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Investigating the Environmental Impact of NO_x and CO_2 Emissions Levels from Al-Khums Electric Power Generation Plant on Surrounding Urban Areas Using Air Dispersion Model

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ABSTRACT

The polluting gas flow and emission levels from Al-Khums electric power generating plant as well as material and energy balance were estimated using the Aspen HYSYS V9.0 simulator. These model simulations were performed under the actual operating conditions of the power plant and at steady state condition for each unit in the power plant. The power plant units targeted for the simulator are: air compressor, gas compressor, pressure release valve, combustion chamber, and the gas turbine. The concentration levels of the two major pollutants under investigation, namely, carbon dioxide (CO_2) and nitrogen oxides (NO_x) were estimated and quantified using the well-known air dispersion model (Gaussian plume type model). Air dispersion model results revealed that the concentration of NO_x and CO_2 are equal to 2367.79 mg/m^3 and 28,683.18 mg/m^3, respectively. These values, when compared with the allowable international standards, were found far to exceed the limits for air pollutants emitted from power generating plants. These values are specific to the meteorological conditions of the site location under the investigation. They may change once the site conditions are changed. The air dispersion model was also used to determine the concentration and the horizontal distance a pollutant can reach from the point source. The results of this air dispersion model, which is highly dependent on the climate and meteorological conditions of the region where the power generating plant is located, revealed that high level concentrations of pollutants can reach a horizontal distance of 22 km from the point source of pollution. According to the World Health Organization (WHO) and United States Environmental Protection Agency (USEPA), these higher concentration levels and this specific horizontal distance may adversely affect the air quality of the environment and cause health hazards to inhabitants in the region.

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Introduction

The rate of demand for energy, *e.g.*, electricity, is increasing every day, not only due to the increase in the population around the world, but also due to industrial and technological development, which has led to increasing the emission sources of toxic gases [1]. Pollution by toxic gaseous emissions is one of the most serious environmental problems threatening our world today, which is affecting everyone in low-, middle-, and high-income countries. According to the WHO reports, about 4.2 million deaths worldwide per year in 2019; this resulted due to short- and long-term exposure to polluted air in cities and rural areas [2]. Statistically, the highest death rate was reached 37% due to heart disease and stroke and the rest, 18, 23 and 11%, were due to chronic lung disease, respiratory infections and cancer within the respiratory tract, respectively [3-5]. Emission of toxic exhaust gases, *e.g.*, NO_x and CO_2 produced from chemical reactions during the combustion of fossil fuels, *e.g.*, as in electrical power plants, which are one of the largest sources of air pollution, in addition to its direct impact on public health, it also contributes to smog and climate change [6,7]. NO_x released into the atmosphere reacts with volatile organic compounds under the influence of hot sunlight to form ground-level ozone, which causes severe damage [8-11], as it has led to the loss of about 4 to 15% of global wheat production [12]. Moreover, it is considered the major component of smog which led to thousands of deaths in Britain in 1950 [13]. Likewise, excess emissions of CO_2 are no less dangerous than toxic NO_x, as they are the primary cause of the rise of atmosphere temperature, which is known as the phenomenon of global warming, which causes climate change [2,14,15]. These changes have a direct impact on the agricultural sector and the distribution of wind and rainfall [16,17]. Accordingly, to reduce these risks, the world air quality guidelines (AQG) offer strict global guidelines for reducing emissions of key air pollutants [2]. Also in the same context, in 2015, the WHO approved resolution A68-8, "Health and the Environment: Addressing the Impact of Air Pollution on Health" [2]. The main objectives of this study are: Evaluate the impact of gaseous emissions emitted from the gas power plant located in the city of Al-Khums, Libya. The impact of gaseous emissions targeted in this study are NO_x and CO_2. Accurate predictions and estimates of pollutant concentrations were obtained in the surrounding area using the currently available mathematical models. Advanced mathematical models targeted for the model predictions are: The Aspen HYSYS V9.0 and the air dispersion model. There were many mathematical models used for the pollutant dispersion and emissions into air are listed in several references [18-24]. One of the widely used accurate dispersion models is the Gaussian dispersion model [25,26]. To obtain an accurate prediction, the Gaussian model will be used not only to obtain accurate results, but also to investigate the impact of several important parameters that may affect the dispersion of pollutants in the air at the site of the power generating plant. Table 1 presents the results and applications of the most common models that are widely used to study the dispersion of pollutants in the atmosphere.

