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NUMERICAL MODEL OF AIR POLLUTANT EMITTED FROM AN AREA SOURCE OF PRIMARY AND SECONDARY POLLUTANTS WITH CHEMICAL REACTION AND DRY DEPOSITION

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Abstract: A two-dimensional mathematical model of primary and secondary pollutants of an area source with the chemical reaction and the dry deposition is presented. One of the important atmospheric phenomena is the conversion of the air pollutants from the gaseous to the particulate form. The primary pollutants which are emitted directly into the atmosphere are converted into the secondary pollutants by means of chemical reaction. The governing partial differential equations of the primary and the secondary pollutants with the variable wind velocity and the eddy diffusivity are solved by using the Crank-Nicolson implicit finite difference technique. Concentration contours are plotted and the results are analyzed for the primary and the secondary pollutants in the stable and the neutral atmospheric conditions for various meteorological parameters, terrain categories and transformation processes.
Key Words: Chemical reaction; settling velocity; primary and secondary pollutants; variable wind velocity; eddy diffusivity; Crank-Nicolson implicit scheme.

1. INTRODUCTION

Rapid industrialization and urbanization have posed a serious threat to the human life and the environment in the recent years. One of the important atmospheric phenomena is the conversion of the air pollutants from the gaseous to the particulate form. The primary pollutants which are emitted directly into the atmosphere is converted into the secondary pollutants by means of the chemical reaction. The study of the secondary pollutants is important as the life period of the secondary pollutants is longer than that of the primary pollutants and it is more hazardous to the human life and the environment protection. Several studies have reported in which the downwind measurements of the large urban complexes were carried out in order to obtain the material balances on the gaseous and the particulate pollutants [1-4]. Acid precipitation can occur when particles and gases are removed from the atmosphere by (i) rain and snow (wet deposition) (ii)

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by impaction on water, soil and vegetation surfaces (dry deposition) and (iii) gravitational settling velocity. In order to justify the controls on the emissions of acid precursors, the relationship between a source and the deposition pattern that it produces needs to be understood [5-6]. The prediction of the concentration of the pollutants is difficult to accomplish by field monitoring. Mathematical modeling is the only way to estimate the relative contribution of the sources to the total deposition at a particular receptor over a long period of time. There is an interesting Lagrangian finite difference model, which has been developed using the fractional step method by [7] to compute time dependent advection of the air pollutants. Here, the Eulerian grid used for the diffusion part of the pollutant transport equation remains unchanged. A two-dimensional analytical model for the turbulent dispersion of the pollutants in the stable atmospheric layer with a quadratic exchange coefficient and a linear velocity profile is presented by [8]. This model does not take into account any removal mechanism. A numerical model for the dispersion of pollutants with chemical reaction and the dry deposition from the area source, which is steady state in nature is developed by [9]. All these area source models deal with only primary inert air pollutants. A time dependent area source mathematical model of the chemically reactive air pollutants and their byproduct in a protected zone above the surface layer with rainout/ washout and settling is presented by [10]. But the horizontal homogeneity of the pollutants and the constant eddy diffusivity are assumed in this model. A two-dimensional time dependent air pollution model for both the primary pollutant and the secondary pollutant with instantaneous (dry deposition) and delayed (chemical conversion, rainout/washout and settling) removals is presented by [11]. However his model being analytical, deals with the uniform velocity and the eddy diffusivity profiles. In our numerical model we consider transformation of the primary pollutants to the secondary pollutants through the chemical reaction in an urban area.

2. MODEL DEVELOPMENT

The physical problem consists of an area source, which is spread over the surface of the city with a finite downwind distance and infinite cross wind dimensions. We assume that the pollutants are emitted at a constant rate from the area source and spread within the mixing layer adjacent to the earth's surface where mixing takes place as a result of the turbulence and the convective motion. This mixing layer extends upwards from the surface to a height where all the turbulent flux-divergences resulting from the surface action have virtually fallen to zero. We have considered

the source region within the urban centre which extends from the origin to a distance l in the downwind x direction ($0 \leq x \leq l$) and the source free region ($l < x \leq X_0$) beyond l, where X_0 is the desired distance for computing the concentration distribution. Assuming the homogeneity of urban terrain the mean concentration of the pollutant is considered to be constant along the crosswind direction and concentration of the pollutant does not vary in cross wind direction. Therefore, no y-dependence and also the lateral flux of pollutants is small and traversing the centre line of the uniform area source. The physical description of the model is shown schematically in Fig.1.

