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Assessment of Air Pollution around Durra Refinery (Baghdad) from Emission NO₂ Gas at April Month

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Abstract:

Nitrogen dioxide NO₂ is one of the most dangerous contaminant in the air, its toxic gas that cause disturbing respiratory effects, most of it emitted from industrial sources especially from the stack of power plants and oil refineries. In this study Gaussian equations modelled by Matlab program to state the effect of pollutant NO₂ gas on area around Durra refinery, this program also evaluate some elements such as wind and stability and its effect on stacks height. Data used in this study is the amount of fuel oil and fuel gas burn inside refinery at a year 2017. Hourly April month data chosen as a case study because it's unsteady month. After evaluate emission rate of the all fuel and calculate exit velocity from stack (consider all refinery unit is a point), effective height resulted. Effective height is test with other atmospheric element and with stability, and there is direct relation with unstable turner classes. After Gaussian model implemented results show that most pollutant area from pollutant of NO₂ is Al-Jadriyah and Al-Karada area, this area is about 3-5 kilometer from the refinery point. The wind direction domain is from the south to south-east, thus most flow is to north, north-west and the pollutant level of NO₂ is over the national ambient air quality standard in this area.

Keyword: NO₂ concentration, stability, air pollution, April month, emission rate.

Introduction:

Power generation plants and refinery produce varying emissions to the surrounding atmosphere that may adversely impact air quality and cause air pollution in the vicinity regions^{1,2}. Through Combustion of fossil fuels atmospheric nitrogen and any nitrogen in the fuel will converts into its oxides, mainly nitric oxide (NO) and with small amounts (5–10%) of NO₂. NO slowly oxidizes to NO₂ in the atmosphere³. Nitrogen oxides, NO_x are the term used to describe the sum of NO, NO₂ and other oxides of nitrogen; all these play a major role in the formation of ozone, particulate matter, and acid rain. Long-term exposures to NO₂ may lead to increase susceptibility to respiratory infection and may cause permanent alterations in the lung⁴. Usually NO₂ in the atmosphere comes from two sources, either directly from emission sources (primary pollutant) or from chemical reactions in the atmosphere⁵. Nitrogen monoxide (NO), in turn, is converted to NO₂ by reactions with proxy radicals (RO₂) or O₃. Nitrogen dioxide is then photolysis in the atmosphere, and the released atomic oxygen

combines with molecule O₂ to form O₃, This gas considers one of gases emitted from flues⁶. Flow rate of Emissions are necessary to determine transfer Contaminants, Where Know the source location will allow us to calculate concentration at a particular region using dispersion model⁷. Inhalation of NO₂ by children increases their risk of respiratory infection and may lead to poorer lung function in later life. Recent epidemiological studies have shown an association between ambient NO₂ exposure and increases in daily mortality and hospital admissions for respiratory disease. NO₂ has also been shown to potentiate the effects of exposure to other known irritants, such as ozone and respirable particles⁶. Animal and human experimental studies indicate that NO₂ at short-term concentrations exceeding 200µg/m³ (one hour) is a toxic gas with significant health effects. Animal toxicological studies also suggest that long-term exposure to NO₂ at concentrations above current ambient concentrations has adverse effects⁸. In this study Assessments the effect of the effective rise of

flue on the pollutant resulted from nitrogen oxides emitted from fuel oil and fuel gas combustion in the regions near to refinery for April month that consider as moderate condition month. The study was focus on the factors affecting the pollutant NO_2 concentration gas overall. For this purpose the program has built up for simulated arithmetic algorithms, also for precision and ease in the use of equations considered.

Site

Durra Refinery is the main refinery of Ministry of oil Midland Refineries Company (MRC) in Iraq. It is located on the western side of the Tigris River and south-west of Baghdad city,

about few kilometers from the city center, it is flat ground. Refinery has Dimensions length 1620 m and width of 860m. From east bounded with small liquid gas filling plant, and the Imam Hassan neighborhood, also from the west and south-west the university district, the residence of employer's borders of the refinery. The highway is located on the east, south-east and south sides. Finally, on the northern side, a small flat area extends across the Tigris River; consider one of the largest cities in Baghdad province known as Karada⁹ Fig. 1. When refinery builds in 1960 it's located outside the Baghdad city but the large urban expansion will made the refinery inside the Baghdad city.

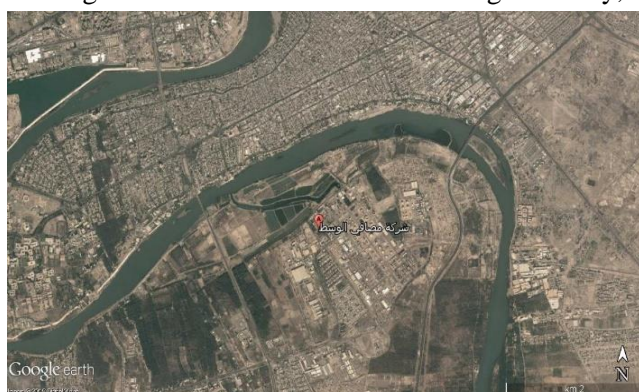


Figure 1. Location of durra refinery in Baghdad and Iraq

Data

Durra refinery data

The Dura refinery operates 24 hours a day and very large quantities of crude oil are refined to produce oil products, its includes 30 plants represented in twelve units¹⁰. Table 1 and 2, show stack height and stack diameter also Stack gas exit temp. And other characteristic of these units, these units are considered as sources of 12 points, but because the distance between them is close to each other, it consider as a point source in this study¹¹. Period study consist of April month from 2017, see

table 2, to know the fuel oil and fuel gas used, where about 27725.3m^3 of fuel oil through 720hour represent total hour of this month through 24hour, this configure in mass about 36890.1kg/hour of fuel oil. But in volumes gas fuel is greater about 6989075m^3 , in mass and equal to about 11163.1kg/hour . At this period (April) most of neutral stability condition is notice over Baghdad city, see reference¹². From data of fuel oil and gas, emission rate of NO_2 can be evaluated according to amounts of fuel burned.

