than CO. On the other hand, it was observed that the concentrations of NO₂ gas was fewer compared to SO₂ and CO. This low value of NO₂ is normal for refineries (Nirel & Dayan, 2001).

Figure 3 shows the concentrations of pollutants emitted from SBPP at slightly stable condition (E). The highest concentration of pollutants was during January which might due mainly to the high quantities of fuel consumed during this month. Also, the wind speed during January was the least leading to an increase in concentrations. It was also observed that the concentration of CO was slightly higher than SO₂, while the concentrations of NO₂ were lowest.

Figure 4 shows the concentrations of pollutants emitted from DPP in a slightly stable weather condition. It was observed that the highest concentration of pollutants was during November, and the lowest was during January and July. Although the wind speed during July is

higher than January, the emission rates of pollutants during July were also high and the values were close to January.

Moderately unstable condition (B)

Figure 5 shows the pollutant concentrations emitted from DR in moderately unstable condition (B). The highest concentration was approximately at distance of 200 m and then decreased greatly with the increase in the distance because the vertical movement was active, which led to mixing and dispersing of the pollutants, and thus the pollutant concentrations decreased. Hence, the pollutants concentration in this unstable condition was greater than in the case of moderately unstable atmosphere and with same wind speed.

In Figure 6, the dispersion of pollutants for SBPP at unstable conditions was very large and the concentrations were at their highest values at distances close

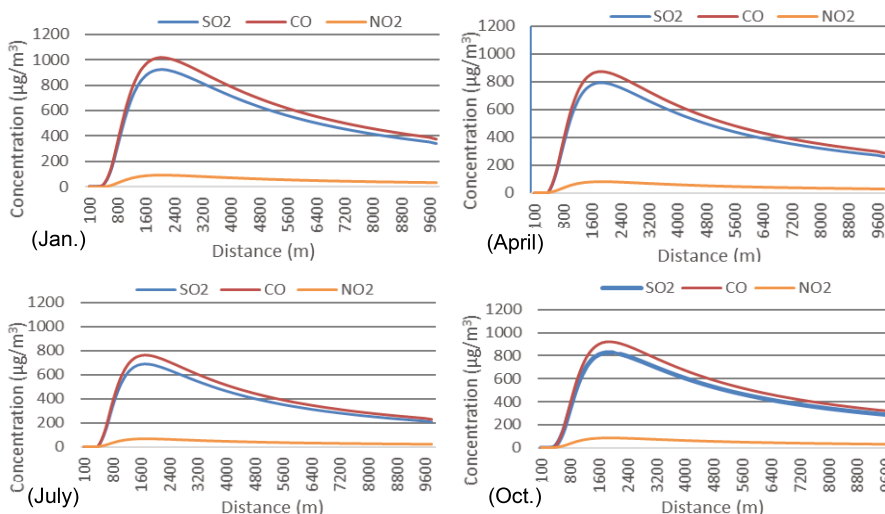


FIGURE 3. Pollutants concentration versus distance at stable conditions, at South of Baghdad Power Plant