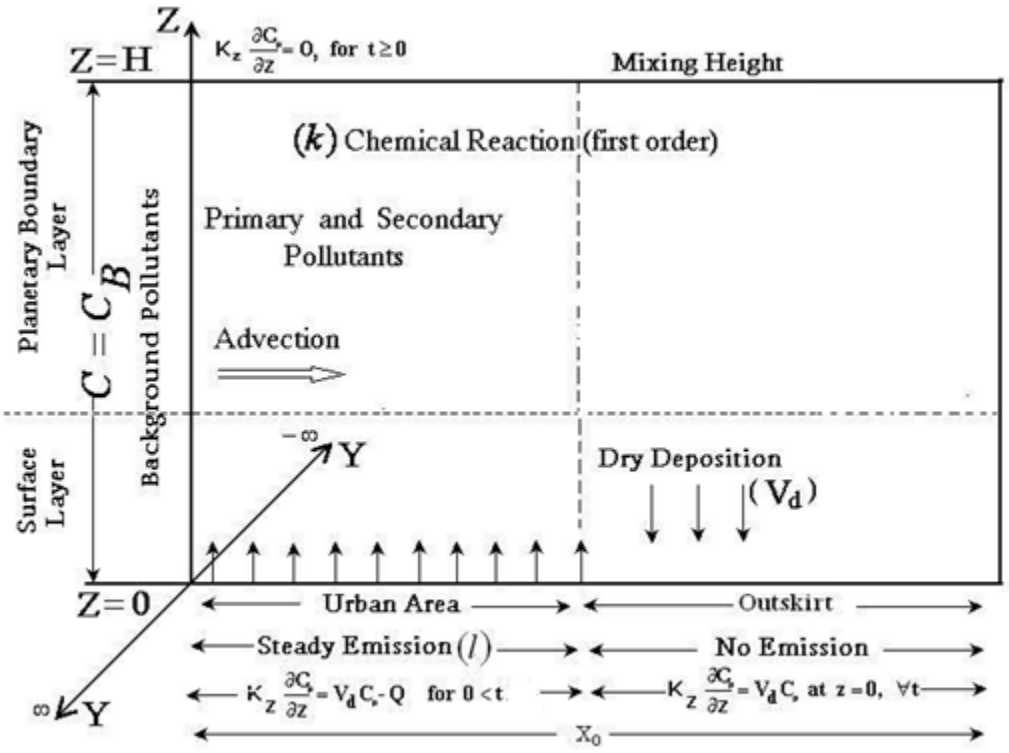

Fig 1. Physical layout of the model

We intend to compute the concentration distribution both in the source region and the source free region till the desired distance $X_0 = 12000$m in the downwind. We have taken the primary source strength $Q = 1\mu gm^{-2}s^{-1}$ at ground level from an area source and the mixing height is selected as 624 meters. We assume that the pollutants undergo the removal mechanisms such as the dry deposition and the gravitational settling velocity. The primary pollutant is considered to be chemically reactive to form the secondary pollutants by means of first order chemical conversion.

The governing equation of primary pollutant can be written as

$$\frac{\partial C_p}{\partial t} + U(z)\frac{\partial C_p}{\partial x} = \frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_p}{\partial z}\right) - kC_p \tag{1}$$

where $C_p = C_p(x, z, t)$ is the ambient mean concentration of pollutant species, U is the mean wind speed in *x*-direction, K_z is the turbulent eddy diffusivity in z-direction and k is the first order chemical reaction rate coefficient of primary pollutant C_p. Equation (1) is derived under the following assumptions:

- The lateral flux of pollutants along crosswind direction is assumed to be small i.e., $V\frac{\partial C_p}{\partial y}$ and $\frac{\partial}{\partial y}\left(K_y\frac{\partial C_p}{\partial y}\right) \to 0$ where V is the velocity in the y - direction and K_y is the eddy-diffusivity coefficient in the y direction.
- Horizontal advection is greater than horizontal diffusion for not too small values of wind velocity, i.e., meteorological conditions are far from stagnation. The horizontal advection by the wind dominates over horizontal diffusion, i.e., $U\frac{\partial C_p}{\partial x} \gg \frac{\partial}{\partial x}\left(K_x\frac{\partial C_p}{\partial x}\right)$, where U and K_x are the horizontal wind velocity and horizontal eddy diffusivity along *x* direction respectively.
- Vertical diffusion is greater than vertical advection since the vertical advection is usually negligible compared to diffusion owing to the small vertical component of the wind velocity.