CO_2

In 2022, total electricity generation in the United States by utility-scale power plants was approximately 4.23 kWh of all energy sources, resulting in emissions of approximately 1.65 billion metric tons-1.82 billion short tons of CO_2, which equates to approximately 0.86 pounds of CO_2 emissions per kWh [32]. Emission rates resulting from electric power generation plants vary depending on the energy sources, as well as the efficiency of the generation plants. The amounts of CO_2 emitted per kWh will vary during any period of time according to the sources of fuel used in the electric station. Therefore, the US energy information administration (EIA) publishes estimates of emissions of gases resulting from electricity generation, *e.g.*, CO_2, on a monthly and annual basis. In the year 2022, electrical power generation plants in the United States depended on fossil fuels to generate electricity, which constitutes approximately 60% of total annual US utility-scale electricity net generation, but they accounted for 99% of US CO_2 emissions associated with utility-scale electric power generation [32]. The other 1% of CO_2 emissions were from other fuels and gases derived from fossil fuels and some types of geothermal power plants. EIA considers electricity generation from biomass, hydro, solar, and wind to be carbon-neutral [33]. Table 2 presents data on total annual electricity net generation and CO_2 emissions at utility-scale electric power plants and a CO_2 emission factor (pounds of CO_2/kWh) for coal, natural gas, and petroleum, and the average of all energy sources. Actual CO_2 emissions per kWh from specific power plants may vary considerably from the factors in Table 2.

Table 1: Dispersion model results for specific pollutants compared with the international standard limits for several research investigations

Model type	Pollutants	Results compared with standard limits	Source	[Ref.]
Box model	CO_2, SO_2 and NO_x	Higher	Electric power plant	[27]
Gaussian models	NO_x, SO_2 and $PM_{2.5}$	Below	Electric power plant	[28]
AUSTAL 2000 model	PM_{10}, CO, SO_2 and NO_x	Below	Cement factory	[29]
CFD models	CO_2	Not found	Thermal power plant	[30,31]
	Particulate matter (PM) and SO_2	Below		

Table 2: US electricity net generation and resulting emissions of CO_2

Energy source	Elect. energy generated (M-kWh)	CO_2 emissions million metric tons	CO_2 emissions million short tons	CO_2 emissions pounds per kWh
Coal	831,512	868.0	957.0	2.30
Natural gas	1,687,067	743.0	819.0	0.97
Petroleum	22,931	25.0	27.0	2.38
Other sources	4,230,672	1650.0	1,819.0	0.86

Data source: US EIA

Libya's production of electrical energy

Libya's production of electrical energy depends on twenty generation stations with a production capacity estimated at about 8,200 MWh in 2023. The operational system of these stations depends on 91% fossil fuel (light, heavy and gaseous fuel) and 9% renewable sources [34]. The heavy reliance on fossil fuels to generate electricity has raised many concerns as a result of the recent increase in the gas emission that may cause adverse health impact to the people living in the surrounding area where the power plant is located.

Parameters and necessary data for model predictions

Investigated area location at Al-Khums city

Al-Khums City is located in northwestern Libya, in the center of Al-Murghab Governorate, on the Mediterranean coast of Libya, at latitude 32° 38' 59' north, and longitude 14° 15' 52' east. 19 meters above sea level. According to the 2018 statistics, the city’s population is estimated at approximately 390,943 people. This area contains two cement factories and two electrical power stations, all of which operate on fossil fuels, where it is considered one of the areas most exposed to environmental pollution that causes global warming and is harmful to the environment and public health. An increase in temperature compared to previous years is clearly shown in Figure 1, which may be caused as a result of NO_x, CO_2 and other emissions. The GE 9FA03 plant is located inside the city of Al-Khums on the Mediterranean coast where it is surrounded by three urban areas with a high population density; Leptis Magna, Al-Sahel, and Sog Al-Khmees. This electric power generation gas station at Al-Khums, which is entered into service in February 2017, is considered as one of the most important and largest electric power generation gas stations operating on the western part of Libya. Likewise, it is intended to contribute and effectively cover the demand of the electric energy required for the whole electric network.

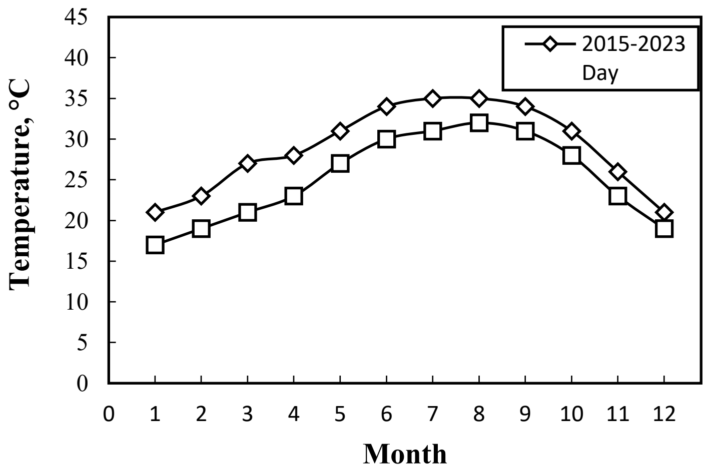

Figure 1: Monthly temperature change at Al-Khums city for the period (1916–2023)

Meteorological data for dispersion model

Dispersion of pollutants into the atmosphere is greatly influenced by various climatic and meteorological parameters such as wind speed and direction, temperature, cloud, and humidity [35]. All of these parameters were collected for the past eight years from 2015 to 2023 from the surface weather observatory station at tripoli international airport (TIA), as shown in Table 3. These parameters were found to be identical to those at the site location under this investigation and were typical of the whole examined area. The wind speed and direction at any location is highly dependent upon many factors like local topography and others, and vary more widely depending on the nature of the place. Figure 2 represents the wind rose diagram from 1985 to 2014. Also, the average temperature and velocity for each season are listed in Table 4.

