ESTIMATION OF EMITTED SO_2 CONCENTRATIONS DOWNWIND OF POWER STATIONS IN LIBYA

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ABSTRACT

Theoretical study is conducted of SO_2 dispersion from stacks of arbitrary seven power plants in Libya, e.g., West Tripoli, Derna, Tobruk, North Benghazi, Khoms (steam), Khoms (gas), South Tripoli and Zweitina. The first five stations are steam power plants, while the rest are gas. Gaussian plume model has been used to identify ground-level SO_2 concentrations profile downwind and crosswind 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 SO_2 impacts for all plants locate at a distance of approximately 0.5 – 3 km from stacks. The site most critical to ambient air SO_2 impact is Zweitina, where the plant site is in direct vicinity to residential areas. Tobruk electric station exhibits the maximum emitted SO_2 intensity, about 246 $\mu g/m^3$, that is lower than allowable concentrations recommended by WHO, 350 $\mu g/m^3$.

Nomenclature

C	Species concentration, $\mu g/m^3$
D_s	Stack diameter, m
D	Diffusivity, m^2/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
v_t	Particle settling velocity, m/s
x	Downwind direction, m
x^*	Distance to final plume rise (m)
y	Crosswind direction, m
z	Vertical direction, m

Subscript	Atmosphere
a	Species
i	Stack
s	x-direction
x	y-direction
y	

Latten symbols	
Δ	Difference
σ	Dispersion coefficient, *m*

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 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, NO_x, SO_2, CO, dust and CO2 with increasing rate annually corresponding to that of conventional electric energy produced.

The toxic substances presented in flue gas, such as SO_2, NO_x, Particulate, and CO may have harmful effects on people, animals, and vegetation. SO_2 reacts in the atmosphere with water, oxygen and other elements to form acidic compounds. Health effect is that breathing of SO_2 may cause permanent damage of the lung. [2].

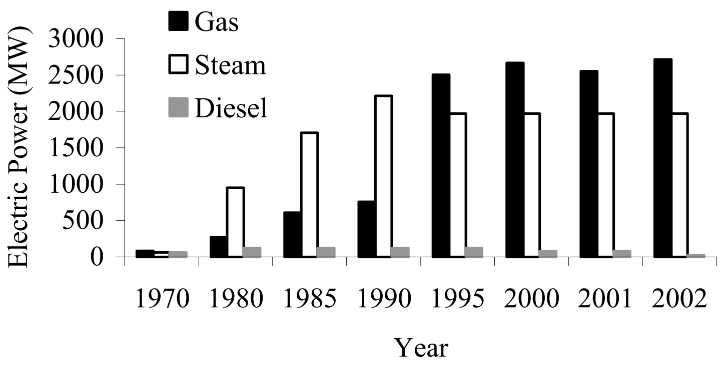

Fig.1. The growth of electric power generations in Libya [1]

The aim of this work is to perform a mathematical model, named Gaussian plume model, describing ground-level SO_2 dispersions through area surrounding 8 electrical thermal power stations in Libya. Besides identifying the locations of maximum ground level concentrations in urban sites.

THEORETICAL APPROACH

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

A mass balance for the elementary volume yields

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

The above is solved subject to the following boundary conditions:

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

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:

