AN INVESTIGATION OF NOx DISPERSION FROM LIBYAN POWER PLANTS

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ABSTRACT
Theoretical investigations were conducted of NOx dispersion from stacks of arbitrary seven power plants in Libya, e.g., West Tripoli, Derna, Tobruk, North Benghazi, Khoms (steam and gas), South Tripoli and Zweitina. The first five stations are steam power plants, while the rest are gas plants. Gaussian plume model has been used to identify ground-level NOx concentrations profile downwind of the chimneys through urban regions and also the location of maximum pollutant concentrations. The study based on the worst-case emission conditions of Pasquill stability categories (class D). Results indicate that maximum ground-level NOx impacts for all plants locate at a distance of approximately 1 – 1.5 km from stacks. The sites most critical to ambient air NOx impact are Zweitina and West Tripoli, where the plant sites are in direct vicinity to residential areas. Khoms electric station exhibits the maximum emitted NOx intensity, $162.8\ \mu g/m^3$ which is lower than allowable concentration recommended by WHO.

1.INTRODUCTION
Libyan electrical generations are based on 17 steams and gas power plant stations, which are sited in the coast at Mediterranean Sea. The total energy produced at the end of 2002 is 4608 MW with the contribution of the steam stations of 42% while, 58% for gas plants [1]. Fig.1 shows the increase of electric power production rate through 32 years. It is due to progressively increase in the demand of electricity, which is subsequently due to exponential growth of population and industries expansions. The energy produced from Libyan stations comes from

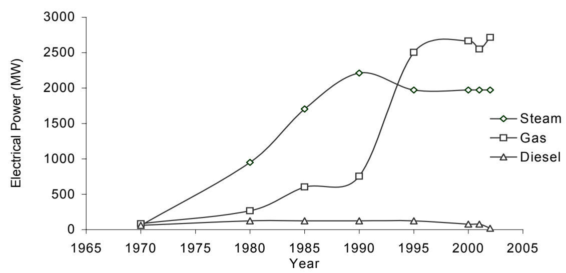

Fig.1. The growth of electric power generations in Libya [1]

combustion of heavy oil, light oil and natural gas. The combustion process of fuel is accompanied by emission to the atmosphere of huge amount of exhaust gases as pollutants, such as, NOx, SO2, CO, dust and CO2 with increasing rate annually corresponding to that of conventional electric energy produced.

Among of these gases is nitrogen oxides which belong to harmful impurities. They are toxic and produce a sharp irritating effect, especially on the mucous membrane of the eye. NOx compounds are poorly soluble in liquids and for that reason can penetrate deeply into lungs and cause injury to the alveolar epithelium and bronchi. People living in NO_2 contaminated area have a higher incidence of respiratory diseases and exhibit certain changes in the peripheric blood.

Nitrogen dioxide in concentrations of 4-6 mg/m^3 can cause heavy injuries to plants [2]. A long exposure of vegetables to NOx at concentrations below 2 mg/m^3 can produce chlorosis.

The aim of this work is to perform a mathematical model, named Gaussian plume model, describing ground-level NOx dispersions through area surrounding 7 electrical thermal power stations in Libya. Besides identifying the locations of maximum ground level concentrations in urban sites.

2. THEORETICAL APPROACH
2.1 Gaussian Plume Model
A control volume is defined in the plume. Bulk motion and diffusion (or dispersion) transport pollutants into the upwind side of the volume and outwind side as shown in Fig.2 with the assumptions as followed:

- Steady state conditions.
- Transport by bulk motion in the x-direction exceeds effective diffusion in the same direction.
- Wind speed in the x-direction does not vary with x. The plume species do not react.
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A mass balance for the elementary volume yields

$$U\frac{\partial c}{\partial x} = D_y \frac{\partial^2 c}{\partial y^2} + D_z \frac{\partial^2 c}{\partial z^2} \qquad (1)$$

The above is solved subject to the following boundary conditions:

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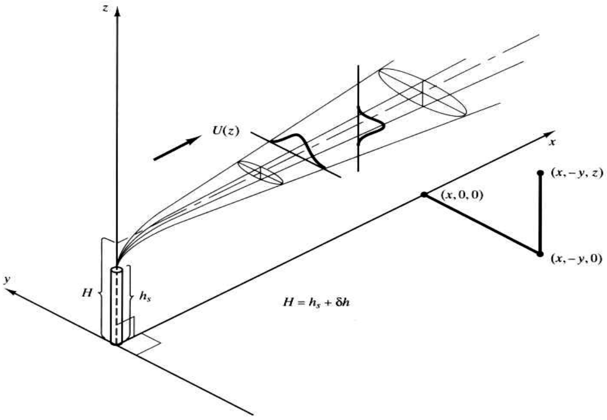

Fig.2. Pollutant dispersion from a stack

- $c \to \infty$ as $x \to 0$
- $c \to 0$ as $x, y, z \to \infty$
- $D_z \, \partial c / \partial z \to 0$ as $z \to 0$
- $\int_0^{\infty} \int_{-\infty}^{\infty} U c(c, y, z)\, dy\, dz = \dot{m}_{i,s} \quad at \quad x \geq 0$

