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Finite Volume Modelling of Carbon Monoxide from Vehicular Emissions at Oshodi Market in Lagos Metropolis of Nigeria

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Abstract

A two-dimensional finite volume mathematical model has been developed to predict the concentration of carbon monoxide emission from idling vehicles at traffic hold-ups. The results of the developed model equation which was solved using MATLAB programme show a similar pattern for the longitudinal and lateral concentration distribution at varying time and wind velocities. The CO concentration increases as emission time increases for both directions while the concentration decreases as the wind velocity increases. The longitudinal concentration of CO was found to increase from 0.00787 mg/m^3, at 5 minutes of continuous emission to 07281 mg/m^3 after one hour (60 minutes) of continuous emission. It could be inferred from the results that traders as well as pedestrians and those living in the vicinity of the ever busy Oshodi market are daily exposed

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to high concentration of lethal CO emission as traffic hold-up at that area of Lagos metropolis spans hours daily.

Mathematics Subject Classification: Modelling

Keywords: Carbon monoxide, vehicular emission, model equation, traffic hold-up, wind velocity

1 Introduction

Carbon monoxide along with other products of combustion such as the green house gases (carbon dioxide (CO_2), and methane (CH_4)), volatile organic compounds (VOC), particulate matters (PM) that are daily emitted into the atmosphere which are anthropogenic have serious effects on humans and the environment. In Nigeria, the primary source of these emissions is natural gas flaring [1, 2], with vehicular emission next in gravity. Vehicular emissions in Nigeria, like any other developing economy of the World [3] is intensified by congested roads network (leading to traffic jams), poor vehicle maintenance, inferior fuels, increasing number of motor vehicles among others. Carbon monoxide is a toxic and lethal gas. It is a dangerous asphyxiant. When combined with haemoglobin of the blood it reduces the blood's ability to carry oxygen to cell tissues [4]. Carbon monoxide, when oxidised in the presence of sunlight initiates photochemical reactions which produces ozone (O_3) in a regional scale [5, 6]. Ozone at the upper atmosphere is a very useful irreplaceable resource that helps to filter out dangerous ultraviolet (UV) rays from our solar system, thereby protecting humans from threat of radiation burns and genetic damage [7]. However, at ground level, ozone is a harmful pollutant, damaging plants and poses great danger to human health as it causes sensitivity to infections, lungs disease, and irritation in eyes, nose, throat and risk asthmatics [8, 9].

Atmospheric dispersion of carbon monoxide and other vehicular emissions is determined by meteorological variables such as wind speed and its directions, inversion mixing and deposition

[3, 10]. Dispersion results from local turbulence that is, motion that last less than the time used to average the transport. Inversion is a factor that interrupts dispersion and causes accumulation of emitted pollutants in the atmosphere. Deposition processes on the other hand, causes downward movement of emitted pollutants in the atmosphere.

There are several natural mechanisms that clean the atmosphere from certain pollutants. Some of these mechanisms include aerosol formation, water cloud formation, and precipitation. Each of these mechanisms removes pollutants from the atmosphere within the specified length of time, depending on water solubility and chemical reactivity of the affected pollutants. However, these mechanisms are not effective in Nigeria as a result of uncontrolled continued emissions of criteria pollutants into the atmosphere from natural gas flaring, motor vehicle exhausts and various industrial activities. The carbon monoxide (CO) concentration at a particular location such as the congested Oshodi market in Lagos metropolis can be known by measurement. However, in order to better understand the air pollutant behaviour in the environment, it becomes pertinent to use air pollution model in predicting the CO concentration level in the environment. Mathematical models integrate our knowledge of the chemical and physical processes of pollutants dynamics into structural framework that can be used to explain the relationship between sources such as motor vehicle exhausts and the resulting impact on human health [10].

Different models have been used in the past to simulate pollutants from vehicular traffic. Tang [11] employed the regional Eulerian chemical transport model to simulate the pollutant emission at urban sites and power plants in Nashville, Middle Tennessee. Boybeyi and Raman [12] in their work applied a three-dimensional meso-scale meteorological model with a Monte Carlo or

Langrangian particle dispersion model (LPM), while Santo et al. [13] compared the results of the LPM, and an adaptive Puff model (APM) to study the dispersion of pollutants (SO_2) from coal-fired As Pontes power plant in Spain. Sathitkunarat et al. [4] in their own work used the hybrid particle and concentration transport model (HYPACT) for the simulation of CO concentration and dispersion in Chiang Mai urban area of Thailand. In estimating vehicle emissions from an urban area of Bangkok, Onchang et al. [14] employed the Graz Langrange model. The most widely used simulation tool for modelling vehicular emissions in many countries today is the COPERT i.e. computer programme to calculate emissions from road transport [15, 16] Very few workers, if any have applied the finite volume method in modelling vehicular emissions in a congested urban area with heavy traffic hold-up spanning several hours daily. In this paper, an attempt is made to model the most lethal pollutant of motor vehicle emissions, carbon monoxide (CO), in Oshodi market, a busy congested suburb of Lagos metropolis of Nigeria.