GE 9FA03 plant and operating conditions

Al-Khums City's power station consists of three primary stages, where the first and second stages entered service in 1982 and 1995, respectively. The third stage (used in the present study) is GE 9FA03, which consists of two gas units with a capacity of 275 MW each. The implementing company is Turkish CALIK ENER, and the type of unit is American GE. The whole electric power generation was connected to the public electricity network in February 2017. The characterization and operating conditions are shown in Table 5 [36,37]. The specifications, composition and operating conditions of the natural gas which is used as a fuel required to operate the plant are shown in Table 6 [36].

Table 3: Climatic characteristics of the investigated area

No.	Meteorological parameters	Month	Month
1	Minimum temperature average	Jan.	13.3 °C
2	Maximum temperature average	Aug.	32.8 °C
3	Maximum percentage of the sky covered by clouds	Nov.	33%
4	Minimum percentage of the sky covered by clouds	Jul.	1%
5	Maximum number of rainy days	Dec.	5 d
6	Maximum number of rainy days	Jul.	0.1 d
7	Maximum rainfall rate	Jan.	40.6 mm
8	Minimum rainfall rate	Jul.	0
9	Maximum hours of daylight	Jun.	14.3 h
10	Minimum hours of daylight	Dec.	10.0 h
11	Maximum muggy days	Aug.	26.2 d
12	Minimum muggy days	Jan., Feb.	0.0 d
13	Maximum relative humidity	Aug, Sep, and Oct	61%
14	Minimum relative humidity	Nov.	56%
15	Maximum wind speed	Jan., Dec.	23.3 km/h
16	Minimum wind speed	Aug.	15.5 km/h
17	Wind direction (usually)	Nov., Jan., Feb., and Mar.	West
18	Atmospheric pressure from sea level	1.02-1.01 bar	

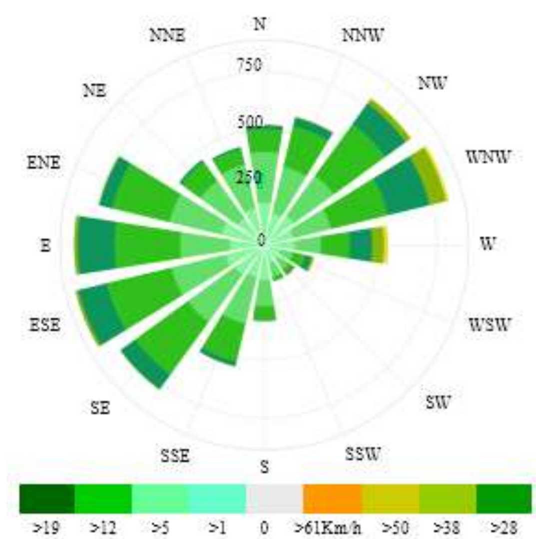

Figure 2: Wind rose of Al-Khums city (1985-2014)

Table 4: Average temperature and velocity for each season in studied area

Data type	Winter	Spring	Summer	Autumn
Air temperature (K)	296.0	303.0	307.5	301.0
Wind speed (m/sec)	4.03	3.90	3.26	3.43

Table 5: Plant characterization and operating conditions

No.	Parameter	Specifications
1	Total design capacity	550 MW
2	Operating efficiency	2× 240 MW = 480 MW
3	Voltage level	220V
4	Type of fuel	Natural gas
5	Operating temperature	1273 ℃
6	Unit thermal efficiency	35.47%
7	Actual excess air	58.84%
8	Relative humidity	32.13%

Table 6: Fuel composition supplied to the GE 9FA03 plant

Compound	***MW = 18.28; Density = 11.15*** kg/m^3 ***Total sulfur content (TS) =0.0009*** g/Nm^3		
	Formula	**Unit**	**Value**
Nitrogen	N_2	mol. %	0.593
CO_2	CO_2	mol. %	2.023
Methane	CH_4	mol. %	86.482
Ethane	C_2H_6	mol. %	10.392
Propane	C_3H_8	mol. %	0.496
Iso-butane	i-C_4H_{10}	mol. %	0.014
Total	--	--	100

Natural gas is transported to the electric power station at Al-Khums through an underground pipeline from Brega natural gas field about 670 km away.

