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Urban Air pollution Evaluation by Computer Simulation: A case study of petroleum refining company Nigeria

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Abstract

Industrialization is highly desirable for the sustenance of a nation's economy and the enhancement of the citizenry's well being. However the negative impact precipitated by introduction of its unwanted by – products into ecological system may be catastrophic if allowed to build up and uncontrolled. Urban Air pollution due to activities of process industries is one of the main problems faced by the industrial area of the world. Experimental analysis was carried out on gas flare to determine the extent of air pollution by the petroleum refinery industry on the concentrations of NO, CO, SO_2 and total hydrocarbon. Attempt at the modeling pollutant concentration from the flare point using visual basic is hereby presented. The model equation was used to simulate the concentration of pollutants at distance of 20, 40, 60, and 80, 100, to 1000 away from the flare point. The result of the simulation of model developed from the modified principle of gaseous dispersion by Gaussian showed a good agreement with the experimental results with average correction coefficient of 0.99. Results obtained reveled that the concentration of pollutants are unacceptable compare to the Federal Environmental protection Agency set limit. The dispersion pattern of pollutants showed that the extent of spreading is dependent on nearness to the source of flare, wind speed, temperature etc.

Keywords

Urban air pollution, Modeling, Simulation, Process industries and oil

Introduction

Air pollution is defined as the presence in the outdoor or indoor atmosphere of one or more gaseous or particulate contaminants in quantities, characteristics and of duration such as to be injurious to human, plant or animal life or to property, or which unreasonably interferes with the comfortable enjoyment of life and property (Odigure, 1998). It has been difficult to achieve cooperation for air pollution control in developing countries like Nigeria, whose chief concern is to provide such basic need as food, shelter and employment for her populace.

Ever since the discovery of oil in Nigeria in the 1950's, the country has been suffering the negative environmental consequences of oil development. The growth of the country's oil industry, combined with a population explosion and a lack of environmental regulation, led to substantial damage to Nigeria's environment especially in the Niger Delta region, the centre of the country's oil industry (Oyekunle, 1999). The country also faces environmental challenges from air pollution and desertification, with the encroachment of the Sahara desert in north and severe air pollution in over crowded cities such as Kaduna, Lagos, and Abuja (Ifeanyichukwu, 2002). The Niger Delta's main environmental challenges result from oil spillage, gas flaring and deforestation. Gas flaring is the one the hottest environmental issues in Nigeria. Flaring is the controlled burning of the waste natural gas associated with oil production (Bassel, 1981 and Aduku, and David, 1997). One of the main sources is the "solution gas" trapped in underground oil supplies, which is released when oil is brought to the surface. Flaring is used to eliminate gas when the volume is insufficient to warrant recovery or collection, it would be uneconomic. In recent years, however, the expansion of oil drilling has resulted in more flaring, triggering public reactions ranging from annoyance to allegation of serious health consequences for animal and people (Alakpodia, 1980). Flaring sometimes results in an unpleasant, "rotten egg" smell. There is no conclusive evidence of chronic or long-term effects to human health (Strauss, 1975).

Nevertheless, even with the end of gas flaring, air pollution is likely to remain a problem in Nigeria as other sources such as automobiles and diesel-fired electricity generators contributes to the choking air in the city, which are plagued by daily smog that covers the skyline of the central city (Ifeanyichukwu, 2002). Studies carried out by the Federal Environmental Protection Agency (F.E.P.A) show a moderate-to-high concentration of pollutants such as carbon monoxide, sulphur dioxide, nitrogen oxides, organic acids, particulate matters and hydrocarbon in the atmosphere. The majority of these come from automotive engines and industries (FEPA Report, 1998).

Since air pollution cause damages to the vegetation and materials on earth apart from damaging the human and animal health, a high degree of air pollution control is essential. But the difficulty to make definite statement about the precise health effect of air pollution is another titanic problem. This may be due to some problems associated with their damages. Some of these reasons are (Perry, 1984):

- It is usually impossible to determine the degree of exposure of a given individual to a specific problem.
- Pollutants are numerous and varied, and many of them are difficult to detect. Techniques for monitoring pollutants are inadequate, and long-term records are almost unavailable.
- Research is complicated because pollutants that do not cause problems when tested alone maybe dangerous in combustion with other pollutants.
- Degree of air pollution is correlated with other factors, such as degree of exposure to various kinds of stress, other kinds of pollution and food additives. However, through the rapid development of modern analytical technique has simulated an exponential increase in the number and the sophistication of industrial cities pollution studies, and hence the near perfect strategy of controlling these air pollution hazards is through the use of appropriate air pollution model (Perry, 1984).