Table 1. The production units in Daura refinery which are used in present study; Symbols, stack information¹⁰.

Item	Name of operation unit	Symbols	Stack's number	stack height	Stack diameter(m)	Stack gas exit temp.(k)
1	Crude Distillation unit_70000 barrel_1	CDU_1	1	21.7	2.4	640
2	Crude Distillation unit_70000 barrel_2	CDU_2	1	21.6	2.7	612
3	Catalytic Reformer_1	CR_1	4	30	1	643
4	Kerosene Hydrogenation	KH	2	20	1	593
5	Catalytic Reformer_2	CR_2	5	30	1.5	548
6	Distillation of Crude oil units_1, and 3.	DCU_1_3	3	30	2	573
7	Power unit_1 (Boiler_1,2,3,4,5,6,7,8)	PU_1	4	30	2	673
8	Power unit_3 (Boiler_11& 12)	PU_3	1	36	2.5	493
9	Lube oil_1	LO_1	3	30	1	573
10	Lube oil_2	LO_2	5	30	1	673
11	Lube oil_3	LO_3	5	30	1	623
12	Power unit_2 (Boiler_9& 10)	PU_2	1	30	3	673

Table 2. The Fuel Oil and Fuel gas amount in Daura refinery at April.

month	Type of fuel	month/ m ³	hour in month	m ³ /hou r	kg/hour
Apr.	Fuel Oil	27725.3	720	38.5074	36890.1
	Fuel gas	698907 5	720	9707.05	11163.1

Meteorological data

To estimate the dispersion of NO₂ gas concentration, most meteorological factor must be known, to understand the behavior of the pollutant plume. Thus hourly data of air temperature, wind speed, relative humidity, atmospheric pressure, and direction from soda site¹³, is plotted in Fig. 2. It's clear from figure correlated between the atmospheric elements.

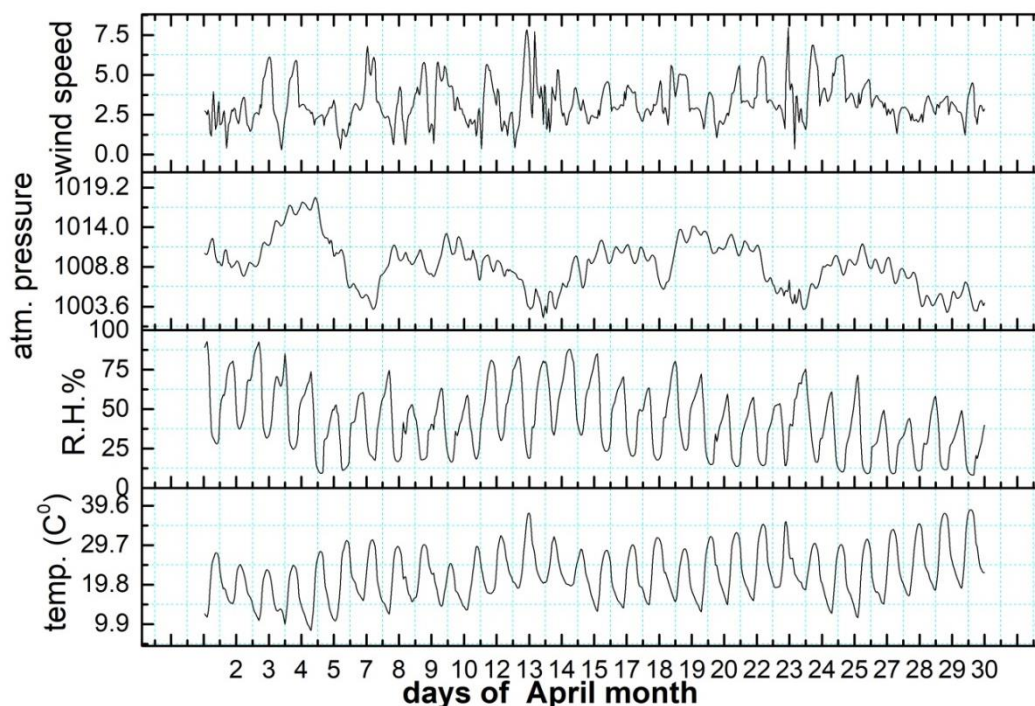


Figure 2. Hourly recorded atmospheric elements, temp., relative humidity, wind speed, atmo. Pressure at April month

The effect is started from synoptic scale to release the local effect, for example atmospheric pressure through this month (April) change between 1002.12mb to 1017.91mb. Decreases in the pressure followed by change in wind speed, where its increases resulted from activity in all atmospheric elements at the same period. This atmospheric situation reflected on relative humidity, temperature and also on changes in wind direction. Effect of change in pressure on air temperature, although its small effect, the domain change in air temperature resulted from daily cycle at daytime temperature

increases, at nighttime decreases. Monitoring ambient air temperature is very useful to given idea about the height of effective plume rise, while relative humidity effect on the photochemical of some trace gases cause's feedback interaction in pollutant concentration to reach NO_2 gas. Change of wind speed and direction effected on the dispersion of plume pollutant gas and on concentration values level at different region around durra refinery. Max and min values of their element is plotted on graphs, see Fig. 2 and 3.