Modeling and simulation process

Modeling and simulation of industrial processes requires a good knowledge of the natural conditions of the process as well as the optimal selection of the mathematical models and simulation programs used. As such, the simulation of the GE 9FA03 plant was carried out using Aspen HYSYS V9.0 simulator to perform mass and energy balance to determine the concentrations emitted and associated conditions during the combustion process. To control any industrial processes and their accompanying changes, it is necessary to study the state of incoming and outgoing compound flows. The main objective of modeling is to describe the behavior of a certain process in a correct and realistic way. Therefore, simulating of any industrial process involving combustion reactions depends mainly on the flow rates and composition of the fuel fed and the excess air used in combustion in order to predict the quantities and concentrations emitted and follow up on improving them. Figure 3 illustrates a simulation of the GE 9FA03 plant. In general, 2855 kg-mol/h of natural gas feed at 42.5 °C and 1600 kPa enters the combustion chamber after being compressed to 3000 kPa by NG compressor. The gas pressure was controlled by pressure valve control to reduce the pressure to 2560 kPa at 93 °C. The air feed at 29.7 °C and 1 atm was compressed to 1480 kPa by an air compressor where the temperature increases to 412 °C. Afterwards, the air feed was mixed with fuel in combustion chamber at a molar ratio of 26.51 air/fuel. After the combustion reactions take place, the exhaust gas with molar flow of 78698.33 kg mole/h at 1480 kPa and 1272.93 °C was formed and entered the turbine to convert thermal energy to electrical energy. The exhaust gas outlet from the turbine goes to the chimney at 620 °C and 122 kPa. The electrical energy product from the turbine is 240 MW [36,37]. Detailed calculations have been conducted on each piece of equipment according to the process flow diagram shown in Figure 3 and compared with those present and installed at Al-Khums gas electric power generation plant.

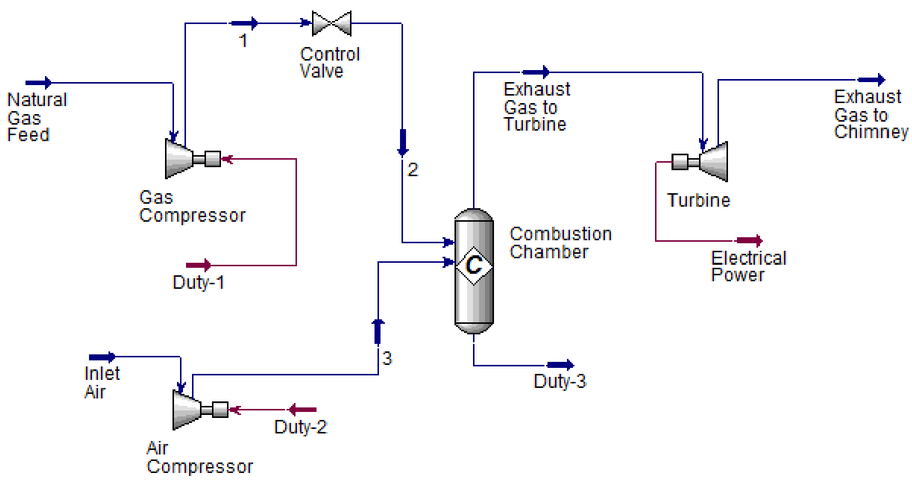

Figure 3: Schematic simulation diagram of GE 9FA03 plant

Combustion reactions at the combustion chamber and pollutants formation

Exhaust gases are formed and emitted in all common types of combustion as a result of the combustion of fuel with oxygen in the air at high combustion temperatures. NO_x and CO_2 generation are due to high temperature reaction between fuel gas, presented in Table 7, and oxygen. A series of theses complete reactions are [38];

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (1)$$

$$C_2H_6 + 3.5O_2 \rightarrow 2CO_2 + 3H_2O \quad (2)$$

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \quad (3)$$

$$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O \quad (4)$$

Where, only 0.15% of the nitrogen present in the inlet air into combustion chamber has been converted to NO according to the following reaction [39];

$$N_2 + O_2 \rightarrow 2NO \quad (5)$$

Likewise, most of the NO resulting from Equation 5 gradually turns into NO_2 as it exits the chimney as a result of interaction with oxygen in the atmospheric air [3].

Air pollutants dispersion modeling

Descriptions of most scientific problems involve equations that relate the changes in some key variables to each other. Air dispersion models are used to estimate how much reduction has occurred through dispersal of chemical releases from point source such as industrial plants to ground level [28,40]. The models commonly require two types of data about the emission source and the ambient meteorological data surrounding the source. The most used of a wide variety of air dispersion models is the Gaussian dispersion model and the computational basis model distributed by USEPA due to extremely fast response time, whereas it solves a single formula [41]. The disadvantage is that their accuracy tends to decrease quickly after long distances (10-20 km). Figure 4 illustrates the Gaussian plume dispersion model. Mathematically [35]:

$$C = \frac{Q}{2\pi u \sigma_y \sigma_z} exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \tag{6}$$

Where, C is the concentration of dispersing pollutant at a certain point ($\mu g/m^3$), Q is the contaminant emission rate from the point source (g/s). u is mean wind speed (m/s), y is crosswind distance (m), z is vertical distance (m), H is effective stack height (m), and σ_y and σ_z are standard deviation of plume concentration distribution in horizontal and vertical direction (m), respectively.