The objective of this work is to evaluate urban air pollution by computer simulation and has necessitated the following aims and objectives of this study:

1. To study the sources of the air pollutant of the industrial city.
2. To calculate the experimental data of pollutants dispersion at various distances away from the stack.
3. To develop a dispersion model of air pollution and use modelling equations to predict the quantity of pollutants released into our environment with respect to distance away from the point of discharge to the atmosphere.
4. To simulate the declined model by computer programme using visual basic.

Methodology

There are various methods of detecting air pollution in an industrial environment. These experimental methods are capital intensive; hence only large or well-established industries can afford them. In this research, air samples were collected at various distances of 20m, 40m, 60m, 80m and 100m away from the flare stack to determine the concentration of pollutants in a flared gas. The samples for this research were collected from Petroleum Company in an industrial city of Nigeria to determine the concentration of NO, SO_2, CO and Total Hydrocarbon in the samples air collected.

Modelling Technique

The assumptions made during the cause of the development of this model are as stated below:

1. A mole of any gas occupy the same volume i.e. the stack gases will occupy the same volume in the industrial area.
2. The pollutant is from fumigating source.
3. Movement of the gas as a result of wind speed is a horizontal movement i.e. we are considering the X-axis for this model: for that is how damage is caused to the inhabitants of the environment. In essence, assumption of a nearly horizontal flow is valid for the model. In the near field, the phenomenon may have a fully three dimensional nature (e.g. a buoyant plume developing from the stack) emission, but in the far field, the horizontal motion prevails over the vertical. In the far field, the phenomenon can be two dimensional, in a horizontal sense.
4. The stack gases emitted from the industries in the atmosphere are not reactive i.e. there is no form of reaction between the pollutant.

Stack gas dispersion model is based on the Gaussian distribution given by (Beychok, 1995) as:

$$n_i = \frac{N\, e^{-\frac{(x_i - x_m)^2}{2\,\sigma^2}}}{\sigma\,(2\pi)^{\frac{1}{2}}} \qquad (1)$$