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

it is convenient to rearrange as below,

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

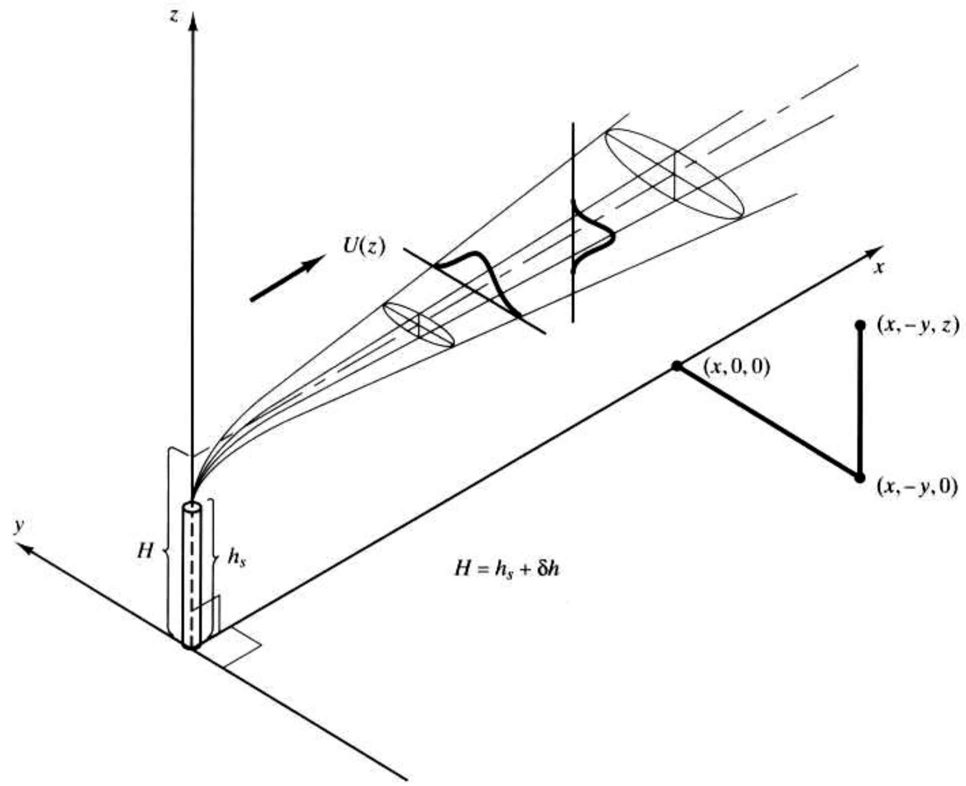

Fig.2. Pollutant dispersion from a stack

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,

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

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

SO_2 emission Concentrations

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]

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

At any downwind distance x, environmental pollution effect people, animals and plants are concentrated at a height 8m above the ground [3]. Equation (7) becomes,

$$C(x,y,8)=\frac{\dot{m}_{i,s}}{2\pi U\sigma_y\sigma_z}\exp[-\frac{1}{2}(\frac{y}{\sigma_y})^2]\{\exp[-\frac{1}{2}(\frac{8-H}{\sigma_z})^2]+\exp[-\frac{1}{2}(\frac{8+H}{\sigma_z})^2]\} \quad (8)$$

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:

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

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,

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

2.6. Wind Speed

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

$$U(z)=U_{10}\left(\frac{z}{10}\right)^P \qquad \text{for} \qquad z<200\,m \quad (16)$$

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

DISCCUSSION OF RESULTS

The results are based on the actual characteristics of eight thermal power stations in Libya (e.g., West Tripoli, Derna, Tobruk, North Benghazi, Khoms (steam), Khoms (gas), 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, Pollutant emission rate, exit gas velocity and temperature, stacks height and diameter, and metrological data. The following hints are considered through the analysis:

- Power plants works at 100% load.

- Receptor 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, that is $V_s > 1.5\ U$. The significant adverse aerodynamic effects are avoided as well.
- Chemical reactions are not taken into account during dispersion of the pollutants.

Figures 4 relates SO_2 concentrations in μg/m^3 emitted from Libyan power stations with downwind distance at receptor height 8 m. Pollutant emission concentrations increase exponentially downstream of the stacks to a certain location where maximum value is reached, after that the gas intensity reduces. The location of the peak concentration is pointed out of the range 0.5 – 3 km. Tobruk power station indicates maximum SO_2 intensity, about 246 $\mu g/m^3$. This is due to the large electric generation, that means of much fuel consumption rate. The stacks height of Tobruk plant are seen to be lower than other locations which in turn causes the pollutant to accumulate on ground rapidly. The site most critical to ambient air SO_2 impact is Zweitina, where the plant site is close to residential areas. Maximum sulfur dioxide gas concentration for studied plants site are shown in figure (5). The steam power stations exhibit more emission intensity of pollutant than gas.