Assuming z = 0 in Equation 6, the concentrations at ground-level are:

$$C = \frac{Q}{2\pi u \sigma_y \sigma_z} exp\left(-\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2}\right) \tag{7}$$

Also, the centerline concentrations are found by setting y = z = 0.

$$C = \frac{Q}{2\pi u \sigma_y \sigma_z} exp\left(-\frac{H^2}{2\sigma_z^2}\right) \tag{8}$$

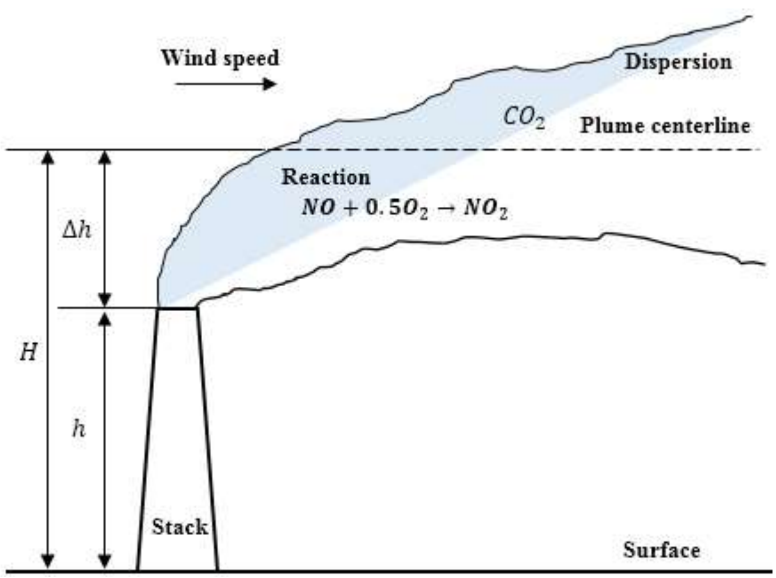

Figure 4: Gaussian plume dispersion illustration

The equations for calculating σ_y and σ_z are presented in Table 8. The values of the dispersion coefficients are strongly dependent on the atmospheric stability classes which classified by Pasquil and Gifford [35]. The six classes of atmospheric stability which characterize the turbulent status of the atmosphere are shown in Table 9. Where, A is the most unstable or turbulent class, D is a neutral atmosphere, and F the stable or least turbulent class.

Air dispersion model simulation results

As a result of simulating the GE 9FA03 plant, the concentrations of NO_x and CO_2 with associated conditions, *e.g.*, temperature at the exit chimney were obtained based on the data presented previously. The dimensions of the chimney and simulating results are listed in Table 10. These concentrations per megawatt-hour (MWh) of electricity generated compared to the international standard limits of emission levels according to [2,38,42], as shown in Table 10, were found to be very high, exceeding permissible levels.

Results and Discussion

Table 7: Equations for dispersion parameters in urban areas*

Stability class	σ_y (m)	σ_z (m)
A-B	$0.32x(1+0.0004\,x)^{-0.5}$	$0.24x(1+0.0001x)^{-0.5}$
C	$0.22x(1+0.0004\,x)^{-0.5}$	$0.2x$
D	$0.16x(1+0.0004\,x)^{-0.5}$	$0.14x(1+0.0003x)^{-0.5}$
E-F	$0.11x(1+0.0004\,x)^{-0.5}$	$0.08x(1+0.0015x)^{-0.5}$

x is the distance to the source in meters.

Table 8: Atmospheric stability classes and categories

Wind speed (m/s)	Day-time insolation			Night-time cloud cover	
	Strong	Moderate	Slight	$\geq 4/8$	$\leq 3/8$
< 2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Table 9: Stack dimensions and emission rates

Emission source	Exit temperature (°C)	Chimney dimensions		*Emissions (mg/m^3)	
		Stack height (m)	Stack diameter (m)	NO_x	CO_2
GE 9FA03 plant	620.0	30.0	6.0	2367.79	28,683.18

**Emission (mg/m^3) = Emission (ug/L)*

Dispersion of NO_x and CO_2

Dispersion of released gases from the GE 9FA03 plant into the environment has been studied very well using Gaussian models based on the surrounding conditions, as summarized in Table 3. As the pollutants transport through the plume in the downwind direction along a distance x, the plume expands to some size in the z- and y-direction. This expansion along a distance x is determined by the dispersion coefficients σ_y and σ_z. Where, σ_y and σ_z are function of the atmospheric stability, and the downwind distance, x, from the source of the pollution. Figure 5 explains the relationship between dispersion coefficients with distance. As the distance increases, the dispersion coefficient increases.