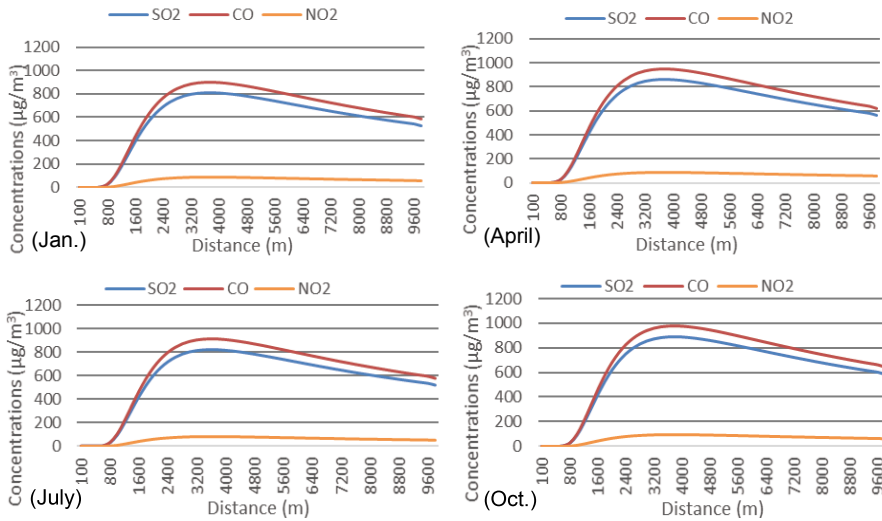


FIGURE 4. Pollutants concentration versus distance at stable conditions, at Daura Power Plant

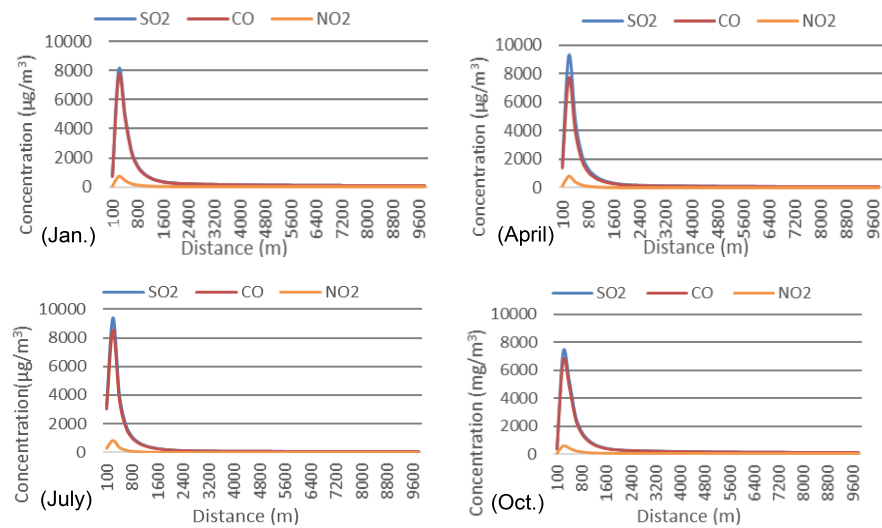


FIGURE 5. Pollutants concentration versus distance at unstable conditions, at Daura Refinery

to the plant. The highest concentration was approximately at 600 m. The concentration then decreases gradually with increasing distance.

Figure 7 shows that the dispersion of pollutants in unstable conditions is very

large for DPP, where the concentrations are at their highest values at distances close to the plant. The highest concentration was approximately at distance of 700 m, then the concentration decreases with increasing distance.

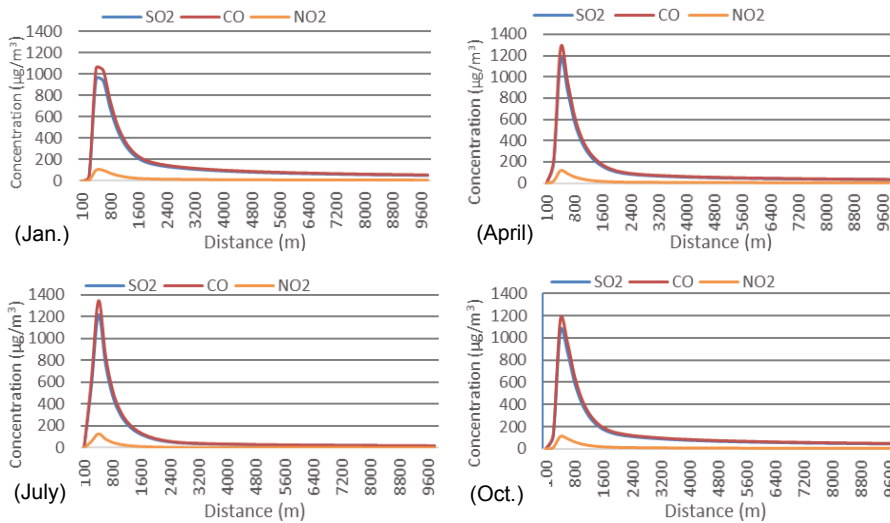


FIGURE 6. Pollutants concentration versus distance at unstable conditions, at South of Baghdad Power Plant