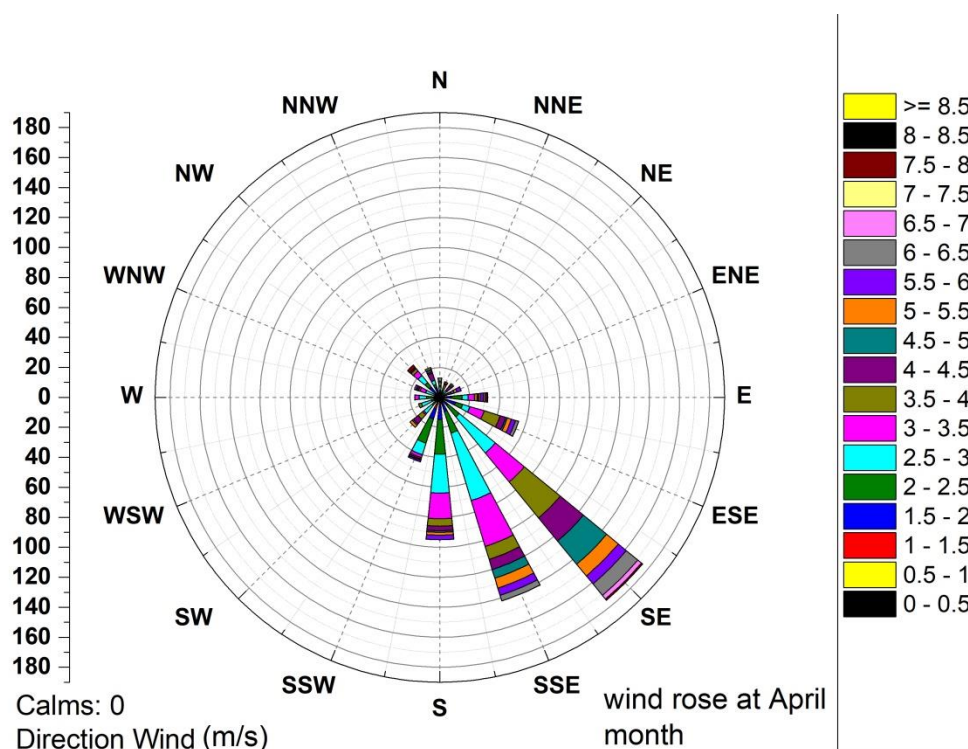


Figure 3. Wind rose for hourly wind speed and direction at April month

Methodology:
Stability

Atmospheric stability effect on the vertical movement of any aerial parcel, it can be determined by several methods or parameters depend on the data available. In this study empirical turner method is adopted¹⁴. This method depends on the wind speed record, solar height angle, and total cloud cover over refinery region,(recorded as hourly) see Table 3. Turner method have seven classes, resulted from intersect the table wind speed data, with insolation class number (ICN), at daytime have values from (1-4), and cloud cover amount at nighttime have negative insolation values (-1 and -2). The amounts of cloud cover available at daytime sometimes modified the ICN, if cloud cover greater than 1/2, and cloud level height less than or equal to 7000ft, where it will became (ICN-2), and if greater than or equal to 7000ft became (ICN-1). If total cloud cover equal to 1 became (ICN-1), where cloud cover level height greater than 7000ft¹⁴. All this bounded conditions assumed in this method to produce hourly class stability data, that used recently to know concentration of NO₂ dispersion according to Gaussian model in area rounded Durra refinery at April month 2017.

Effective Stack Height:

If neglect effect of turbulent from land surface, and assumed plume is dispered in open area, the effective stack height resulted from a summed stack and plume height ΔH will effected by number of element, concerning stack shape, and external concerning the meteorological factor influence the rise of the plume. The emission interning factors are velocity of the effluent at the top of the stack, v_s , temperature of the effluent at the top of the stack, T_s and diameter of the stack opening d . The meteorological factors influence plume rise are ambient wind speed, u temperature of the air, T_a , shear of the wind speed with height du/dz and atmospheric stability¹⁵. To calculate plume rise, the buoyancy flux must first be calculated using equation 1 where¹⁶:

$$F = \frac{g v_s d^2 \Delta T}{4 T_s} \tag{1}$$

F =buoyancy flux m^4s^{-3}
 g =acceleration of gravity $9.8m/s^2$
 v_s =stack gas exist velocity m/s
 d =top inside stack diameter

After calculate buoyancy flux, Effective plume rise height can estimated according to stability, it's divided to:

Table 3. Show how can calculate stability by definition of turner classes 1,very unstable , 2 unstable , 3 slightly unstable , 4 neutral , 5 slightly stable , 6 stable , 7 very stable (14).