Thus, the initial and boundary conditions are

$$C_p = 0 \quad at \quad t = 0,\ 0 \le x \le X_0 \quad and \quad 0 \le z \le H$$

$$C_p = 0 \quad at \quad x = 0,\ 0 \le z \le H \quad and \quad \forall\ t > 0$$

$$K_z\frac{\partial C_p}{\partial z} = \begin{cases} V_{dp}C_p - Q & at \quad z = 0,\ 0 < x \le l \\ V_{dp}C_p & at \quad z = 0,\ l < x \le X_0 \end{cases} \quad \forall\ t > 0 \qquad K_z\frac{\partial C_p}{\partial z} =$$

$$0 \quad at \quad z = H,\ x > 0,\ \forall t$$

where H is the mixing height, V_{dp} is the dry deposition velocity of the primary pollutant C_p.

The governing equation for the secondary pollutant C_s is

$$\frac{\partial C_s}{\partial t} + U(z)\frac{\partial C_s}{\partial x} = \frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_s}{\partial z}\right) + V_g kC_p \tag{2}$$

where, V_g is the mass ratio of the secondary particulate species to the primary gaseous species which is being converted. In deriving equation (2) we have made similar assumptions as in the case of primary pollutant.

The appropriate initial and boundary conditions on C_S are:

$$C_s = 0 \quad at \quad t = 0, \; for \quad 0 \le x \le X_0 \quad and \; 0 \le z \le H$$

$$C_s = 0 \quad at \quad x = 0, for \quad 0 \le z \le H \quad and \quad \forall\, t > 0$$

$$K_z \frac{\partial C_s}{\partial z} + W_{gs} C_s = V_{ds} C_s \quad at \quad z = 0, \; 0 \le x \le X_0 \; and \; \forall\, t > 0$$

$$K_z \frac{\partial C_s}{\partial z} = 0 \quad at \; z = H \quad and \; \forall\, t > 0$$

where V_{ds} is the dry deposition velocity and W_{gs} is the gravitational settling velocity of the secondary pollutant C_s.

The common characteristic of K_z is that it has a linear variation near the ground, a constant value at mid mixing depth and a decreasing trend as the top of the mixing layer is approached. Based on theoretical analysis of neutral boundary layer [12],

$$K_z = 0.4 u_* z e^{-4z/H} \tag{3}$$

For stable condition, the eddy-diffusivity is of the form [13],

$$K_z = \frac{\kappa u_* z}{0.74 + 4.7 z/L} exp(-b\eta)\,, \tag{4}$$

$b = 0.91, \; \eta = z/(L\sqrt{\mu})\,, \quad \mu = u_*/|fL|$

The above form of K_z was derived from a higher order turbulence closure model which was tested with the stable boundary layer data of Kansas and Minnesota experiments.

Eddy-diffusivity profiles given by equations (3) and (4) have been used in this model developed for neutral and stable atmospheric conditions.

In order to incorporate more realistic form of the velocity profile in our model which depends on Coriolis force, surface friction, geosrtophic wind, stability characterizing parameter L and vertical height z, we integrate equation $\frac{\partial U}{\partial z} = \frac{u_* \phi_M}{\kappa z}$ from z_0 to $z + z_0$ for the neutral and the stable conditions. So we obtain the following expressions for wind velocity:

In case of neutral stability with $< 0.1\kappa \frac{u_*}{f}$, we get

$$U = \frac{u_*}{\kappa} \ln\left(\frac{z+z_0}{z_0}\right) \tag{5}$$

In case of stable flow with $0 < z/L < 1$, we get

$$U = \frac{u_*}{\kappa}\left[\ln\left(\frac{z+z_0}{z_0}\right) + \frac{\alpha}{L} z\right] \tag{6}$$

In case of stable flow with $1 < z/L < 6$, we get

$$U = \frac{u_*}{\kappa}\left[\ln\left(\frac{z+z_0}{z_0}\right) + 5.2\right] \tag{7}$$