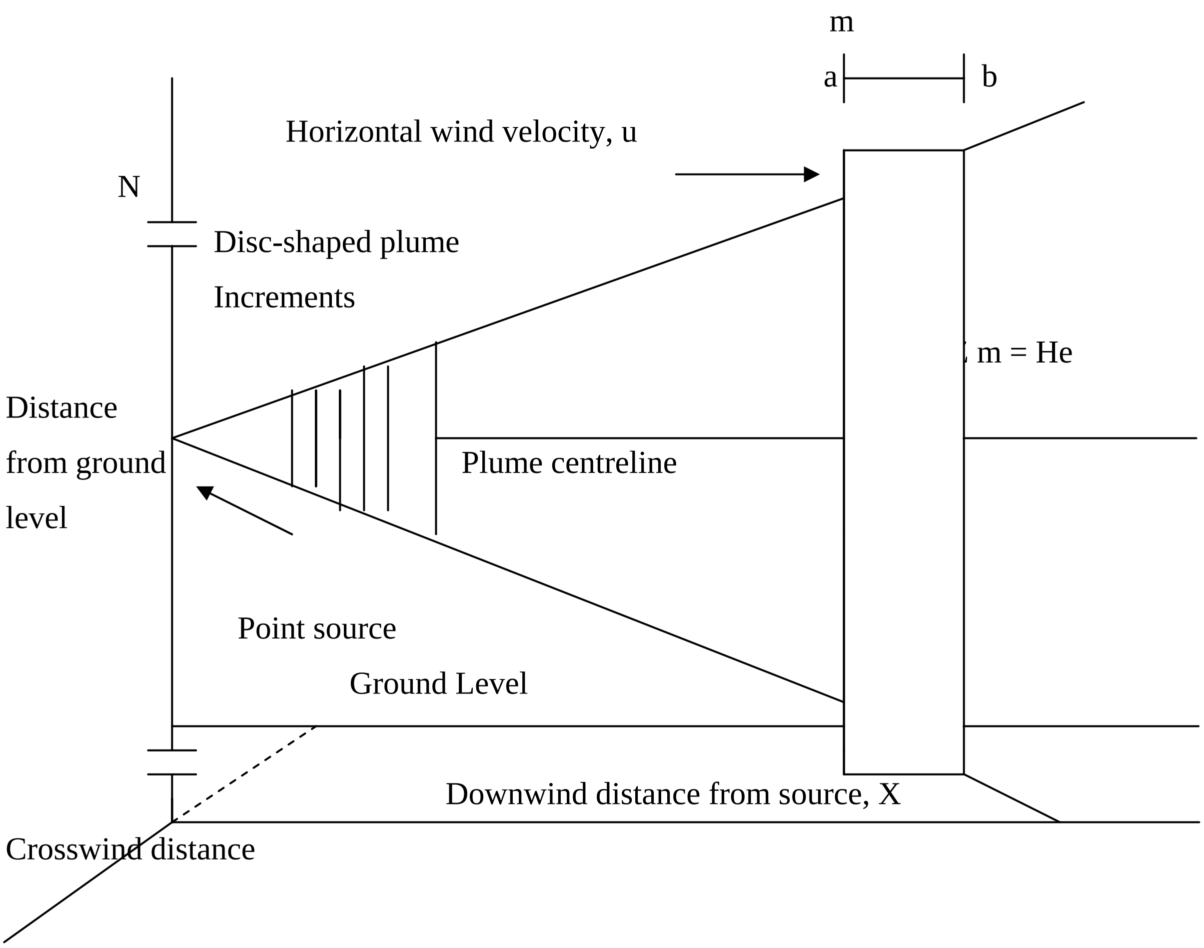

Fig. 1. Schematic diagram of a continuous point source (Beychok, 1995)

Neglecting the crosswind and looking only at the total emissions as seen by viewing the vertical dimension from a far distance and applying the Gaussian distribution equation i.e. Equation (1):

$$n_r(x,z) = \frac{N\ e^{-\frac{(z_r - z_m)^2}{2\sigma_z^2}}}{\sigma_z (2\pi)^{\frac{1}{2}}} \tag{2}$$

where:

N - Total grams of emission;

Z_r - any receptor location in the z dimension where the emission density is to be determined;

Z_m- Location of the mean density in the z dimension (ie the plume centreline);

σ_z - Vertical dispersion coefficient of the emission in meters;

$n_r(x,z)$ - the integrated crosswind emission density in g/m^3, seen at the captor located at z_r when viewing the x –z plane.

Considering the effect of upwards reflection from the ground, the Gaussian distribution becomes:

$$n_r\ (x,z) = \frac{N\, e^{-\frac{(z_r - z_m)^2}{2\sigma_z^2}}}{\sigma_z (2\pi)^{\frac{1}{2}}} + \frac{N\, e^{-\frac{(z_r - z_m)^2}{2\,\sigma_z^2}}}{\sigma_z (2\pi)^{\frac{1}{2}}}, \tag{3}$$

where $N = \frac{Q}{u}$ - weight of emission (g/m)

Let: $z_r - z_m = H_r - H_e$ and for the reflection from the ground level

$H_e = -\, H_e$ (Beychok, 1995)

Therefore: $Z_r - Z_m = H_r - (-H_e) = H_r + H_e$

Therefore:

$$n_r(x,z) = \frac{Q}{u\ \sigma_z (2\pi)^{\frac{1}{2}}} \left(e^{-\frac{(H_r - He)^2}{2\sigma_z^2}} + e^{-\frac{(H_r + H_e)^2}{2\sigma_z^2}} \right) \tag{4}$$

Equation (4) can be modify to include the effect of crosswind on Gaussian distribution of $n_r(x,z)$ in the y dimension to give:

$$n_r\left(x,y,z\right) = \frac{n_r(x,z)}{\sigma_y \left(2\pi\right)^{\frac{1}{2}}}\ e^{-\frac{(y - y_m)^2}{2\sigma_y^2}} \tag{5}$$

Substitute equation (4) into equation (5) to obtain:

$$n_r(x,y,z) = \frac{Q}{u\sigma_z\sigma_y 2\pi} e^{-\frac{(y - y_m)^2}{2\sigma_y^2}} \left(e^{-\frac{(H_r - H_e)^2}{2\sigma_z^2}} + e^{-\frac{(H_r + H_e)^2}{2\sigma_z^2}} \right) \tag{6}$$