2 Model Development and Solution Methods

2.1 Model Development

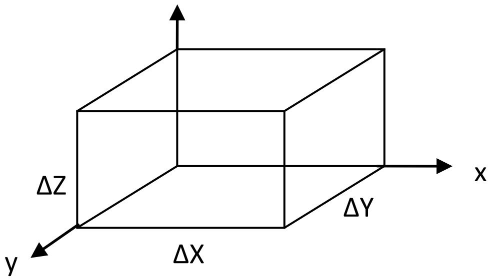

Figure 1: Conservation of mass flux in an elemental control volume of air system

Consider an elemental volume of air system shown in Figure 1 which is taken to represent a small section of Oshodi market area of Lagos metropolis. Applying Fick's first law of diffusion gives the flux (J) of material being mixed across any surface of the cube as:

$$J_{\varphi} = -k\frac{\partial c}{\partial \varphi} \tag{2.1}$$

where c = concentration of pollutant

φ = distance in the direction considered (x, y, z)

k = turbulent dispersion coefficient

However,

The total flux of material = diffusional flux + flux due to bulk flow

i.e

$$J = -k\frac{\partial c}{\partial \varphi} + uc \tag{2.2}$$

Taking material balance around the elemental control volume of Figure 1, we have:

Net flow into the cube in the x-direction as

$$\left(-k\frac{\partial c}{\partial x} + uc\right)\Delta y\Delta z - \left(-k\frac{\partial c}{\partial x} + uc + \frac{\partial}{\partial x}\left(-k\frac{\partial c}{\partial x} + uc\right)\Delta x\right)\Delta y\Delta z \tag{2.3}$$

which gives

$$\left(-k\frac{\partial^2 c}{\partial x^2} + \frac{\partial(u.c)}{\partial x}\right)\Delta x\Delta y\Delta z \tag{2.4}$$

Similarly the net flow in both the y-, and z-directions gives

$$\left(-k\frac{\partial^2 c}{\partial y^2} + \frac{\partial(v.c)}{\partial y}\right)\Delta x\Delta y\Delta z \tag{2.5}$$

and

$$\left(-k\frac{\partial^2 c}{\partial z^2} + \frac{\partial(w.c)}{\partial z}\right)\Delta x\Delta y\Delta z \tag{2.6}$$

where u, v and w are the bulk flow velocities in x, y, w directions.

The production of pollutants from the vehicle exhaust is given by

$$q\ \Delta x \Delta y \Delta z \tag{2.7}$$

The rate of accumulation from vehicle exhaust in the environment is represented by

$$V\frac{\partial c}{\partial t} = \frac{\partial c}{\partial t}\ \Delta x \Delta y \Delta z \tag{2.8}$$

Combining equations (2.4), (2.5), (2.6), (2.7) and (2.8) yields

$$\frac{\partial c}{\partial t}\ \Delta x \Delta y \Delta z$$
$$= \left(k\frac{\partial^2 c}{\partial x^2} - \frac{\partial (u.c)}{\partial x} + k\frac{\partial^2 c}{\partial y^2} - \frac{\partial (v.c)}{\partial y} + k\frac{\partial^2 c}{\partial z^2} - \frac{\partial (w.c)}{\partial z} \right) \Delta x \Delta y \Delta z + q\ \Delta x \Delta y \Delta z \tag{2.9}$$

Assuming that bulk velocities, u, v, w are constant and that diffusion of pollutant in the atmosphere is turbulent, then we can recast equation (2.9) as

$$\frac{\partial c}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = k_x\frac{\partial^2 c}{\partial x^2} + k_y\frac{\partial^2 c}{\partial y^2} + k_z\frac{\partial^2 c}{\partial z^2} + q \tag{2.10}$$

Apart from natural transport and dispersion processes, considerable mixing are caused by moving vehicles which influences pollutant concentration, if we therefore assume complete mixing below an arbitrary mixing height, H, downward flow of plume will no longer spread vertically but only horizontally. In such situation equation (2.10) becomes 2-dimensional. i.e.

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} = k_x\frac{\partial^2 c}{\partial x^2} + k_y\frac{\partial^2 c}{\partial y^2} + q \tag{2.11}$$

or

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} - \frac{\partial c}{\partial x}\left(k_x\frac{\partial c}{\partial x} \right) - \frac{\partial c}{\partial x}\left(k_y\frac{\partial c}{\partial y} \right) - q = 0 \tag{2.12}$$

with the following boundary conditions

$$
\begin{aligned}
C\,(x_0, y_o, 0) &= 0 \\
C\,(x_0, 0, t) &= C_0 \\
C\,(0, y_0, t) &= C_0 \\
C\,(\infty, y_0, t) &= 0 \\
C\,(x_0, \infty, t) &= 0
\end{aligned}
$$

Equation (2.12) is a non-linear Richards Equation which can be solved using any numerical methods. Assuming weak non-linearity of the model equation (2.12), the finite volume method can conveniently be used in solving it. We apply this method here.

2.2 Finite Volume Solution Method of the Model Equation

To solve equation (2.12) using the finite volume method, it has to be transformed into a diffusion equation viz;

$$u\frac{\partial c}{\partial x} - \frac{\partial}{\partial x}\left(k_x \frac{\partial c}{\partial x}\right) = A_x \frac{\partial}{\partial x}\left(k_x B_x \frac{\partial c}{\partial x}\right) \tag{2.13}$$

and

$$v\frac{\partial c}{\partial y} - \frac{\partial}{\partial y}\left(k_y \frac{\partial c}{\partial y}\right) = A_y \frac{\partial}{\partial y}\left(k_y B_y \frac{\partial c}{\partial y}\right) \tag{2.14}$$

$$A_x k_x \frac{\partial B_x}{\partial x} = u, \quad A_x B_x = -1 \tag{2.15}$$

$$A_y k_y \frac{\partial B_x}{\partial y} = v, \quad A_y B_y = -1 \tag{2.16}$$

From equation (2.15), we have

$$A_x k_x \frac{\partial B_x}{\partial x} = u, \quad A_x = -\frac{1}{B_x}$$

Substituting for A$_x$ yields

$$-\frac{1}{B_x}\frac{\partial B_x}{\partial x} = \frac{u}{k_x} \qquad \text{or} \qquad \frac{\partial B_x}{B_x} = -\frac{u}{k_x}dx \tag{2.17}$$

Integrating equation (2.17) gives

$$B_x = e^{\int -\left(\frac{u}{k_x}dx + cons\right)} \quad \text{or} \quad B_x = e^{const.}.*e^{\int -\frac{u}{k_x}dx} \tag{2.18}$$

Let $e^{\text{const.}} = B_0(x)$, then

$$B_x = B_0(x)e^{-\int \frac{u}{k_x}dx} \tag{2.19}$$

The same transformation for B_y gives

$$B_y = B_1(y)e^{-\int \frac{v}{k_y}dy} \tag{2.20}$$

where $B_0(x)$ and $B_1(y)$ are constants.