In the planetary boundary layer, above the surface layer, power law scheme has been employed.

$$U = \left(u_g - u_{sl}\right)\left(\frac{z-z_{sl}}{H-z_{sl}}\right)^p + u_{sl} \tag{8}$$

where, u_g is the geostrophic wind, u_{sl} the wind at $z_{sl,}$ z_{sl} the top of the surface layer, H the mixing height and p is an exponent which depends upon the atmospheric stability. Jones *et al*. [14] suggested the values for the exponent p, obtained from the measurements made from urban wind profiles, as follows:

$$p = \begin{cases} 0.20 & for\ neutral\ condition \\ 0.35 & for\ slightly\ stable\ flow \\ 0.50 & for\ stable\ flow \end{cases}$$

Wind velocity profiles given by equations (5) - (8) due to [15] are used in this model.

3. NUMERICAL SOLUTION

It is to be noted that it is difficult to obtain the analytical solution for equations (1) and (2) because of the complicated form of the wind speed and the eddy diffusivity profiles considered in this model. Hence, we have used numerical method based on the Crank-Nicolson finite difference scheme to obtain the solution. The dependent variable C_p is a function of the independent variables x, z and t, i.e., $C_p = C_p(x, z, t)$. First, the continuum region of interest is overlaid with or subdivided into a set of equal rectangles of sides Δx and Δz, by equally spaced grid lines, parallel to z axis, defined by $x_i = (i-1)\Delta x$, $i = 1,2,3, \ldots$ and equally spaced grid lines parallel to x axis, defined by $z_j = (j-1)\Delta z$, $j = 1,2,3, \ldots$ respectively. Time is indexed such that $t_n = n\Delta t$, $n = 0, 1, 2, 3 \ldots$, where Δt is the time step. At the intersection of grid lines, i.e. grid points, the finite difference solution of the variable C_p is defined. The dependent variable $C_p(x, z, t)$ is denoted by, $C_{pij}^n = C_p\,(x_i, z_j, t_n)$, where (x_i, z_j) and t_n indicates the (x, z) value at a node point (i, j) and t value at time level n respectively.

We employ the implicit Crank-Nicolson scheme to discretize the equation (1). The derivatives are replaced by the arithmetic average of its finite difference approximations at the n^{th} and $(n+1)^{th}$ time steps. Then equation (1) at the grid points (i, j) and time step $n + 1/2$ can be written as

$$\left.\frac{\partial C_p}{\partial t}\right|_{ij}^{n+\frac{1}{2}} + \frac{1}{2}\left[U(z)\left.\frac{\partial C_p}{\partial x}\right|_{ij}^{n} + U(z)\left.\frac{\partial C_p}{\partial x}\right|_{ij}^{n+1}\right]$$

$$= \frac{1}{2}\left[\frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_p}{\partial z}\right)\Big|_{ij}^{n} + \frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_p}{\partial z}\right)\Big|_{ij}^{n+1}\right] - \frac{1}{2}k\left(C_{pij}^{n} + C_{pij}^{n+1}\right),$$

$for\ i = 1,2, \ldots \quad j = 1,2, \ldots$ (9)

We use the backward differences for advective term in the primary pollutant equation.

i.e $\left.\frac{\partial C_p}{\partial t}\right|_{ij}^{n+\frac{1}{2}} = \frac{C_{pij}^{n+1} - C_{pij}^{n}}{\Delta t}$

$$U(z)\left.\frac{\partial C_p}{\partial x}\right|_{ij}^{n} = U_j\left[\frac{C_{pij}^{n} - C_{pi-1j}^{n}}{\Delta x}\right]$$

and $U(z)\left.\frac{\partial C_p}{\partial x}\right|_{ij}^{n+1} = U_j\left[\frac{C_{pij}^{n+1} - C_{pi-1j}^{n+1}}{\Delta x}\right]$