Table 10: Comparison of estimated NO_x & CO_2 emissions from GE 9FA03 plant vs. international standard limits

Pollutant	Unit	Estimated	*USEPA
NO_x	Ib/MWh	98.46	1.3
CO_2	Ib/MWh	2,556.62	1,100

*USEP

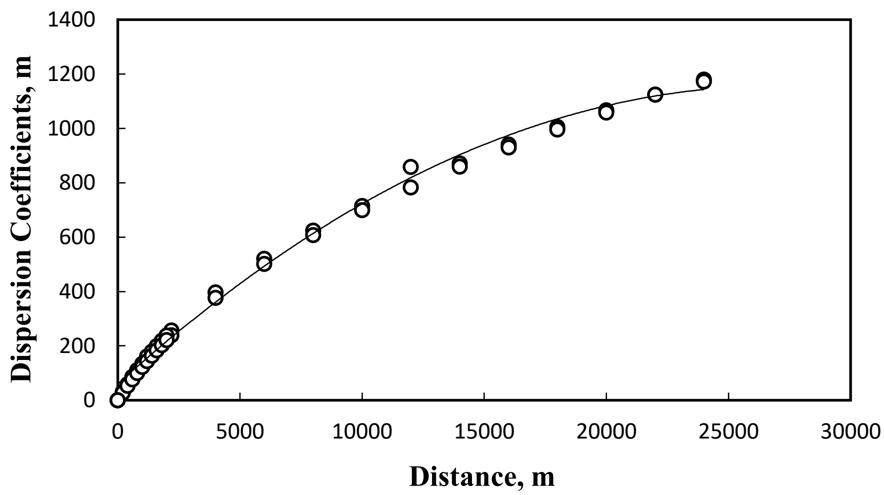

Figure 5: Relation between dispersion coefficients vs. distance from point source

The plume dispersion is due to the turbulent diffusion of the constituent pollutants, where the concentration of the dispersed pollutants has a normal (Gaussian) shape in both the horizontal and vertical aspects, as determined through experimental measurements of the plume dispersion. This behavior can be clearly observed in Figures 6 and 7, respectively.

In general, Figures 6 and 7 show the relationship between changes of emissions concentration with change of distance from the point source in hourly during the seasons of year. The maximum concentrations of NO_x and CO_2 were recorded in summer, autumn, spring, and winter, respectively, in coastal areas near the sea and about 2 km from the source of the point. According to the seasonal variation in meteorological data in Figure 2 and Table 3, these concentrations in some seasons may reach a very long range, especially in areas located between east-northeast (ENE) to southeast (SE) and west-northwest (WNW) to northwest (NW), respectively. In the summer, the highest value of NO_x concentration reaches 5472.69 μg/m^3, which continues to decrease in direction of wind flowing as we move away from the source approximately 210.65 μg/m^3 after 24 kilometers. In this season, it is flows from the north, reaching a peak of approximately 47% in July, and from the eastern side at a rate of approximately 1.9 months from May to June. In autumn, the climatic conditions do not differ much compared to summer, as the winds flow mostly from the north in September and at a rate of 3 weeks from October to November, as the concentration gradually decreases from the highest value of 4768.72 μg/m³ to 200.41 μg/m³ in this direction after 24 kilometers away. In the spring, the winds often blow from the north at a rate of 2.2 months and from the east, where they reach their peak at 40%, which reduces the emission rate in this direction from 4191.73μg/m³ to 194.06μg/m³ after 22 kilometers away. In general, the most affected areas in these seasons are Leptis Magna, Al-Sahel, Sog Al-Khmees, Celine and Al-Amamraa regions to the south. As for the winter, the highest degree of concentration was observed in this season, 4054.66 μg/m³, which continued to decrease to 186.98 μg/m³ after 20 km from the station. The winds often blow from the west.

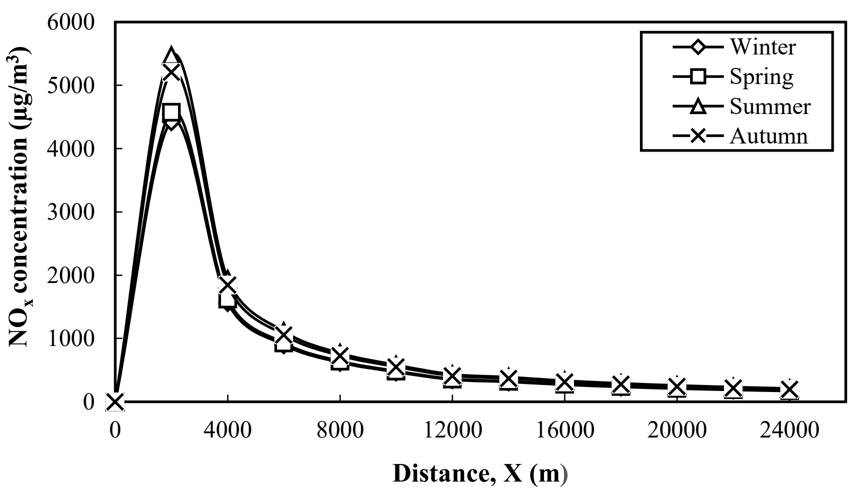

Figure 6: Change of NO_x concentration during the four seasons of the year vs. distance from point source