Equation 1 is called Gauss's equation. It is used to describe the behavior of plumes, the resulting analytical description is called Gaussian plume model [3]. The solution to equation 1 is:

$$C_i(x,y,z) = \left(\frac{\dot{m}_{i,s}}{2\pi x (D_y D_z)^{1/2}} \right) \exp\left(-\frac{U}{4x} \right) \left(\frac{y^2}{D_y} + \frac{z^2}{D_z} \right) \qquad (2)$$

it is convenient to rearrange as below

$$C_i(x,y,z) = \frac{\dot{m}_{i,s}}{\pi U \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y} \right)^2 - \frac{1}{2}\left(\frac{z}{\sigma_z} \right)^2 \right] \qquad (3)$$

Where,

$$\sigma_y^2 = \frac{2 x D_y}{U}, \; \sigma^2{}_z = \frac{2 x D_z}{U} \qquad (4)$$

2.2 Dispersion Coefficients

Briggs presented a series of dispersion coefficients equations for the urban region depending on atmospheric stability class with the averaging time of 1 h [4]. The U.S. EPA adopted these equations. For D stability in urban region,

$$\sigma_y = 0.16 x (1 + 0.0004 x)^{-1/2} \qquad (5)$$

$$\sigma_z = 0.14 x (1 + 0.0003 x)^{-1/2} \qquad (6)$$

2.3. NOx Ground - Level Concentrations

NOx pollutant has poor solubility in soil, water, vegetation, and so on. Hence, it is assumed to be accumulated along the ground. A mathematical model accounting for the accumulation is performed, which depends on the superposition of the plume and its mirror image located a distance $(z = -H)$ below the ground. The model is [5]

$$C_i(x,y,z) = \frac{\dot{m}_{i,s}}{2\pi U \sigma_y \sigma_z} \left\{ \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y} \right)^2 \right] \right\} \left\{ \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z} \right)^2 \right] \right\} + \left\{ \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z} \right)^2 \right] \right\} \qquad (7)$$

At any downwind distance x, the largest ground-level NOx concentration is shown in fig.3 and expressed as followed

$$C_{i,GL}(x,0,0) = \frac{\dot{m}_{i,s}}{\pi U \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z} \right)^2 \right] \qquad (8)$$

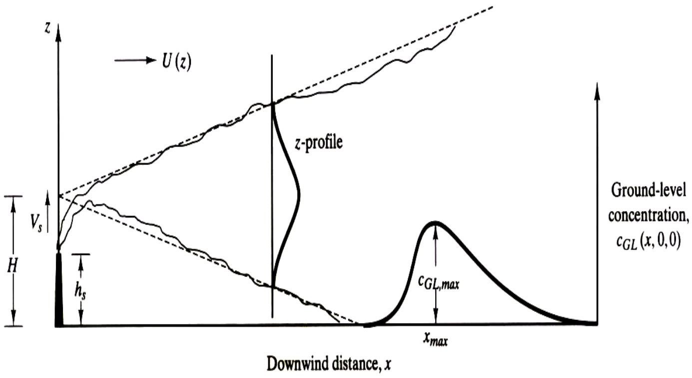

Fig.3. The ground-level pollutant concentration profile

2.4. Modified Briggs Plume Rise Formula

The plume rise is the maximum height achieved by the plume after leaving the stack. The height to which the plume rises must be estimated to calculate the effective stack height. Hence:

$$H = h_s + \Delta h \qquad (9)$$

For buoyancy-dominated plumes, unstable or neutral conditions, A, B, C, and D, the plume rise is calculated as followed [6],

$$\Delta h = \frac{1.6F_b^{1/3}(3.5x^*)^{2/3}}{U} \quad (10)$$

$$x^* = 34F_b^{2/5} \qquad F_b \geq 55 \quad (11)$$

$$x^* = 14F_b^{5/8} \qquad F_b < 55 \quad (12)$$

where,

$$F_b = gV_s \frac{d_s^{\,2}}{4}(1 - \frac{T_a}{T_s}) \quad (13)$$

2.5. Wind Speed

The wind speed at stack exit is required in the analysis. The expression used is [7]:

$$U(z) = U_{10}\left(\frac{z}{10}\right)^P \qquad \text{for} \qquad z < 200\,m \quad (14)$$

The value of P is 0.25 for D stability in urban areas.