Note that the transformed equation is the combination of equations (2.13) and (2.14), i.e.

$$\frac{\partial c}{\partial t} + A_x \frac{\partial}{\partial x}\left(k_x B_x \frac{\partial c}{\partial x}\right) + A_y \frac{\partial}{\partial y}\left(k_y B_y \frac{\partial c}{\partial y}\right) + q = 0 \tag{2.21}$$

Now substituting equations (2.19) and (2.20) into (2.21) with little rearrangement gives

$$\frac{\partial c}{\partial t} - \frac{1}{e^{-\int \frac{u}{k_x}dx}} \frac{\partial}{\partial x}\left(k_x e^{-\int \frac{u}{k_x}dx} \frac{\partial c}{\partial x}\right) - \frac{1}{e^{-\int \frac{v}{k_y}dy}} \frac{\partial}{\partial y}\left(k_y e^{-\int \frac{v}{k_y}dy} \frac{\partial c}{\partial y}\right) + q = 0 \tag{2.22}$$

Multiplying both sides of equation (2.22) by $\left(e^{-\int \frac{u}{k_x}dx} * e^{-\int \frac{v}{k_y}dy} \right)$ and rearranging yields

$$\begin{aligned} \left(e^{-\int \frac{u}{k_x}dx} * e^{-\int \frac{v}{k_y}dy} \right)\left(\frac{\partial c}{\partial t} + q \right) - e^{-\int \frac{v}{k_y}dy} \frac{\partial}{\partial x}\left(k_x e^{-\int \frac{u}{k_x}dx} \frac{\partial c}{\partial x}\right) & \\ - e^{-\int \frac{u}{k_x}dx} \frac{\partial}{\partial y}\left(k_y e^{-\int \frac{v}{k_y}dy} \frac{\partial c}{\partial y}\right) = 0 & \end{aligned} \tag{2.23}$$

Assuming that u/k_x and v/k_y are constant or that they average within the integration range, then the 2-dimensional diffusion equation (2.23) can be written in terms of the global Peclet number in both directions, i.e.

$$Pe_x = \frac{uL_x}{2k_x} \quad \text{and} \quad Pe_y = \frac{uL_y}{2k_y}$$

But

$$\int_0^x \frac{u}{k_x} dx = \frac{ux}{k_x} = \left(\frac{uL_x}{2k_x}\right)\frac{2x}{L_x} = \frac{2Pe_x}{L_x}$$

Thus, the simplified form of the 2-dimensional diffusion equation (2.23) becomes

$$\begin{aligned} & e^{-\left(\left(\frac{2p_x x}{L_x}.\right)\left(\frac{2p_y y}{L_y}\right)\right)}\left(\frac{\partial c}{\partial t}+q\right)-e^{-\left(\frac{2p_y y}{L_y}\right)}\frac{\partial}{\partial x}\left(k_x e^{-\left(\frac{2p_x x}{L_x}\right)}\frac{\partial c}{\partial x}\right) \\ & \qquad -e^{-\left(\frac{2p_x x}{L_x}\right)}\frac{\partial}{\partial y}\left(k_y e^{-\frac{2p_y y}{L_y}}\frac{\partial c}{\partial y}\right)=0 \end{aligned} \tag{2.24}$$

where L$_x$ and L$_y$ are the characteristic lengths in the x-, and y- directions respectively.

The transformed equation (2.24) can now be conveniently solved by the finite volume method.

With an unsteady pollutant flow as represented in Figure 2, equation (2.24) can be discretized over the control volume and over time interval from t to t + Δt

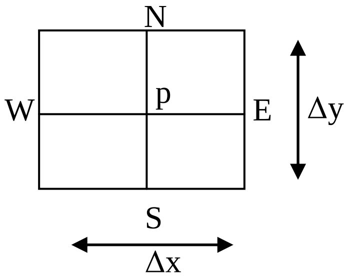

Figure 2: Two-dimensional discretized control volume of pollutant

Thus,

$$\int_{t}^{t+\Delta t}\int_{S}^{N}\int_{W}^{E}[e^{-\left(\left(\frac{2p_x x}{L_x}\right).\left(\frac{2p_y y}{L_y}\right)\right)}\left(\frac{\partial c}{\partial t}+q\right)-e^{-\left(\frac{2p_y y}{L_y}\right)}\frac{\partial}{\partial x}\left(k_x e^{-\left(\frac{2p_x x}{L_x}\right)}\frac{\partial c}{\partial x}\right)-e^{-\left(\frac{2p_x x}{L_x}\right)}\frac{\partial}{\partial y}\left(k_y e^{-\left(\frac{2p_y y}{L_y}\right)}\frac{\partial c}{\partial y}\right)]dxdydt=0 \tag{2.25}$$