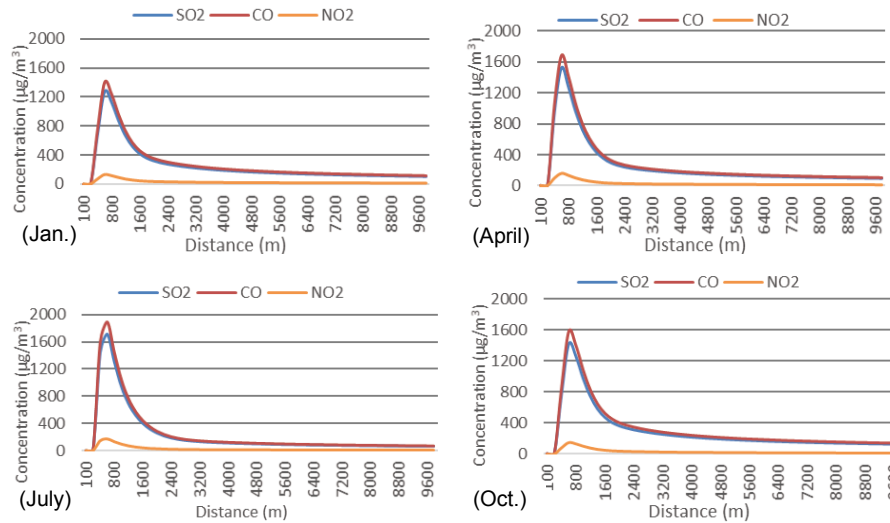


FIGURE 7. Pollutants concentration versus distance at unstable conditions, at Daura Power Plant

Wind direction impact on pollutants dispersion

Table 3 shows that the prevailing wind is northwest. In stable conditions, high pollutants concentrations can reach greater distances than in unstable

conditions since they maintain near the ground. During January and July, Daura District was the most affected by DPP, while Zafarania District was the most affected by DR and SBPP because it was affected by northwest winds. Dur-

TABLE 3. Prevailing wind in the study area for January, April, July, and October 2017

Month	Wind speed [m·s ⁻¹]	Direction							
		N	NE	E	SE	S	SW	W	NW
January	0–5	28	9	11	20	7	7	16	135
	6–10	0	0	0	6	0	3	1	5
April	0–5	72	17	11	10	5	6	11	70
	6–10	6	2	3	4	3	0	1	20
July	0–5	25	4	0	0	5	6	16	70
	6–10	18	0	0	0	0	0	2	103
October	0–5	53	37	30	31	5	4	10	66
	6–10	0	0	0	6	4	0	0	3

ing April, one can notice that along with the northwest winds, there were eastern winds that contribute to the transfer of pollutants emitted from DR and SBPP to Daura area, while Sayidia area was more affected by DPP. October had the most variable wind direction.

Comparison of the three sources

The emission rates and concentrations of pollutants emitted from DR, DPP and SBPP were visualized to make a comparison among them (Fig. 8). It is clear that the pollutants concentrations