Also, for the diffusion term, we use the second order central difference scheme

$$\frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_p}{\partial z}\right)\Big|_{ij}^{n} = \frac{K_z(z)\left.\frac{\partial C_p}{\partial z}\right|_{ij+1/2}^{n} - K_z(z)\left.\frac{\partial C_p}{\partial z}\right|_{ij-1/2}^{n}}{\Delta z}$$

$$= \frac{1}{\Delta z}\left(\frac{K_{j+1}+K_j}{2}\right)\left(\frac{C_{pij+1}^{n} - C_{pij}^{n}}{\Delta z}\right) - \frac{1}{\Delta z}\left(\frac{K_j+K_{j-1}}{2}\right)\left(\frac{C_{pij}^{n} - C_{pij-1}^{n}}{\Delta z}\right)$$

Hence,

$$\frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_p}{\partial z}\right)\Big|_{ij}^{n} = \frac{1}{2(\Delta z)^2}\left[\left(K_{j+1}+K_j\right)\left(C_{pij+1}^{n} - C_{pij}^{n}\right) - \left(K_j + K_{j-1}\right)\left(C_{pij}^{n} - C_{pij-1}^{n}\right)\right]$$

Similarly,

$$\frac{\partial}{\partial z}\left(K_z(z)\frac{\partial C_p}{\partial z}\right)\Big|_{ij}^{n+1} = \frac{1}{2(\Delta z)^2}\left[\left(K_{j+1}+K_j\right)\left(C_{pij+1}^{n+1} - C_{pij}^{n+1}\right) - \left(K_j + K_{j-1}\right)\left(C_{pij}^{n+1} - C_{pij-1}^{n+1}\right)\right]$$

Substituting above equations in equation (9) and rearranging the terms we get the finite difference equations for the primary pollutant C_p in the form

$$A_j C_{pi-1j}^{n+1} + B_j C_{pij-1}^{n+1} + D_j C_{pij}^{n+1} + E_j C_{pij+1}^{n+1} = F_j C_{pi-1j}^{n} + G_j C_{pij-1}^{n} + M_j C_{pij}^{n} + N_j C_{pij+1}^{n}$$

for each $i = 2,3,4, \ldots imaxl \ldots imaxX_0$, for each $j = 2,3,4, \ldots jmax - 1\ and\ n = 0,1,2, \ldots$

The discritized form of the initial and the boundary conditions on primary pollutant are:

$C_{pij}^{0} = 0\ \ for\ j = 1,2, \ldots j_{max},\ \ i = 1,2, \ldots imaxl \ldots imaxX_0$

$C_{pij}^{n+1} = 0\ \ for\ \ i = 1\ and\ j = 1,2, \ldots jmax\ ,\ \ n = 0,1,2, \ldots$

$\left(1 - V_d\frac{\Delta z}{K_j}\right)C_{pij}^{n+1} - C_{pij+1}^{n+1} = -\frac{Q\Delta z}{K_j}$ for $\ j = 1,\ \ i = 2,3,4, \ldots . imaxl$ and $\ n = 0,1,2,3 \ldots$

$\left(1 - V_d \frac{\Delta z}{K_j}\right) C_{pij}^{n+1} - C_{pij+1}^{n+1} = 0$ for $j = 1, i = imaxl + 1, \ldots imaxX_0$ *and* $n = 0,1,2,3\ldots$

$C_{pijmax-1}^{n+1} - C_{pijmax}^{n+1} = 0 \qquad for\ j = jmax,\ i = 2,3,4, \ldots imaxl \ldots imaxX_0.$

Similarly the finite difference equations for the secondary pollutant C_s can be written as

$A_j C_{si-1j}^{n+1} + B_j C_{sij-1}^{n+1} + D_j C_{sij}^{n+1} + E_j C_{sij+1}^{n+1} = F_j C_{si-1j}^{n} + G_j C_{sij-1}^{n} + M_j C_{sij}^{n} + N_j C_{sij+1}^{n} +$

$\frac{\Delta t}{2} v_g k C_p^n \qquad$ for $i = 2,3,4 \ldots imaxl, \ldots imaxX_0, \quad j = 2,3,4, \ldots jmax - 1$

The discritized form of initial and boundary conditions secondary pollutant are:

$C_{sij}^0 = 0\ \ for\ j = 1,2, \ldots jmax,\ \ i = 1,2, \ldots imaxl \ldots imaxX_0$

$C_{sij}^{n+1} = 0\ \ for\ \ i = 1,\ j = 1,2, \ldots\ jmax,\ \ n = 0,1,2, \ldots$

$\left(1 + \left(V_d + W_{gs}\right)\frac{\Delta z}{K_j}\right) C_{sij}^{n+1} - C_{sij+1}^{n+1} = 0$ for $\quad j = 1,\ i = 2,3, \ldots imaxl \ldots imaxX_0$

$C_{sij-1}^{n+1} - C_{sij}^{n+1} = 0 \qquad for\ \ j = jmax,\ \ i = 2,3,4, \ldots imaxl, \ldots imaxX_0$

Both the system of equations is solved using Thomas algorithm for tri-diagonal equations. Thus, ambient concentration of primary and secondary pollutant is obtained for various atmospheric conditions.