If the dependent variable at the node is assumed to prevail over the whole control volume, integration of the transient term can be written as

$$\begin{aligned}&\int_{t}^{t+\Delta t}\int_{S}^{N}\int_{W}^{E}\left[e^{-\left(\left(\frac{2p_x x}{\Delta x}\right).\left(\frac{2p_y y}{\Delta y}\right)\right)}\left(\frac{\partial c}{\partial t}\right)\right]dxdydt\\&=\frac{\Delta x}{2pe_x}-\frac{\Delta x}{2pe_x}\left(e^{pe_x}-e^{-pe_x}\right)\left(e^{pe_y}-e^{-pe_y}\right)\left(\frac{C_p^{n+1}+C_p}{\Delta t}\right)\end{aligned} \tag{2.26}$$

where n and n + 1 refer to time levels

Applying centred difference and assuming uniform grid spacing in both directions, the spatial integration of the other terms of equation (2.25) is

$$\begin{aligned}&-\frac{\Delta y}{2pe_y}\frac{k_x}{\Delta x}\left(e^{pe_y}-e^{-pe_y}\right)\left[e^{pe_x}C_w-\left(e^{pe_y}-e^{-pe_y}\right)C_p+e^{-pe_y}C_E\right]\\&-\frac{\Delta x}{2pe_x}\frac{k_y}{\Delta y}\left(e^{pe_x}-e^{-pe_x}\right)\left[e^{pe_y}C_s-\left(e^{pe_y}-e^{-pe_y}\right)C_p+e^{-pe_y}C_N\right]\\&+\frac{\Delta x}{2pe_x}\frac{\Delta y}{2pe_y}\left(e^{pe_x}-e^{-pe_x}\right)\left(e^{pe_y}-e^{-pe_y}\right)+q=0\end{aligned} \tag{2.27}$$

Equation (2.27) can be rearranged as

$$\begin{aligned}&-\frac{2pe_x k_x}{\Delta x^2}\left[\left(\frac{e^{pe_x}}{e^{pe_x}-e^{-pe_x}}\right)C_w-\left(\coth pe_x\right)C_p+\left(\frac{e^{-pe_x}}{e^{pe_x}-e^{-pe_x}}\right)C_E\right]\\&-\frac{2pe_y k_y}{\Delta y^2}\left[\left(\frac{e^{pe_y}}{e^{pe_y}-e^{-pe_y}}\right)C_w-\left(\coth pe_y\right)C_p+\left(\frac{e^{-pe_y}}{e^{pe_y}-e^{-pe_y}}\right)C_N\right]+q=0\end{aligned} \tag{2.28}$$

The time integration can be evaluated using the mean value theorem. Making the same simplification between equations (2.27) and (2.28), for transient time given in equation (2.26), the result of the integration of equation (2.25) can be written as

$$
\begin{aligned}
&\frac{C_p^{n+1}+C_p}{\Delta t}+\theta\left(\frac{k_x}{\Delta x^2}\left\{-\left[pe_x\left(\alpha_x+1\right)+1\right]C_W^{n+1}+\left[2pe_x\alpha_x+2\right]C_p^n\right\}\right)\\
&\theta\left(\frac{k_x}{\Delta x^2}\left\{-\left[pe_x\left(\alpha_x-1\right)+1\right]C_E^{n+1}\right\}\right)\\
&\theta\left(\frac{k_y}{\Delta y^2}\left\{-\left[pe_y\left(\alpha_y+1\right)+1\right]C_S^{n+1}\right\}\right)\\
&+\theta\left(\frac{k_y}{\Delta y^2}\left\{\left[2pe_y\alpha_y+2\right]C_N^{n+1}-\left[pe_y\left(\alpha_y-1\right)+1\right]C_N^{n+1}\right\}+q^{n+1}\right)\\
&=-\left(1-\theta\right)\left(\frac{k_x}{\Delta x^2}\left\{-\left[pe_x\left(\alpha_x+1\right)+1\right]C_W^n+\left[2pe_x\alpha_x+2\right]C_p^n\right\}\right)\\
&\left(1-\theta\right)\left(\frac{k_x}{\Delta x^2}\left\{-\left[pe_x\left(\alpha_x-1\right)+1\right]C_E^n\right\}\right)\\
&-\left(1-\theta\right)\left(\frac{k_y}{\Delta y^2}\left\{-\left[pe_y\left(\alpha_y+1\right)+1\right]C_S^n\right\}\right)\\
&-\left(1-\theta\right)\left(\frac{k_y}{\Delta y^2}\left\{\left[2pe_y\alpha_y+2\right]C_N^n-\left[pe_y\left(\alpha_y-1\right)+1\right]C_N^n\right\}+q^n\right)
\end{aligned}
\tag{2.29}
$$

where

$0 \le \theta \le 1$, employing Crank-Nicholson, $\theta = \frac{1}{2}$

α_x and α_y are defined as

$\alpha_x = \coth Pe_x - \frac{1}{Pe_x}$ and $\alpha_y = \coth Pe_y - \frac{1}{Pe_y}$

Equation (2.29) can be written in the following form:

$$
\begin{aligned}
&a_s\theta C_W^{n+1}+f_s\theta C_S^{n+1}+\left(b_t+b_s\theta\right)C_p^{n+1}+h_s\theta C_E^{n+1}+g_s\theta C_N^{n+1}\\
&=-d_i-a_s\left(1-\theta\right)C_W^n+f_s\left(1-\theta\right)C_S^n+\left(b_t-b_s\left(1-\theta\right)\right)C_p^n-h_s\left(1-\theta\right)C_E^n\\
&-g_s\left(1-\theta\right)C_N^n
\end{aligned}
\tag{2.30}
$$

where

$$a_s = \left[pe_x\left(\alpha_x+1\right)+1\right] \tag{2.31}$$

$$f_s = \frac{k_y}{\Delta y^2}\left[pe_y\left(\alpha_y+1\right)+1\right] \tag{2.32}$$

$$b_s = (2pe_x\alpha_x + 2) + (2pe_y\alpha_y + 2) \tag{2.33}$$

$$h_s = \frac{k_x}{\Delta x^2}\left[pe_x(\alpha_x - 1) + 1\right] \tag{2.34}$$

$$g_s = \frac{k_y}{\Delta y^2}\left[pe_y(\alpha_y - 1) + 1\right] \tag{2.35}$$

$$b_s = \frac{1}{\Delta t} \tag{2.36}$$

$$d_i = \left[\theta q^{n+1} + (1-\theta)q^n\right] \tag{2.37}$$

3 Application and Parameterization

To solve the transformed Richards equation (2.30), the turbulent diffusivity coefficient, k, the source strength q, the exiting carbon monoxide velocity must be known in a continuous form. The initial concentration of the exiting carbon monoxide also needs to be estimated.