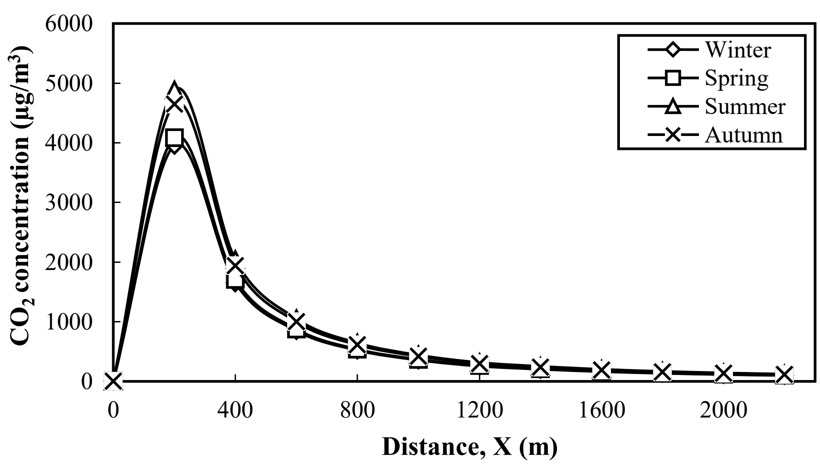

Figure 7: Change of CO_2 concentration during the four seasons of the year vs. distance from point source

Therefore, the eastern regions *e.g.,* Sog Al-Khmees, Al-Sahel, and Kaam are the most affected regions in this season. Furthermore, the high emission rate of CO_2 emitted from the GE 9FA03 plant and others *e.g.*, steam plant, and two cement factories in this city has caused some climate changes, *e.g.,* increasing temperatures, as shown in Figure 1.

The main reason for high emission rates of NO_x and CO_2 may be referred to excess air used in combustion of fuel because the relative humidity of the air used in a combustion process is relatively high, about 32.1%. This may not lead to reaching the required heating value, temperature and pressure for operating the turbine to convert the generated thermal energy into electricity. In addition, the high percentage of humidity in the air may contribute to erosion of some internal parts of the turbine. Therefore, operators at this station work to increase the excess percentage of inlet air to approximately 58.84%, to avoid such operational problems. However, the authors recommend removing moisture from the air entering the combustion chamber, which contributes to reducing the amount of air used in the combustion process, and this would reduce the level of high emissions of resulting oxides. In addition, it is recommended to install an effective removal system that works to remove toxic oxides from the exhaust gases in order to reduce the high emissions and protect the environment.

Impact of parameters on NO_x and CO_2 emissions at Al-Khums power plant

The rate of pollutant emissions was found to be directly related to the amount of excess air and the amount of fuel (natural gas) entering the combustion chamber. The following is a detailed discussion of the impact of some important parameters on the NO_x and CO_2 emissions:

Impact of the inlet fuel to the power plant

Increasing the amount of fuel (natural gas) will increase the amount of electric energy generated, but at the same time, the pollutant emission rate and concentration of both NO_x and CO_2 will increase. Therefore, it is essential to operate the Al-Khums power plant in such a way that there will be a minimum pollutant emission with higher electrical energy generated. It is believed that the inconsistent flow of fuel (natural gas) from the source is the principal cause of the pollutant emissions and inconsistent electric energy production rate. It is also believed that sometimes the national network in deep shortage of electrical energy, the power plant at Al-Khums is operated in such a way to fulfill the requirement of the national network of electrical energy. In these situations, it is expected the rate of pollutant emission will increase drastically. Figure 8 illustrates the impact of amount of fuel entering the combustion chamber on the amount of electrical energy generated.

Impact of the excess air entering the combustion chamber on pollutant emission

Excess air in combustion chambers plays many roles. It provides adequate oxygen to prevent the formation of carbon mono-oxide, and it can also reduce the formation of NO_x. Excess air can also increase the mass flow in convective furnaces which will improve the temperature uniformity.

Impact of other critical parameters on pollutant emission during fuel combustion

Four other critical parameters are known to affect the release of pollutants to the air. These critical parameters may include the average flame temperature, mean combustion residence time, percent of O_2 entering, and the combustion of air velocity at the entrance. The impact of these critical parameters on the pollutant emissions are not investigated in this study but it is worth to emphasize for future investigations. Hangebrauck and Schwartz in 2012 investigated the impact of these critical parameters on pollutant emissions. Figure 9 demonstrates the impact of these critical parameters on the stoichiometric ratio of the fuel [43].