4. RESULTS AND DISCUSSION

The results of this numerical model have been illustrated graphically from Figures 2 to 9 to analyze the dispersion of the air pollutants in the urban area with the downwind and the vertical direction for the stable and the neutral conditions of the atmosphere.

In Figure 2, the effect of the dry deposition on the primary and the secondary pollutants with respect to the distance for the stable case is analyzed. As the deposition velocity increases the concentration of the primary pollutant and the secondary pollutant decreases. If $V_d = 0$, the ground level concentration of the primary pollutant increases up to 240 and as V_d increases the ground level concentration decreases very rapidly with the downwind distance. The ground level concentration of the secondary pollutant is high if $V_d = 0$ and as V_d increases the ground level concentration decreases with the downwind distance for the gravitational settling velocity $W_s = 0$

In Figure 3, the effect of the dry deposition on the primary and the secondary pollutants with respect to the distance for the neutral case is analyzed. As the deposition velocity increases the

concentration of the primary and the secondary pollutants decreases. If $V_d = 0$ the ground level concentration of the primary pollutant increases up to 65 and as V_d increases the ground level concentration decreases very rapidly with the downwind distance. Same effect is observed for the secondary pollutant with respect to the downwind distance. The concentration of the primary and the secondary pollutants attains the maximum value and it steadily decreases as the removal mechanism V_d increases. From the Figures 2 and 3 it is found that the magnitude of the concentration of the primary and the secondary pollutants in the stable case is higher than the neutral case in the downwind distance.

In Figure 4, the effect of dry deposition on the primary and the secondary pollutants at distance $6000m$ with respect to the height for the stable case is analyzed. As the deposition velocity increases the concentration of the primary and the secondary pollutants decreases very rapidly with respect to the height. The concentration of the primary and the secondary pollutants is zero at $Z = 55m$. The concentration of the primary and the secondary pollutants is high near the ground level.

In Figure 5, the concentration of the primary and the secondary pollutants for different values of the dry deposition with respect to height for the neutral case is analyzed. Similar effect is observed in the neutral case as in the case of the stable atmosphere but the concentration of the primary and the secondary pollutants is zero around the height of $300m$. This indicates that the neutral atmospheric case enhances the vertical diffusion of the primary and the secondary pollutants.

In Figure 6, the ground level concentration of the secondary pollutant for different values of the gravitational settling with the downwind distance and the height for the stable case is studied. The concentration of the secondary pollutant decreases as the gravitational settling velocity increases with respect the distance and the height. If $W_s = 0$, the concentration of the secondary pollutant is high in the downwind distance and as W_s increases the ground level concentration of the secondary pollutant decreases. The concentration of the secondary pollutant is zero around the height $Z = 50m$. This shows that the concentration of the secondary pollutant is spread over the surface layer of the earth.

In Figure 7, the ground level concentration of the secondary pollutant for different values of the gravitational settling with the downwind distance and the height for the neutral case is analyzed.

Similar effect is observed when compared to the stable case but the magnitude of the secondary pollutant is less in the neutral case. The neutral case enhances the vertical diffusion because the concentration of the secondary pollutant is carried over up to $350m$ height as compared to the stable case.

In Figure 8, the concentration of the primary pollutant versus the distance with respect to the chemical reaction for the stable case is analyzed. By means of chemical reaction the primary pollutant is converted into the secondary pollutant. Therefore we find that as the rate of the chemical reaction increases the concentration of the primary pollutant decreases for $V_d = 0$ as well as $V_d = 0.008$. But the concentration of the primary pollutant is high for $V_d = 0$ when compared to $V_d = 0.008$ near the ground level surface.