3. DISCCUSSION OF RESULTS

The results are based on the actual characteristics of seven thermal power stations in Libya (e.g., West Tripoli, Derna, Tobruk, North Benghazi, Khoms, South Tripoli and Zweitina). These characteristics are station type (e.g., steam or gas), kind of fuel used (e.g., heavy oil, light oil, or natural gas), fuel consumption rate, NOx emission rate, exit gas velocity and temperature, stacks height and diameter, and the atmosphere temperature. The following hints are considered through the analysis:

- Power plants works at 100% load.
- Receptor height (z) is taken to be 1.5 m. Its position is fixed at the centerline of the mid- stack for some stations and at the centerline of stack of high emission for others.
- Super position criteria are used to analyze total emission from multiple stacks
- Downwind and crosswind dispersions of pollutant are considered.
- The Khoms gas and steam plants are considered as one station, since the stacks of both plants are close to each other.
- Predominant wind direction at plants sites is concerned in the analysis.
- For plants using two types of fuel, one that gives rise more amount of pollutant is used.
- Surrounded plants area is proposed to be simple terrain.
- Background of No_x and SO_2 concentrations are zero.
- Number of stacks for the station is of the range, 3-10.
- No stacks and buildings downwash conditions. The significant adverse aerodynamic effects are avoided as well.
- Chemical reactions are not taken into account during dispersion of the pollutants.

Fig.4 relates NOx ground level concentrations in μg/m^3 emitted from Libyan power stations with downwind distance. Pollutant emission concentrations increase exponentially downstream of the stacks to a certain location where maximum ground-level value is reached, after that the gas intensity at the ground reduces. The location of the peak ground level concentration is pointed out of the range 1 – 1.5 km. Fig.5 shows the maximum ground-level NOx concentration downwind of the chimneys corresponding to each plant site. Khoms power station points out the maximum value, which is $162.8\ \mu g/m^3$. This is due to the large electric generation, that means of much fuel consumption rate. The sites most critical to ambient air NOx impact are Zweitina and West Tripoli, where the plant sites are close to residential areas.

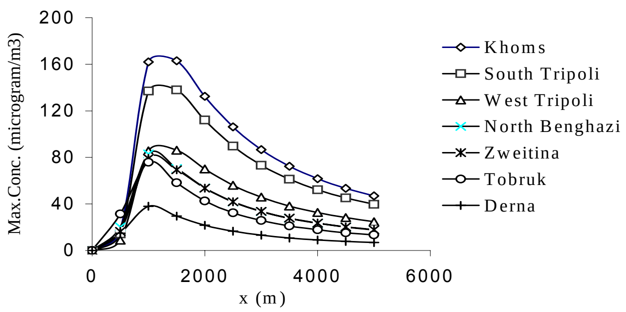

Fig.4. Ground-level NOx concentrations downwind of plants stacks

However, Maximum ground level NO_X concentrations from studied power stations are in compliance with air pollution regulations recommended by WHO. The recommended Concentration is 400 μg/m^3.

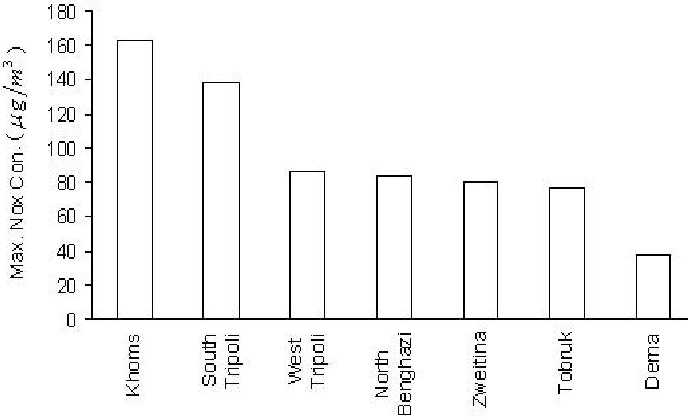

Fig.5. Maximum ground-level NOx concentration vs plant site.

4.CONCLUSIONS

Analytical method based on Gaussian plume model is performed to predict NOx concentration at ground - level and the location of maximum values for Libyan electric power plants. The location of maximum NOx concentration is found to be 1 – 1.5 km. Zweitina and West Tripoli plants are located in approximately to populated areas. Thus, these sites are expected to be most critical to ambient NOx impact. Khoms electric station exhibits the peak intensity of NOx pollutant of value $162.8\ \mu g/m^3$. Nox emitted from Libyan power plants are found to be in compliance with air pollution regulations recommended by WHO. The recommended max. Concentration is 400 μg/m3.

The representative practical monitoring, of pollutants hourly, daily or annually is essential at different locations surrounding power plants. Moreover, it is worthwhile to measure pollutant intensity continuously to insure that populated areas are safe.

Nomenclature

C	Species concentration, $\mu g/m^3$
D_s	Stack diameter, m
D	Diffusivity, m/s
F_b	Buoyancy flux parameter, (m^4/sec^3)
h_s	Stack height, m
H	Effective stack height, m
δh	Plume rise, m
$\dot{m}_{i,s}$	Pollutant emission rate from stack, $\mu g/s$
P	Power in equation (14)
T	Temperature, K
U	Wind speed, m/s
V_s	Exit gas velocity, m/s
x	Downwind direction, m
x^*	Distance to final plume rise (m)
y	Crosswind direction, m
z	Vertical direction, m

Subscript

a	Atmosphere
i	Species
GL	Ground level
s	Stack
x	x-direction
y	y-direction

Greec Letters

Δ	difference coefficient
θ	temperature, K

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