Wind speed (knots)	Net radiation index						
	4	3	2	1	0	-1	-2
0-1	1	1	2	3	4	6	7
2-3	1	2	2	3	4	6	7
4-5	1	2	3	4	4	5	5
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8-9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
12	3	4	4	4	4	4	4

Solar altitude	Insolation	Insolation class number
60°<a	Strong	4
35°<a<60°	Moderate	3
15°<a<35°	weak	2
a≤15°	Very weak	1

1-unstable – neutral buoyant and momentum rise:

In atmospheric conditions of unstable, the values resulted from equation 1, responsible for equation used in calculated ΔH . For buoyancy flux less than 55

$$\Delta h = 21.425 \frac{F^{\frac{3}{4}}}{u_h} \quad (2)$$

$u_h =$ wind speed at stack top

For F greater or equal to 55:

$$\Delta h = 38.71 \frac{F^{3/5}}{u_h} \quad (3)$$

Other effective plume rise equation Δh with unstable neutral momentum plume rise is calculated as:

$$\Delta h = \frac{3dv_s}{u_h} \quad (4)$$

2-stable buoyancy and momentum rise:

To calculate the final plume rise for stable condition, stability parameter s must be evaluated¹⁵:

$$s = \frac{g \left(\frac{d\theta}{dz} \right)}{T} \quad (5)$$

g = acceleration of gravity 9.8m/s²

$\frac{d\theta}{dz}$ = Change of potential temperature with height k/m

T=ambient air temperature k

$$\Delta h = \left(\frac{F}{u \cdot s} \right)^{1/3} \quad (6)$$

Power Wind:

In the lower part of the earth's boundary layer (the surface layer), wind speed increase with increasing height and has strong gradient near the

ground. It's often used simple power law of the form¹⁷:

$$u(z) = U_{10} \left(\frac{z}{10} \right)^p \quad (7)$$

Thus to describe wind speed at stack top, where:

u(z): The wind speed at height is z in (m / s) units.

u₁₀: Wind speed at height 10m in (m / s) units.

The power law coefficient p increases with increases surface roughness. For different types of terrain Table 4

Table 4. Wind profile Exponent p for rough and smooth terrain (18)

Stability Class	Description	Exponent, p	
		Rough terrain	Smooth terrain
A	Very unstable	0.15	0.09
B	Moderately unstable	0.15	0.09
C	Slightly unstable	0.20	0.12
D	Neutral	0.25	0.15
E	Slightly	0.40	M, 0.24
F	Stable	0.60	0.24

Emission rate:

Fuel data from Durra refinery is monthly averages, thus amount of fuel oil and fuel gas divided by 720 hour to get fuel quantity in kg per hours that used to estimated hourly emission rate (kg/hour) for NO₂ gas, see table 2. Gzar study is adopted as tool to estimated emission rate of NO₂¹⁹⁻²⁰, its depend on the emission factor for fuel oil and fuel gas to transformed units for NO₂ gas as follow:

$$\text{(For fuel oil)} \frac{2900 \text{ pound}}{1000 \text{ barrels}} * \frac{1 \text{ barrels}}{0.159 \text{ pound}} * \frac{1 \text{ kg}}{2.205 \text{ pound}} = 8.272 \text{ kg/m}^3$$

$$\text{(For fuel gas)} \frac{0.23 \text{ pound}}{1000 \text{ feel}} * \frac{1 \text{ feel}}{0.02882} * \frac{1 \text{ kg}}{2.205 \text{ pound}} = 3.68 * 10^{-3} \text{ kg/m}^3$$

From results of emission factor and Data from Table 2, emission rate for NO₂ evaluated according to Table 5, below, its notes that emission rate of fuel gas have %09.15 from fuel oil, thus the large rate of pollution in NO₂ come from burned of fuel oil.

Table 5. Emission rate for NO₂ from burned fuel oil and fuel gas at April Month 2017

	Emission factor kg/m ³ for NO ₂	Amount of fuel in (kg/hour)	Volume of burn fuel in units m ³ /hour	Emission rate g/s
Fuel oil	8.272	36890.1	38.508	88.4829
Fuel gas	3.68*10 ⁻³	11163.1	7917.093	8.0931

Dispersion coefficients

Dispersion coefficients such as σ_y and σ_z computed from the atmospheric stability class and the downwind distance. The stability class can be computed using the Pasquill or Turner methods²¹. Briggs 1973 examine versions of σ_y and σ_z , in urban and rural, and provide an interpolation scheme that agrees with Pasquill-Gifford in the downwind range from 100 m to 10 km, except that σ_z values for A and B stability approximate the B₂ and B₁ Brookhaven curves²². Table 6 a and b gives the Briggs sigmas. The U.S. EPA recommends these sigma values as the ones most appropriate for dispersion simulations in urban areas²³.

Table 6. The Briggs (1973) sigma junctions for (a) urban and (b) rural conditions (From Panofsky and Dutton, 1984)¹⁴.

Pasquill stability	σ_y	σ_z
A-B	$0.32x(1+0.0004x)^{-0.5}$	$0.24x(1+0.001x)^{-0.5}$
C	$0.22x(1+0.0004x)^{-0.5}$	0.2x
D	$0.16x(1+0.0004x)^{-0.5}$	$0.14x(1+0.0003x)^{-0.5}$
E-F	$0.11x(1+0.0004x)^{-0.5}$	$0.08x(1+0.00015x)^{-0.5}$

5- Gaussian plume model:

The Gaussian plume model, which is at the core of almost all regulatory dispersion models, is obtained from the analytical solution of simplified diffusion equation. For a continuous point source released at the origin in a uniform (homogeneous) turbulent flow the solution to diffusion Equation. Then the final form of the Gaussian plume equation, for an elevated plume released at $z = H_p$ is²⁴:

$$C(x, y, z) = \frac{Q}{2\pi u_p \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{ \exp\left(-\frac{(z-H_p)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H_p)^2}{2\sigma_z^2}\right) \right\} \quad (8)$$

Where:

C = point concentration at receptor, in $\mu\text{g}/\text{m}^3$;

(x, y, z) = ground level coordinates of the receptor relative to the source and wind direction, in meters;

H_p = effective release height of emissions, in meters (m);

Q = mass flow of a given pollutant from a source located at the origin, in $\mu\text{g}/\text{s}$;

u_p = wind speed, in m/s;

σ_y and σ_z = standard deviation of plume concentration distribution in y and z plane, in meters.