The turbulent diffusivity coefficient, k, for carbon monoxide system at normal atmospheric pressure of 1 atmosphere and a temperature of 25^{o}C can be estimated using the semi-empirical relation enunciated by Fuller et al., [17]. The relation is given by

$$K_{co,air} = \frac{1.0x10^{-7}T^{1.75}\left({}^{1}\!/\!{}_{M_{co}} + {}^{1}\!/\!{}_{M_{air}} \right)^{0.5}}{P\left\{\left(\sum V_{co}\right)^{0.33} + \left(\sum V_{air}\right)^{0.33}\right\}^{2}} \tag{3.1}$$

where

$\sum V_{co}$ = structural volume increment of CO = 30.7 g/mol

$\sum V_{air}$ = structural volume increment of air = 29.9 g/mol

T = absolute temperature = 298K (25^{0}C)

P = absolute pressure = 1 atm.

Substituting these values, gives $K_{co,\ air} = 1.49 \text{ x } 10^{-2}$ m/s.

The source strength, q is the amount of pollutant emitted into the air (volume per time) calculated as the sum of emission factor multiplied by number of vehicles for different class of vehicles. It can be estimated using the relation given by the World enformatika society as reproduced in the works of Adiotomre [10], i.e.

$$q = \frac{1}{3600} \sum e_i N_i \tag{3.2}$$

where

e = emission factor of 1 type of vehicle (g/km/vehicle)

N = vehicle/hour

For this study, emission factor of buses was chosen since more than 80% of vehicles caught up in Oshodi traffic jam each day are mass transit buses. The CO emission factors for various classes of vehicles as given by Anjaneyulu et al. [18] is shown in Table 1.

Table 1: CO emission factor for vehicles (Anjaneyulu et al., [18]

S/N	Type of Vehicle	CO (g/km)
1	Bus	4.38
2	Truck	3.425
3	Four wheeler	23.4

On substituting the values in Table 1 into equation (3.2) for one bus with appropriate conversion, we have q = 4.305 mg/m^3.s

The values of concentrations used as boundary conditions in this study were obtained from the works of Charlot et. al [19], since Chennai, a metropolitan city in India has similar features as Oshodi in Lagos. The initial CO concentration of 0.0787 mg/m^3, was adopted from that study.

The velocity of carbon monoxide exiting from vehicle tailpipes depends on the vehicles operating conditions. Values ranging between 2.0 m/s and 3.1 m/s were considered. This consideration was based on the operating conditions of a temperature of 2300K and a pressure of 1000 kPa to 2250 kPa for a bus moving at a uniform speed of 25 km/h as correlated by Metghalachi and Keck [20]. For this work, however, the emitted carbon monoxide was assumed to be dispersed at a constant wind velocity of 2.0 m/s.

The developed model equations were solved using MATLAB 7.0.

4 Results and Discussion

4.1 Spatial Dispersion of Carbon Monoxide at Varying Time

Figures 3 and 4 show the simulated results of longitudinal and lateral concentration distribution of CO for varying time at a constant wind velocity of 2 m/s. From the results, it can be seen that for both lateral and longitudinal dispersion, the pollutant concentration increases as time increases. This trend is expected, because the longer, vehicles are held-up in traffic jam the more, the quantity of pollutants that are emitted into the atmosphere by idling vehicles. From Figure 3, it can be observed that at $y = 0$, the longitudinal CO concentration was 0.00787 mg/m^3 for 5 minutes, 0.03149 mg/m^3 for 25 minutes, 0.05920 mg/m^3 for 30 minutes and 0.07281 mg/m^3 for 60 minutes respectively. The lateral CO concentration distribution also exhibited similar trend at $x = 0$. However, as the distance from source increases the CO concentrations decreases, eventually coming to zero. It is noteworthy though, that the lateral distribution is more uniform than the longitudinal distribution, with the latter curve skewed to the left. This may be as a result of variation in the wind velocity from the lagoon in that direction which probably alters the simulated constant wind velocity. It had been demonstrated that when CO emission follow a Beta distribution, the plot is usually skewed to the left [21]. From the results it is clear that traders and individuals living around Oshodi market are at high risk of CO poisoning considering the number of hours that vehicles stay in traffic jam there, emitting high concentration of this lethal pollutant into the atmosphere.