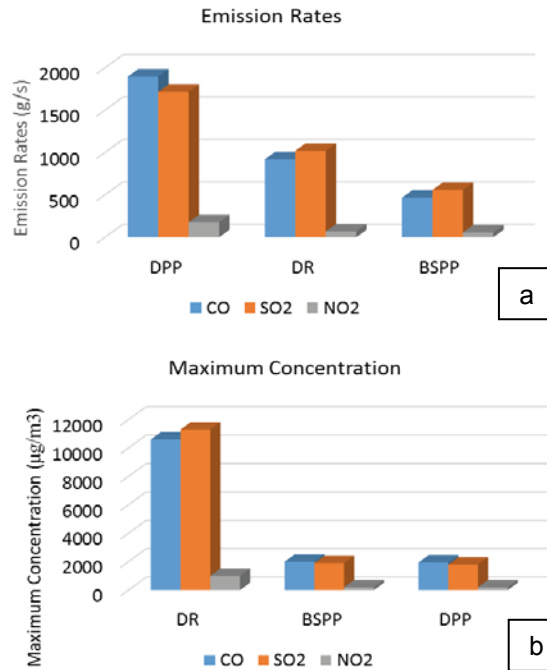


FIGURE 8. Facilities (a) emission rates and (b) maximum concentration

emitted from DR at the ground level are greater than those emitted from DPP. This may be due to the difference in effective plume height, as the greater the effective height of the plume, the greater the dispersion of pollutants. This gives an indication that this facility has serious problems on the human health and even the plants. The height of the chimney, the gas exit velocity, and the gas temperature lead to an increase in the effective height of the plume. Considering the diameter, the larger the diameter, the faster the gas leaving the chimney, the lower the effective height of the plume. Because of the high altitude of DPP chimneys, the wind speed is greater at the top causing greater reduction of pollutants. The high altitude of the chimney does not mean it is environmentally friendly because pollutants will just spread for longer distances. In these three sources, it was observed that the effect of the height of the chimney as well as the velocity of the gas leaving the chimney were more clear on the dispersion of pollutants than the effect of diameter and the temperature of the gas leaving the chimney.

Conclusions

1. The concentrations of pollutants in DR, BSPP and DRR increase in stable conditions due to the less air turbulence. Hence, the unstable atmospheres are better at dispersing pollutants.
2. Since the prevailing wind direction is northwest, Zafarania District is the most affected by the pollutants emitted from DR and BSPP while Daura District is very affected by DPP.

3. Wind speed has a clear effect on the dispersion of pollutants, the higher the wind speed, the lower the pollutant concentrations.
4. Pollutant concentrations increase with increasing emission rates and chimney diameter, and decrease with increasing chimney height, speed of the gas leaving the chimney.
5. DPP has higher emission rates than DR and SBPP. However, at the surface level, the concentrations emitted from DR are greater than those emitted from DPP and SBPP. Thus, DR is the most affecting source on the health of people in the areas surrounding the refinery.
6. Although increasing the height of the chimney contributes to reducing the concentrations of pollutants at the surface level that does not mean it is environmentally friendly because pollutants will just spread for longer distances.

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Summary

Estimating gaseous pollutants in the air near Daura Refinery, Daura Power Plant and South of Baghdad Power Plant by calculating the fuel discharge. This study addresses estimation of emission rates and concentrations of SO₂, CO and NO₂ gases emitted from Daura Refinery (DR), Daura Power Plant (DPP) and South of Baghdad Power Plant (SBPP) by calculating the fuel discharge. The estimations were made by using the Gaussian plume model of dispersion at distances within 10 km from the pollution source for January, April, July and October 2017 under two stability conditions,

slightly stable and moderately unstable. The effect of wind speed and direction as well as the ambient temperature of the surrounding air on the dispersion and transmission of air pollutants were also investigated. It was found that the unstable conditions are better for dispersing out atmospheric pollutants. The results showed that Zafarania District was the most affected by pollutants emitted from DR and BSPP while Daura District was more affected by DPP due to the prevailing wind direction. It was also found that an increase in wind speed leads to a decrease in the concentration of pollutants. The concentration of pollutants is inversely proportional to the height of the chimney, the speed of the gas leaving the chimney, while it is directly proportional to the diameter of the chimney. DPP has higher emission rates than DR and SBPP while at the surface level, the pollutants concentrations emitted from DR are greater than those emitted from DPP and SBPP.

Authors' address:

Thaer O. Roomi – corresponding author
(<https://orcid.org/0000-0002-5764-5075>)
Adel S. Abed
(<https://orcid.org/0000-0001-5175-904X>)
Mustansiriyah University
College of Science
Department of Atmospheric Science
Palestine Street, 46131 Baghdad
Iraq
e-mail: th.roomi.atmssc@uomustansiriyah.edu.iq
a.adelsaad96@gmail.com