6-Results and Discussion

6-1 model implemented

The set of equations from 1 to 8 modelling by program, developed to simulate the effect of many elements on the NO₂ concentration gas emitted from the constant source point (Durra refinery). These element ensemble stability classes, wind speed, roughness surface effect, all tested to its effect on NO₂ ground level concentration as an air quality. Procedure outline in number of step as in Fig. 4.

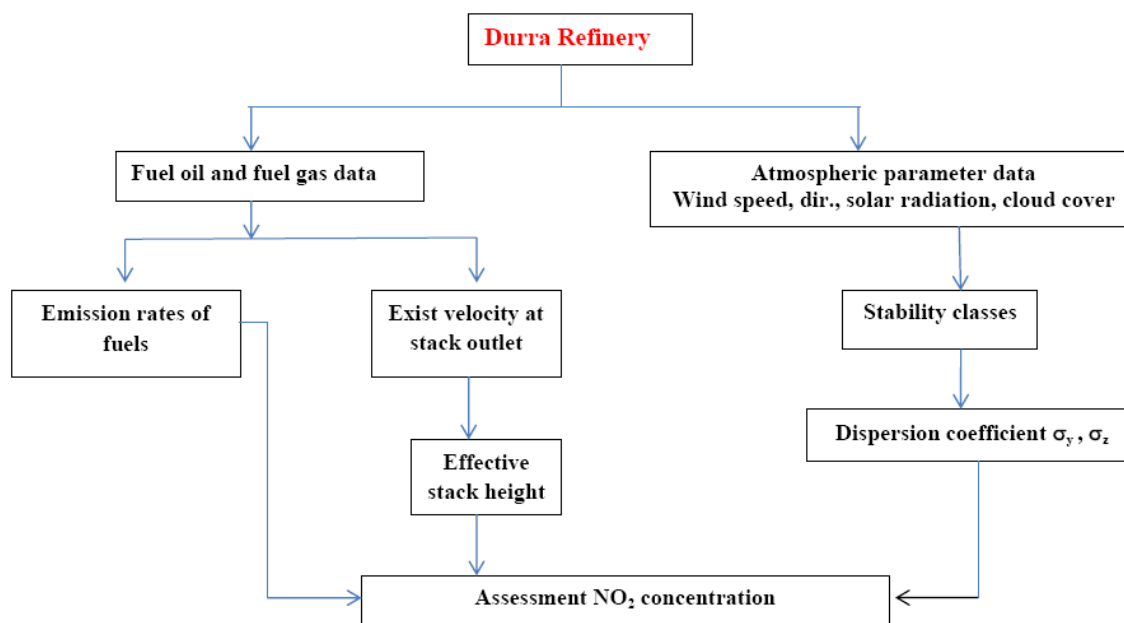


Figure 4. Flow chart of steps processes

Distribution of stability classes:

Unfortunately there is don't direct measure of stability in refinery location because security difficult, most data obtain from satellites site on internet, thus empirical turner method used to put atmospheric stability at this study, this scheme depend on information in Table 3 and paragraph 4-1. Hourly data of wind speed at 10m, total cloud, and solar angle height used by turner method at April month. Fig. 4 show frequency distribution stability classes, it's about 36% of classes is in class D and 22% at class C, while about more than 30% in classes E and F, this will effect on plume concentration dispersion of NO₂ gas after its emitted from stack.

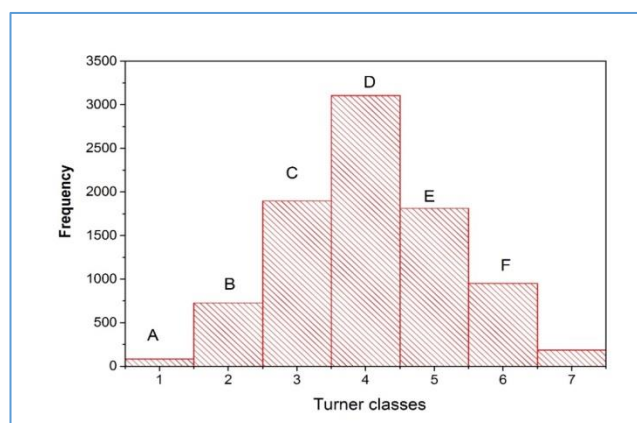


Figure 4. Stability turner Classes at April month over Durra refinery

Wind speed at stack plume:

Durra located inside or near Baghdad city, power law (p) in power law equation consider as urban class according to table 4. This table also taken hourly stability condition from stability paragraph in methodology, on other hand most of stacks in refinery have height about 30m, as average according to Table 1. Fig. 5 compare between wind speed at 10m observed and 30m calculated at stack outlet according to power low.