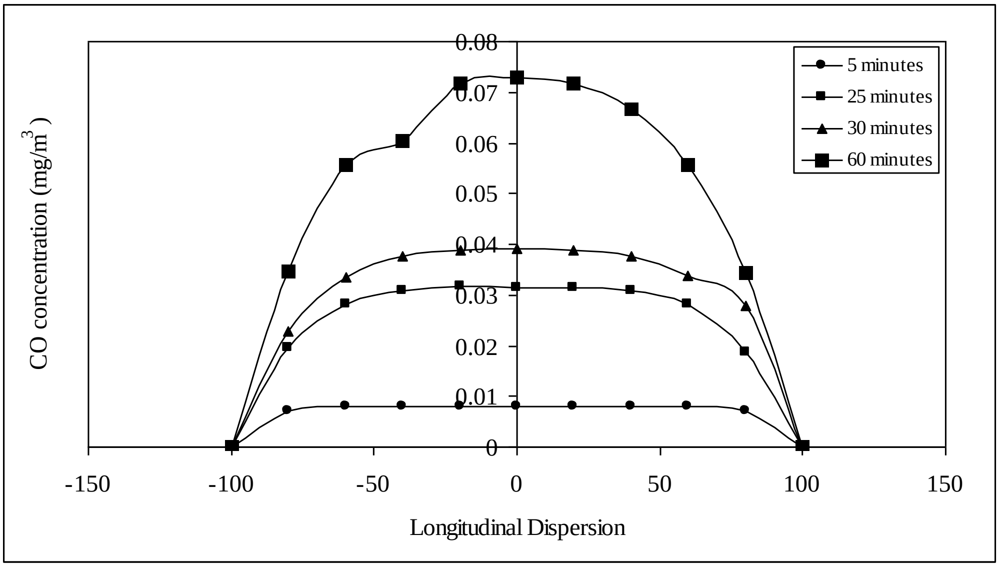

Figure 3: Simulated Concentration distribution of CO longitudinally

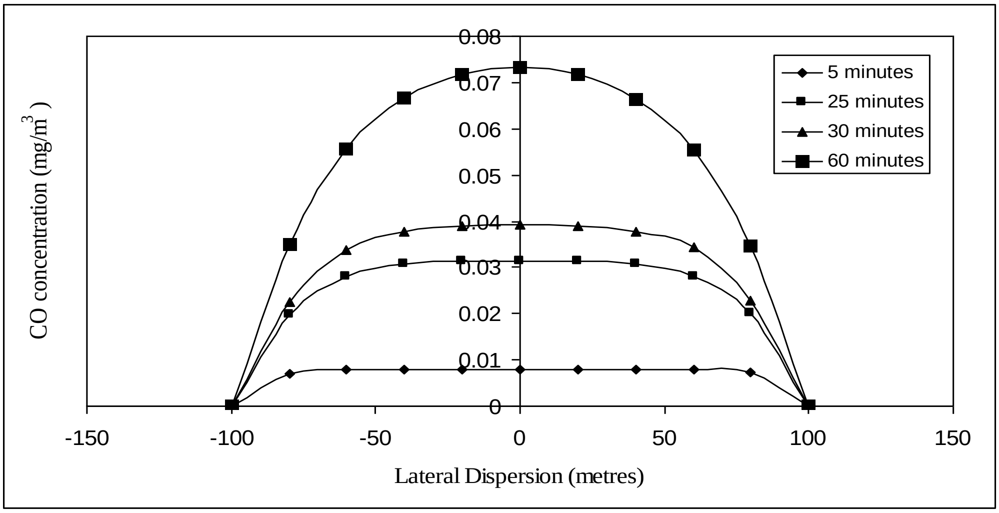

Figure 4: Simulated Concentration distribution of CO laterally

4.2 Carbon Monoxide Concentration Distribution Rate at Varying Distance

The model was also tested for the variation of concentration with time at varying distances. Distances of 20 metres, 40 metres and 60 metres from source were simulated for different wind velocities. The results for wind velocities of 1 m/s, 1.5 m/s and 2 m/s are given in Figures 5–7. A general trend was observed at the three wind velocities simulated, i.e. the pollutant concentration increases as the dispersion time increases. The increase however is dependent on the distance. As the distance increases, the concentration of emitted pollutant also increases. Though there is marked increase in concentration distribution at wind velocities of 1 m/s and 1.5 m/s for the three simulated distances, the reverse is the case at a wind speed of 2 m/s. The concentration distribution at this latter wind speed remained relatively constant at below 0.01mg/m^3 for a distance of 60 metres. This is an indication that pollutant dispersion is enhanced by increased wind velocity and longer distance as the pollutant is diluted by wind and carried away from the point of discharge.

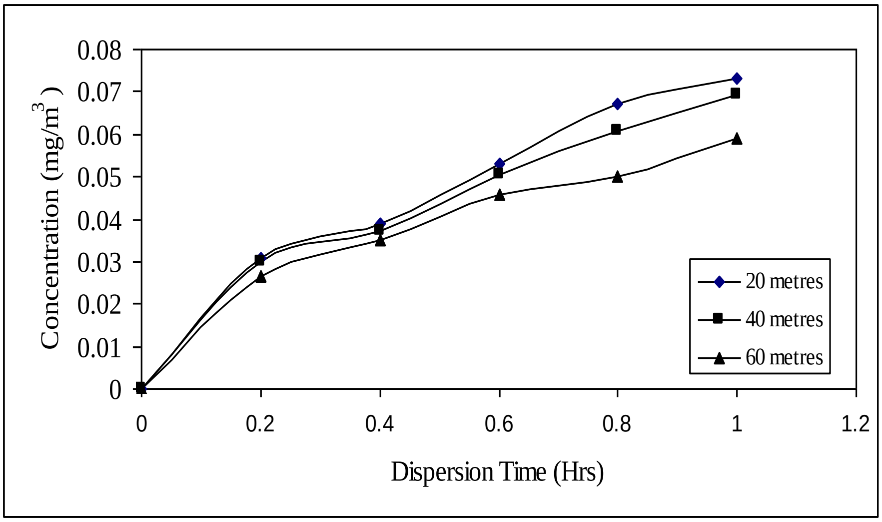

Figure 5: Simulated concentration distributions against dispersion time at a wind Velocity of 1 m/s