Let n_r (x,y,z) = C(mg/m^3), Y_m= 0, for the location of the mean emission density at the plume centreline in the crosswind or y dimension, and equation (6) then becomes:

$$C = \frac{Q}{2\pi u \sigma_z \sigma_y} e^{-\frac{y^2}{2\sigma_y^2}} \left(e^{-\frac{(H_r - H_e)^2}{2\sigma_z^2}} + e^{-\frac{(H_r + H_e)^2}{2\sigma_z^2}} \right) \tag{7}$$

On the basis that fumigation results in uniform vertical dispersion from the ground to the plume top, Chimaroke, 2004 shows that:

$$e^{-\frac{(H_r - H_e)^2}{2\sigma_z^2}} + e^{-\frac{(H_r + H_e)^2}{2\sigma_z^2}} = \frac{1}{H_e + 2.5\sigma_z} \tag{8}$$

where He + 2.5σ_z - distance from the plume top to ground (m); He - Plume centreline height of the stack (m).

Equation (8) then becomes:

$$C = \frac{Q}{2\pi\sigma_z\sigma_y u} e^{-\frac{y^2}{2\sigma_z^2}} \left(\frac{1}{H_e + 2.5\sigma_z} \right) \tag{9}$$

According to Onyiah (2005), the dispersion coefficient σ_z is given as:

$$\sigma_z = \frac{0.359H}{\eta} \tag{10}$$

where H - Humidity, η - thermal efficiency.

Substitute equation (10) into equation (9):

$$C = \frac{Q\,\eta}{0.718\ u\ \sigma_y \pi}\ e^{-\frac{y^2}{2\,\sigma_y^2}} \left(\frac{1}{H_e + \frac{0.8975\ H}{\eta}} \right) \tag{11}$$

But:

$$H_e = h_s + \Delta h \tag{12}$$

where h_s - height of the stack (m) and Δh - plume rise (m).

$$\Delta h = 2.4 \left(\frac{F}{u\ S} \right)^{\frac{1}{3}} \tag{13}$$

$$F = \frac{g\ v_s}{\pi} \left(\frac{T_s - T_a}{T_s} \right) \tag{14}$$

$$S = \frac{g\ \frac{dT}{dZ}}{T_a + 273} \tag{15}$$

Substitute equations (14) and (15) into equation (13) to obtain:

$$\Delta h = 2.4 \left(\frac{v_s\left(T_a + 273\right)}{\pi u \frac{dT}{dZ}} \left(\frac{T_s - T_a}{T_a} \right) \right)^{\frac{1}{3}} \tag{16}$$

Substitute equation (16) into (12):

$$H_e = h_s + 2.4 \left(\frac{v_s\left(T_a + 273\right)}{\pi u \frac{dT}{dZ}} \left(\frac{T_s - T_a}{T_s} \right) \right)^{\frac{1}{3}} \tag{17}$$

where v_s - stack discharge velocity m/s, T_s - stack discharge velocity °C, T^a - ambient temperature °C, dT/dZ - potential temperature gradient.

Equation 11 is the model equation for pollutant dispersion from refinery.

Results and Discussion of results

Experimental results are presented in tables 1 and 2:

Table1. Concentrations of pollutants with respect to distances from the point of flaring for the month of June 2003

Distance (m)	Concentration of pollutant (mg/m^3)			
	NO (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)	Total Hydrocarbon (mg/m^3)
20m	0.096	1.12	14.64	0.282
40m	0.093	1.06	13.21	0.221
60m	0.091	1.04	12.63	0.182
80m	0.086	1.02	11.21	0.18
100m	0.084	0.04	11.18	0.12
FEPA LIMIT	0.062 – 0.93	0.05	11.43	0.16

Table 2. Concentration of pollutants with respect to distances from the point of flaring for the month of July 2003

Distance (m)	Concentration of pollutant (mg/m^3)			
	NO (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)	Total Hydrocarbon (mg/m^3)
20m	0.098	1.11	14.63	0.312
40m	0.095	1.04	13.41	0.294
60m	0.092	0.92	12.82	0.227
80m	0.091	0.87	11.75	0.198
100m	0.087	0.05	11.49	0.17
FEPA LIMIT	0.062 – 0.93	0.05	11.45	0.16

The model equations were simulated using Visual Basic Programme. The results obtained are presented in tables 3 to 5.