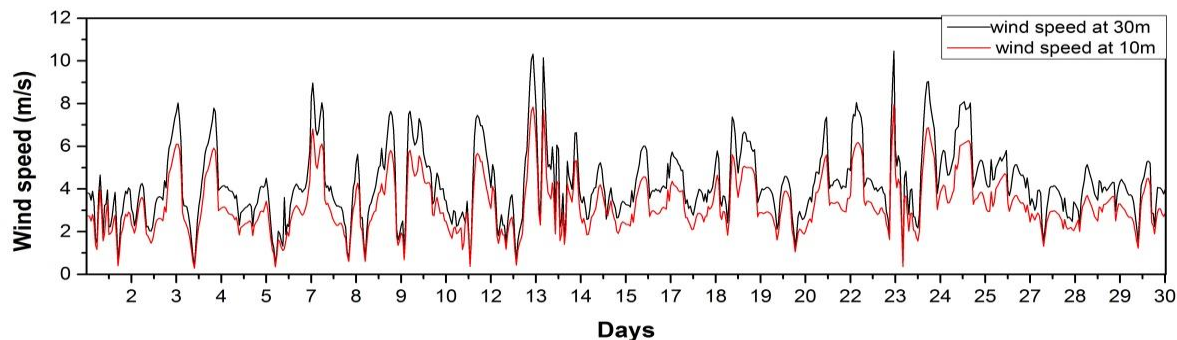


Figure 5. Wind speed calculated at stack height according to power law

Calculates Effective stack height:

According to Effective stack height paragraph in methodology part equations from 1 to 6 used to calculate hourly effective stack height at April month according to stability classes, unstable included classes A, B, C, D and stable classes E,F,G. average effective height is reached to about 500meter in unstable classes , but this height decreases to more than 30meter in unstable classes, see Fig. 6.

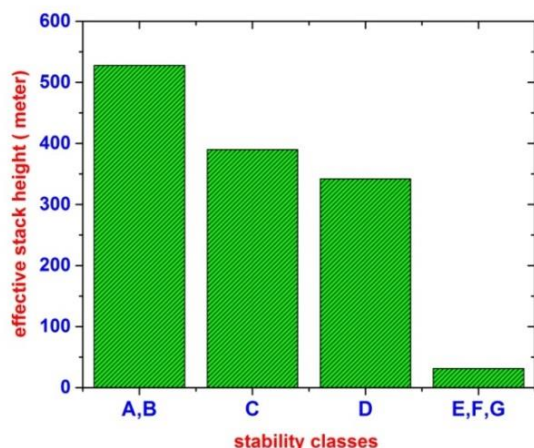


Figure 6. Average effective stack height resulted from stability classes

If stability element is compere with atmospheric element such as wind speed and air temperature, it notes wind speed have very clear effect on effective plume height specifically at unstable-neutral buoyant, see Fig. 7. Air temperature also affected on air pollutant dispersion at stack height, in this study case it's not clear because the effect of stability class and strong the horizontal force advection by wind speed, see Fig. 8 at stable and unstable condition.

NO₂ concentrations at different distances:

Gaussian model equation 8 for dispersion of NO₂ gas is calculated at different distance from refinery point area. This equation calculate concentration of NO₂ received by ground at different distance 1000m , 2000m.....10000m, also at different domain directions, but this equation need to calculate vertical and horizontal diffusion coefficients of σ_y and σ_z , from Table 6, also effective stack height from methodology paragraph. Emission rate at April month for fuel oil and fuel gas is applied in this model equation according to Table 5. Result show great effect of

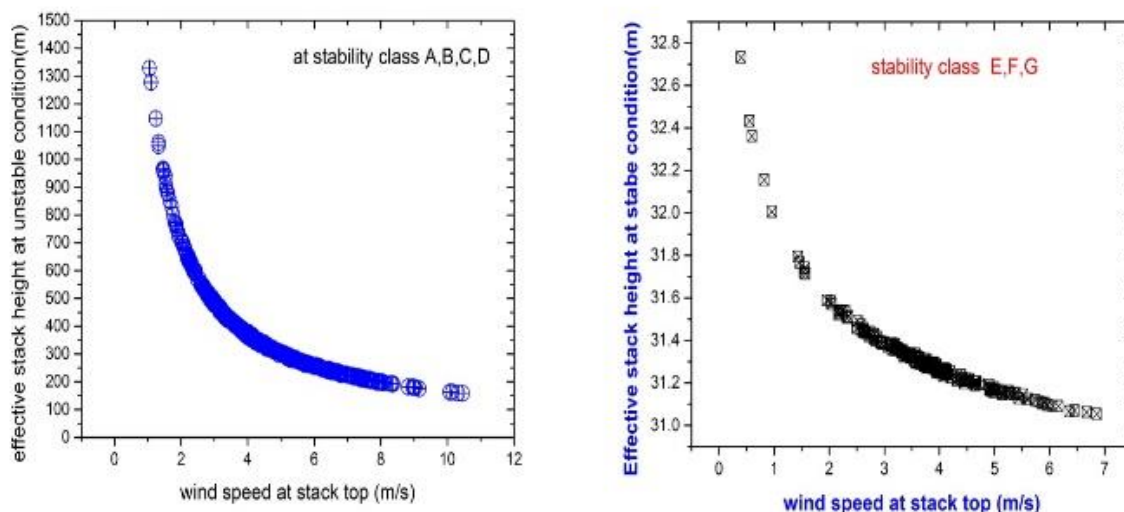


Figure 7. Effect of wind speed on effective stack height according to stability classes

Stability classes on concentration amount at different time hours, see Fig. 9. At 1000m distance around refinery point as a circle have this distance as a radius; most NO_2 concentration is very high at range about from 0-12000 $\mu\text{g}/\text{m}^3$, the large values concentrated at stability class F and G or 6 and 7 according to turner classification. In distance 5000m the concentration is in range (0-12000) $\mu\text{g}/\text{m}^3$, while at 10000m distance from the refinery concentration reduce to range (0-500) $\mu\text{g}/\text{m}^3$, see Fig. 9. Overall most concentration of NO_2 is over

national ambient air quality standard it's about 100 $\mu\text{g}/\text{m}^3$, this depend on stability class domain. The most important factor in determine level of pollutant in any area is domain wind direction at specified period. At April month wind direction different from other months it's from south to south east, see Fig. 3, this will causes increases in pollution levels in area located north to north-west of Durra refinery point, see Fig. 10.