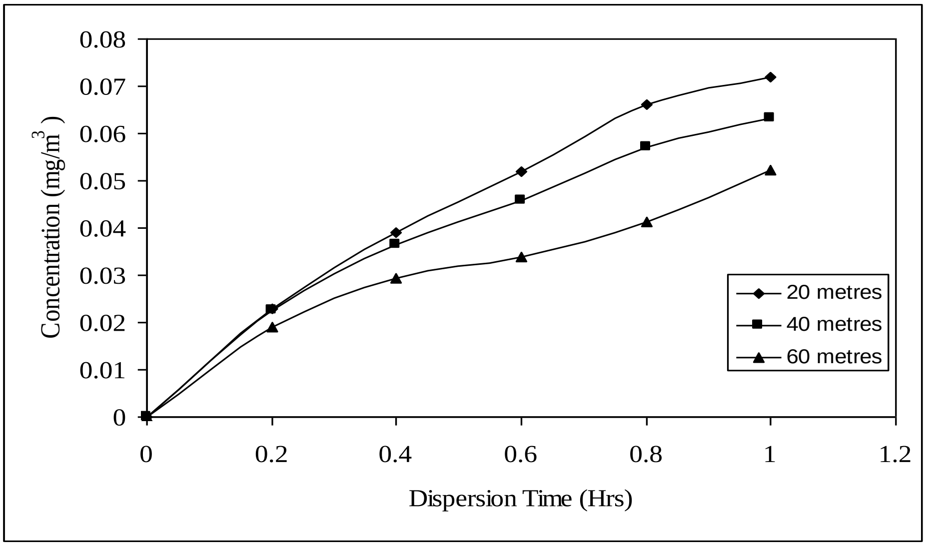

Figure 6: Simulated concentration distributions against dispersion time at a wind Velocity of 1.5 m/s

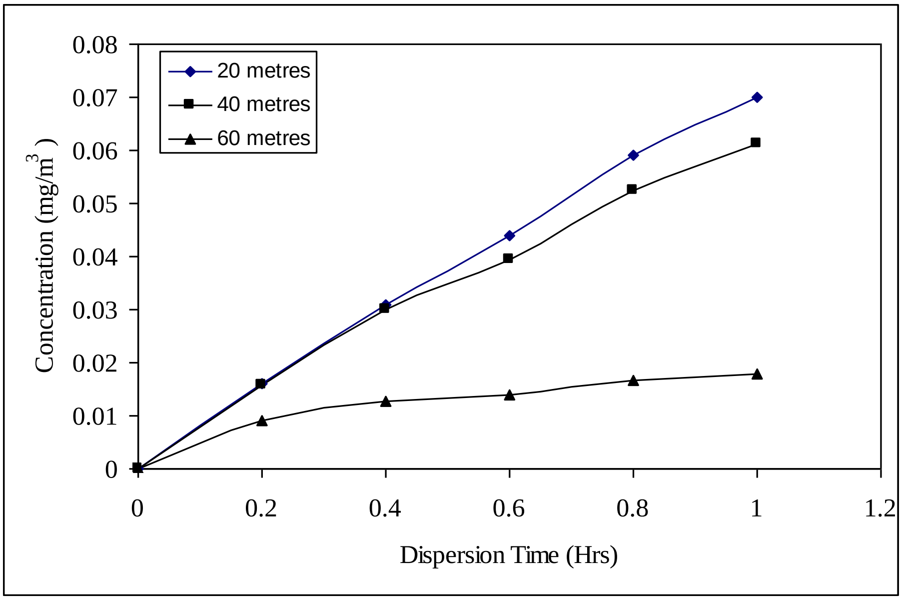

Figure 7: Simulated concentration distributions against dispersion time at a wind Velocity of 2 m/s

4.3 Variation of Carbon Monoxide Concentration with Wind Velocity

The concentration of emitted CO against wind velocity at three different distances (20 metres, 40 metres and 60 metres) away from source at 0.2, 0.4 and 0.6 hours was simulated. The results are presented in Figures 8–10.

It could be observed from Figures 8, 9 and 10 that the CO concentration generally decreases with increase in wind velocity. The decrease in concentration for 0.2 and 0.4 hours of continuous emission was very sharp at points close to the source but becomes sluggish as the distance increases. However, a more drastic reduction in concentration with increase in wind velocity is observed at 0.6 hours for a distance of 60 metres. This is an indication that at very high wind velocity, the dilution rate of pollutants concentration is high and fast, as a result the pollutants cannot travel a long distance before dispersing to ground level.

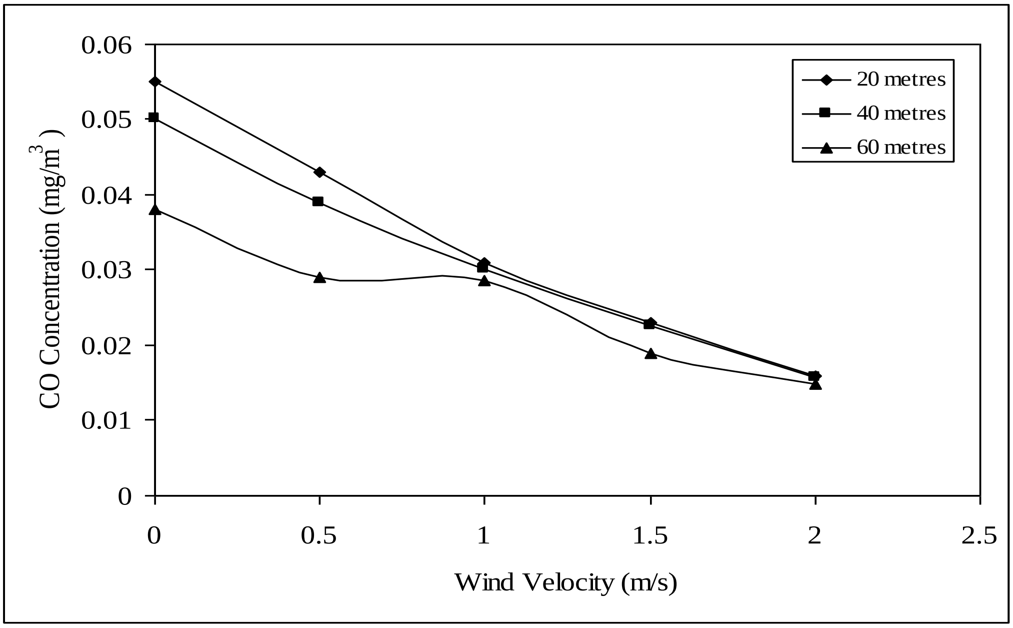

Figure 8: Simulated concentration distributions against wind velocity at 0.2 hours