Table 3. Computed concentration (mg/m^3) for thermal efficiency of 65%

Concentration of pollutants at various distances				
Distance (m)	NO (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)	THC (mg/m^3)
20	0.083	0.970	12.688	0.244
40	0.081	0.920	11.449	0.191
60	0.078	0.902	10.940	0.159
80	0.075	0.879	9.706	0.155
100	0.073	0.036	9.683	0.105
200	0.052	0.034	9.066	0.097
300	0.050	0.023	6.126	0.096
400	0.038	0.018	4.633	0.093
500	0.031	0.014	3.728	0.085
600	0.026	0.012	3.120	0.084
700	0.022	0.010	2.684	0.072
800	0.019	0.009	2.355	0.063
900	0.017	0.008	2.098	0.056
1000	0.015	0.007	1.892	0.051

Table 4. Computed concentration (mg/m^3) for thermal efficiency of 75%

Concentration of pollutants at various distances				
Distance (m)	NO. (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)	THC (mg/m^3)
20	0.093	1.120	14.640	0.228
40	0.093	1.062	13.209	0.221
60	0.090	1.041	12.623	0.183
80	0.087	1.014	11.199	0.179
100	0.084	0.042	11.172	0.121
200	0.060	0.040	10.461	0.113
300	0.058	0.027	7.068	0.110
400	0.044	0.020	5.346	0.108
500	0.035	0.016	4.301	0.0.98
600	0.029	0.014	3.600	0.097
700	0.025	0.012	3.097	0.083
800	0.022	0.010	2.717	0.073
900	0.020	0.009	2.421	0.065
1000	0.018	0.008	2.183	0.059

Table 5. Computed concentration (mg/m^3) for thermal efficiency of 85%

Concentration of pollutant various distances				
Distance (m)	NO (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)	THC (mg/m^3)
20	0.109	1.296	16.592	0.319
40	0.106	1.204	14.971	0.250
60	0.102	1.179	14.307	0.208
80	0.098	1.150	12.693	0.203
100	0.095	0.047	12.662	0.137
200	0.068	0.045	11.856	0.127
300	0.066	0.030	8.011	0.125
400	0.050	0.023	6.058	0.122
500	0.040	0.019	4.875	0.111
600	0.033	0.015	4.080	0.110
700	0.029	0.013	3.509	0.094
800	0.025	0.012	3.079	0.083
900	0.022	0.010	2.744	0.074
1000	0.020	0.009	2.474	0.067

Knowledge of the types and rates of emission is fundamental to evaluation of any air pollution problems. Estimates of rates at which pollutants are discharge from various processes can be obtained by utilizing emissions factors. Emissions factors are affected by the techniques employed in the processing, handling or burning operations (Gwedolyn et. - al, 1993). The aim of this work is to develop a mathematical model for urban air pollution due to the activities of oil refinery companies. The emission from the industries into the atmosphere normally result into the contamination of the environment and the pollutant when discharge and dispersed in the atmosphere are present in varying concentration and this has reduced the life expectancy of the inhabitants of industrial area (Gavriel, 1991).

It could be observed from the tables 1 and 2 of experimental results that there is an appreciable variation in the concentration of pollutants at the various distances of 20, 40, 60, 80 and 100 m away from the point of discharged. This variation could be attributed to the effect of meteorological parameters, which are temperature, wind speed, humidity and thermal efficiency. The simulation results are presented in tables 3 to 5. It could be seen from the results that the concentration of pollutants varies with the thermal efficiency. The higher the thermal efficiency the higher the concentration of the pollutant dispersed and vice versa. This could be attributed to the fact that the thermal efficiency is inversely proportional to the stack efficiency (Onyiah, 2005). The lower the thermal efficiency induces the better the performance of the stack. Comparism of experimental results with the simulation results shows a little variation with average correlation coefficient of 0.99 the variation between experimental and simulation results is as a results of some of the assumption made during the conceptualisation of the model equation (Odigure and Abdulkareem, 2001). Experimental values are a measure of the concentration of the pollutants for the prevailing meteorological conditions while the simulated results are the instantaneous values i.e. it measured the possible amount of pollutants that could be released and dispersed at a given time. The results also revealed that the concentration of the pollutants at distances of 20,40and 60m from the point of flare does not conform to the Federal Environmental Protection Agency (FEPA) set limit.

Conclusion

Based on the results obtained, it can be deduced that:

1. The results of simulation of the model developed based on the modified principles of gas dispersion by Gaussian showed a remarkable agreement with experimental results.
2. The quality of air with respect to the pollutant measured is unacceptable when compared with FEPA set limit.
3. The dispersion pattern of the pollutant showed that the extent of dispersion of pollutant in air depends on the wind velocity, humidity and thermal efficiency.

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