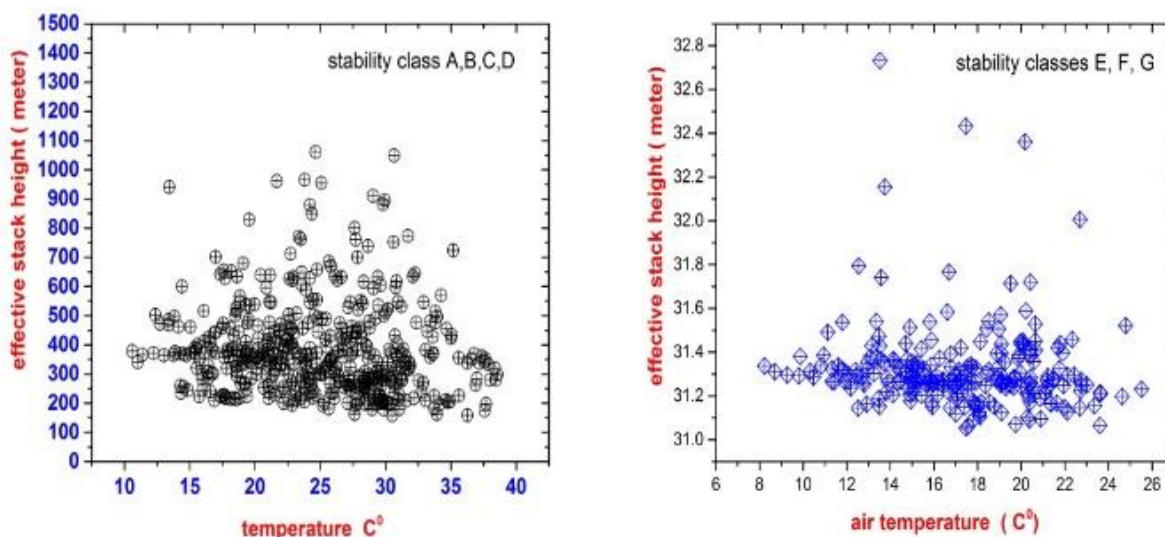


Figure 8. Effect of air temperature on effective stack height according to stability classes

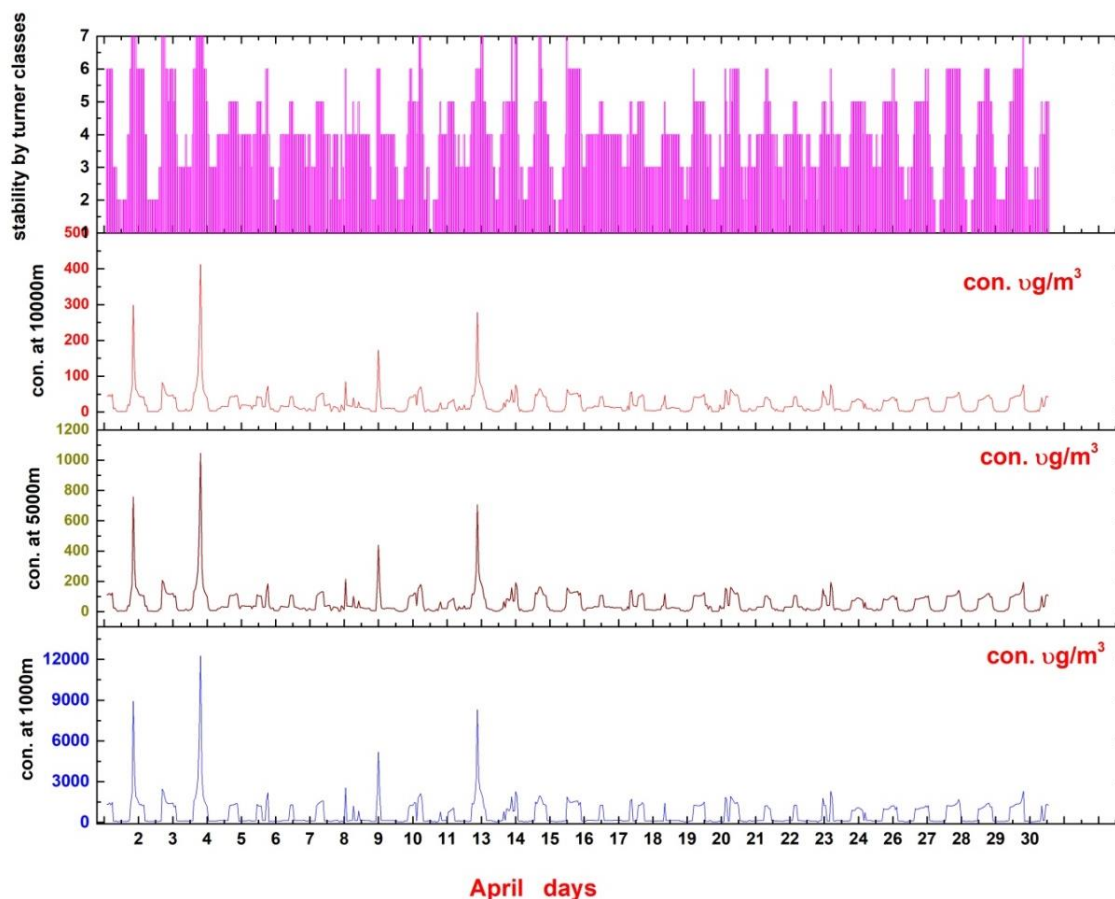


Figure 9. Change in concentration of NO₂ with distance according to stability class