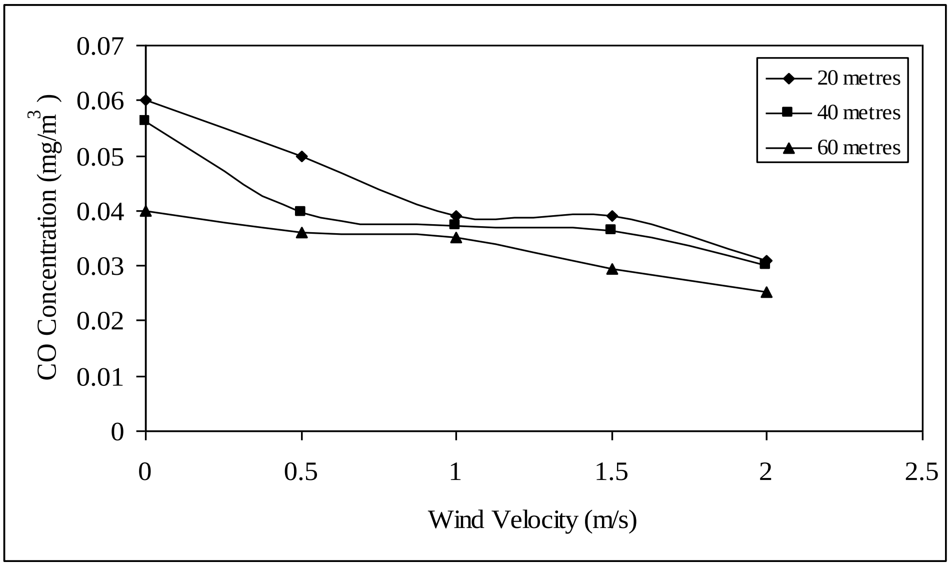

Figure 9: Simulated concentration distributions against wind velocity at 0.4 hours

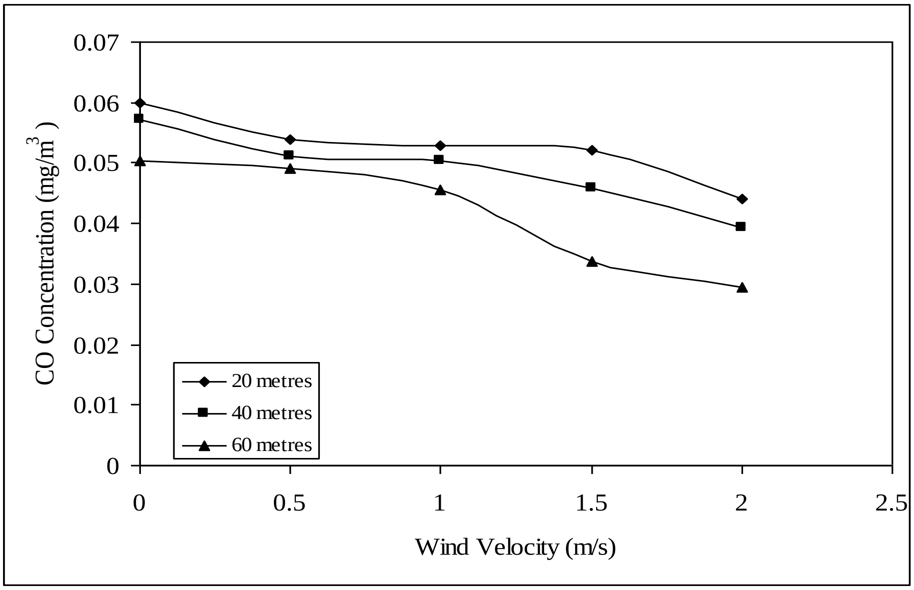

Figure 10: Simulated concentration distributions against wind velocity at 0.6 hours

This result agrees with the works of Gumus and Yelebe, [22]. The non linear nature of the curves of Figures 8–10, shows that the concentration distribution is unsteady. This phenomenon can be explained by the interference of the simulated wind velocity by wind from the lagoon located downstream the study area.

5 Conclusion

From the results of the two-dimensional finite volume mathematical model developed for the prediction of the spread of vehicular emission from idling vehicles in heavy traffic congestion zone, it can be noted that:

1. The concentration levels of emitted pollutant is higher at source point and decreases as the distance from source increases
2. The wind velocity plays a prominent role in pollutant dispersion. Pollutant concentration decreases as the wind velocity increases
3. The concentration of emitted pollutant at the point of discharge increases as the time of emission increases

From the above, it can be concluded that accumulation of vehicular emissions in traffic jams which is a major phenomenon in many congested roads in Lagos and other cities in Nigeria is a pandemic problem that needs to be addressed urgently. Serious attention should therefore be given by the government to the rehabilitation of bad roads that dots every nook and cranny of major cities of Nigeria which is responsible for heavy traffic congestions with its attendant high concentration of emitted lethal air pollutants.

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