Impact of moisture content in the region where the power plant is located

The moisture content of air to be compressed and fed to the combustion chamber is believed to change sometimes on daily basis due to the location of the plant near the coastal area. Higher or lower levels of air moisture content of the air will impact the amount of compressed air to be fed to the combustion chamber. Consequently, the air to fuel ratio and the percent excess oxygen will vary accordingly; as a result, the NO_x and CO_2 emission concentration are changing.

Impact of physical and chemical properties of the natural gas during transportation to the power plant

Natural gas used as a fuel to the power plant need to be closely monitored through the pipe line for temperature and pressure especially during summer, the temperature might have an effect on density and amount of feed to the combustion chamber and consequently the rate and concentration of pollutants from the power plant.

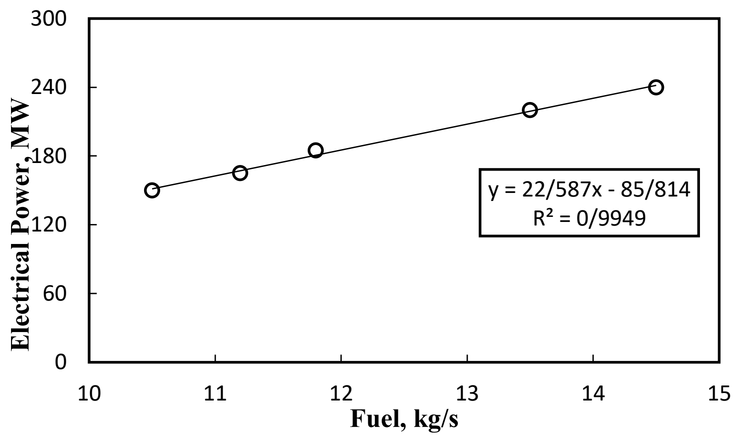

Figure 8: Impact of fuel consumption rate on the generated electrical power.

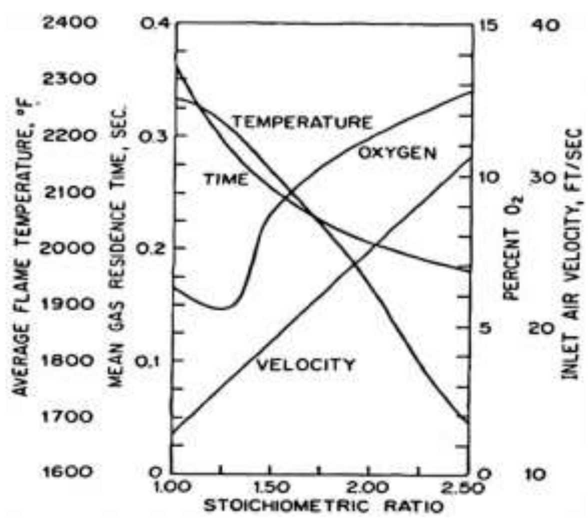

Figure 9: Critical parameters affecting the pollutant emission formation

Conclusion

Model simulation results showed the higher levels of NO_x and CO_2 emissions were released by the gas power generating plant at Al-Khums. These higher levels were attributed to the burning of the compressed natural gas with air and the formation of exhaust gases with high heat energy. These exhaust gases with high energy content flow to the gas turbine to produce electric power and release to the atmosphere. The higher concentration levels of nitrogen oxide emissions is attributed to the reaction of nitrogen with 58.84% excess oxygen during combustion at higher temperature. The maximum concentration of NO_x emissions released to the atmosphere, was found to be approximately 5472.7 μg/m^3 in summer days from 2017 to 2023 at a reach horizontal distance of about 2 km from the power plant chimney. To ensure a complete combustion reaction and to avoid the formation of carbon monoxide, the more toxic and dangerous gas to human health, the optimum molar ratio of air to the gas entering the combustion chamber was estimated to be 26.5. At this optimum ratio, it is expected a complete combustion reaction will take place without any carbon oxide formation. The application of air dispersion model and the Aspen HYSYS V9.0 simulator are proven to be excellent tools for quick estimates and design calculations of the various units of the power plant as well as determine the extent of the environmental emissions from the electric power plant.

Recommendations for further research

It is strongly recommended that a complete, detailed investigation specifically is performed on the combustion chamber, considered the most important unit in the power generating plant. Such investigation must include the impact of the most important and critical parameters on the emission rate and concentration levels of pollutants. Air quality monitoring must be conducted so often especially near the vicinity of the power generating plant to protect the environment and natural habitat. Likewise, for the new power generating plants, it essential to use a low emission fuels and non-combustible renewable energy sources such as solar, wind or hydropower to reduce the air pollution emissions. New development of design mechanisms is needed especially the mixing nozzles of fuel with air and burners may lead to a decrease in concentrations of NO_x in the exhaust gases. Whenever there is a change in the operating conditions of the power plant, more model simulations using the air dispersion model are needed in order to obtain the optimum horizontal reach distance of a particular pollutant.

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