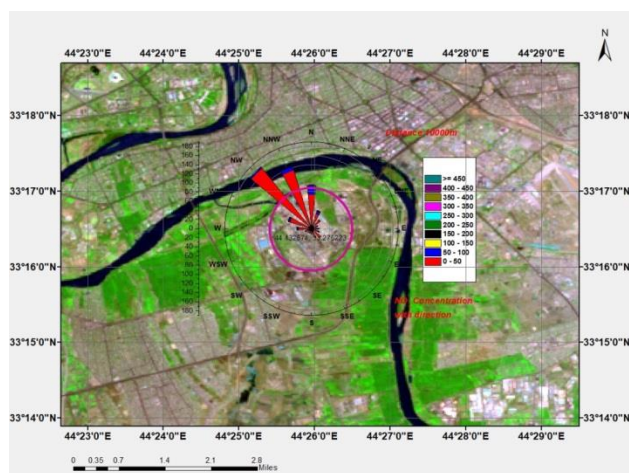


Figure 10. Effect of domain wind direction on concentration NO₂ around refinery

Conclusion:

From the analysis of meteorological data, it can be found that Hourly atmospheric parameter in April month has a large change in its values at range (0-9)m/s , (989.3-1027.1)mb, and (268.9-324.5)k for wind speed, atmospheric pressure and air temperature respectively. At hours of April month when the domain wind direction is south –east to south south-east, the pollutant plume path will be

changed to north-west area. The most frequent stability class considered from turner method is class 4 or D, about 36% from other, this represents the neutral condition. Wind speed calculated at output plume stack is different from wind speed at about 10m in range 0.3 to 2.5m/s, this is because of the difference in hourly stability classes. The highest effective plume height is concentrated at stability classes A and B, and reaches in this study to more than 500m, because of heat convection. Wind speed has a great inverse effect on the value of effective stack height, while temperature affects indirectly. On the other hand, the analysis of fuel data refers to that emission rate resulting from burned fuel oil and fuel gas which are 88.5 and 8.1 g/s respectively. There is a great concentration level of NO₂ at some hour, because of the domain stability classes E,F,G , despite the large distances from refinery point area about 10000m. This concentration level exceeds the national ambient air quality standard 100 µg/m³, this depends on stability class domain. The north-west area from refinery such as Jadriyah and Karada located 3-4 kilometer from Dura refinery are considered the most affected areas by NO₂ gas pollutants through this period because in these distances NO₂ pollutant

is out of national ambient air quality standard according to World Health Organization (WHO).

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Authors' declaration:

Conflicts of Interest: None.

- We hereby confirm that all the Figures and Tables in the manuscript are ours. Besides, the Figures and images, which are not ours, have been given the permission for re-publication attached with the manuscript.

- Ethical Clearance: The project was approved by the local ethical committee in Mustansiriyah University.

Authors' contributions statement:

Abbas M. Anad, Ahmed F. Hassoon, Monim. H. Al- Jiboori contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript

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تقييم تلوث الهواء حول مصفاة الدورة (بغداد) من انبعاثات غاز NO₂ في شهر أبريل

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الخلاصة:

غاز النتروجين هو واحد من الملوّثات الخطره الموجوده في الهواء، انه غاز سام ويسبب تاثيرات صحيه كبيره على الجهاز التنفسي، اغلب مصادر هذا الغاز تنبعث من المصادر صناعيه وبشكل خاص من مداخن محطات الطاقه ومصافي النفط. في هذه الدراسه معادله كاوس تم نمذجتها باستخدام برنامج الماتلاب لتوضيح تاثير غاز ثاني اوكسيد النتروجين NO₂ على منطقه محيطه بمصفي الدوره وايضا هذا البرنامج يقوم بتقييم بعض العناصر مثل سرعه الرياح والاستقراريه وتأثيرها على ارتفاع المدخنه. البيانات المستخدمه في هذه الدراسه هي كميه النفط الاسود ووقود الغاز المحترق في داخل المصفي خلال سنه 2017. البيانات الساعيه الشهرية اختبرت كحاله دراسيه بسبب هذا الشهر كحاله متقلبه. بعد تحديد نسبه الانبعاث للوقود وحساب سرعه الخروج من المدخنه (سنعبر كل المصفي نقطه واحده) وحساب الارتفاع الفعال الناتج. تم مقارنة بين الارتفاع الفعال والعناصر الجويه وايضا الاستقراريه حيث وجد ان هناك علاقته طرديه مباشره عند ظروف الجويه الغير مستقره. بعد تنفيذ موديل كاوس تبين ان اغلب المناطق الملوّثه بغاز ثاني اوكسيد النتروجين NO₂ هي الجادريه ومنطقه الكراراده وهي منطقه تبعد 3-4 كم من المصفي ان الرياح السائده هي الجنوب الشرقي.

الكلمات المفتاحيه: تركيز NO₂, الاستقراريه، تلوث الهواء، شهر ابريل، معدل الانبعاث