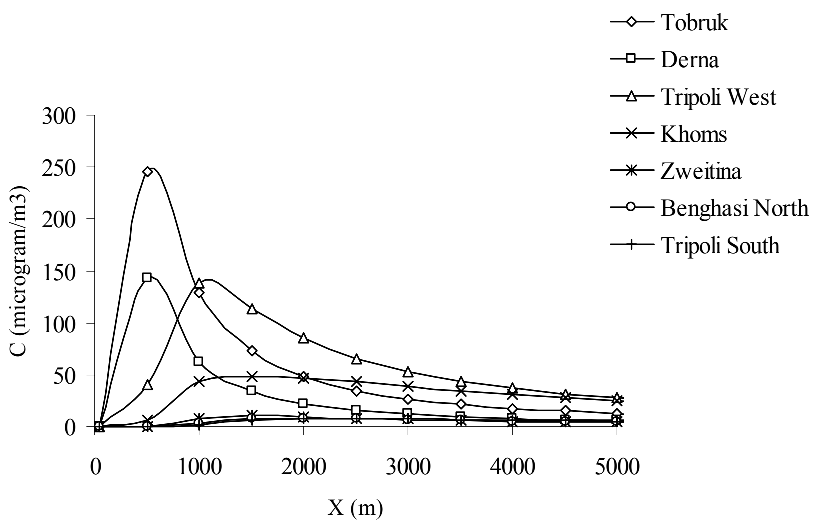

Fig.4. SO_2 concentration downwind of Libyan power plants.

However, Maximum ground level Pollutants concentration from studied power stations are in compliance with air pollution regulations recommended by WHO. The recommended Concentration is 350 $\mu g/m3$ for SO_2 .

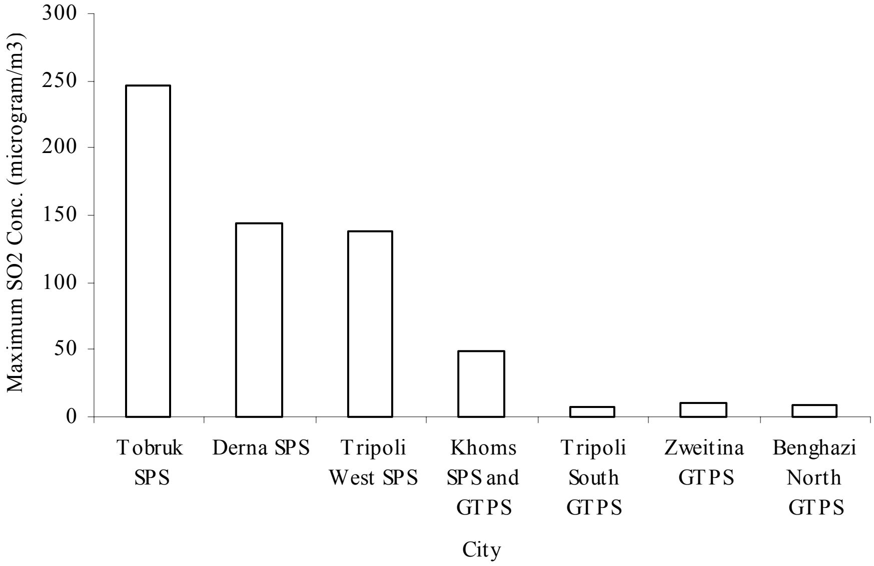

Fig.5. Maximum SO_2 concentration vs plant site

CONCLUSIONS

Analytical method based on Gaussian plume model is performed to predict SO_2 concentrations at 8 m above ground - level and the location of maximum values for Libyan electric power plants. The location of maximum sulfur dioxide gas concentration is found to be 0.5 – 3 km. Zweitina plant is located in approximately to populated areas. Thus, this site is expected to be most critical to ambient SO_2 impact. Tobruk electric station exhibits the peak intensity of SO_2 , about 246 $\mu g/m^3$. Steam power stations recorded the highest emission concentrations. However, pollutant emitted from Libyan power plants are in compliance with air pollution regulations recommended by World Health Organization, WHO.

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.

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