Figure 9 gives the combined effect of the chemical reaction rate coefficient and the deposition velocity of the primary pollutant in neutral atmospheric condition. The similar effect is observed in the neutral case but the concentration of the primary pollutant is less near the ground level when compared to stable case as in Figure 8.

5. CONCLUSION

A numerical model is developed to study the effect of removal mechanisms namely dry deposition and gravitational settling on the concentration distribution of primary and secondary pollutants over an urban area. From the graphs we conclude that the ground level concentration increases in the downwind distance within the source region and then decreases rapidly in the source free region to an asymptotic value. We notice that the effect of deposition velocity, gravitational settling and chemical reaction rate coefficients on primary and secondary pollutants will reduce the concentration in the urban region. In the case of stable atmospheric condition the concentration of primary pollutants is high at the surface region and the secondary pollutant concentration is high near the lower atmosphere. But in the case of neutral atmospheric condition the pollutant concentration reaches more heights reducing the concentration near the ground level surface when compared to the stable case. This indicates that neutral case enhances vertical diffusion of primary and secondary pollutants.

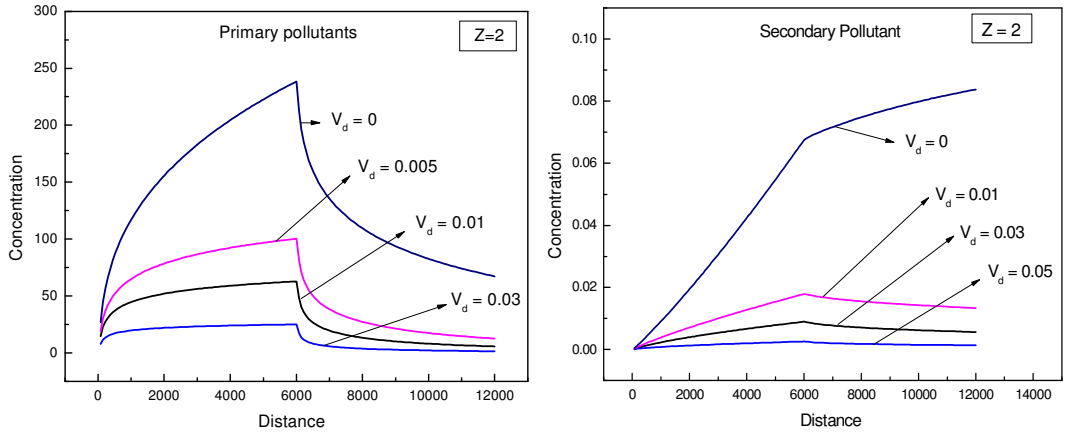

Fig. 2. Variation of ground level concentration with respect to distance of the primary and the secondary pollutant with different values of dry deposition velocity for the stable case.

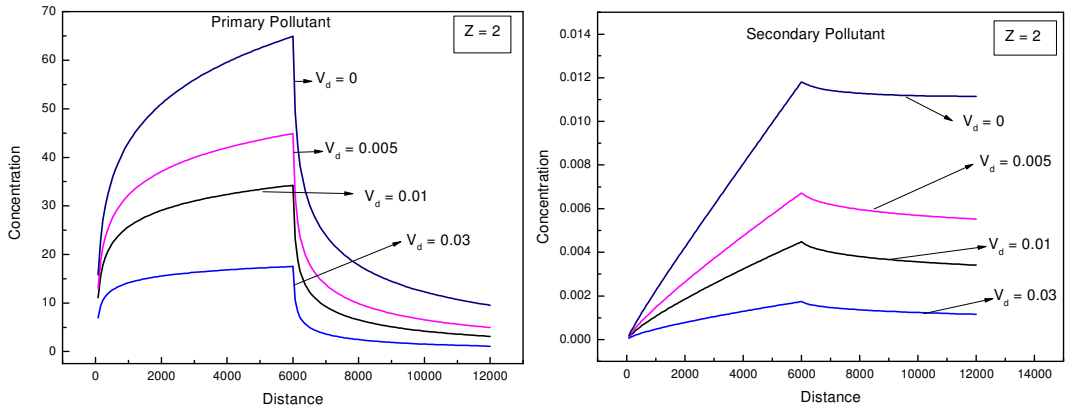

Fig. 3. Variation of ground level concentration with respect to distance of the primary and the secondary pollutant with different values of dry deposition velocity for the neutral case.

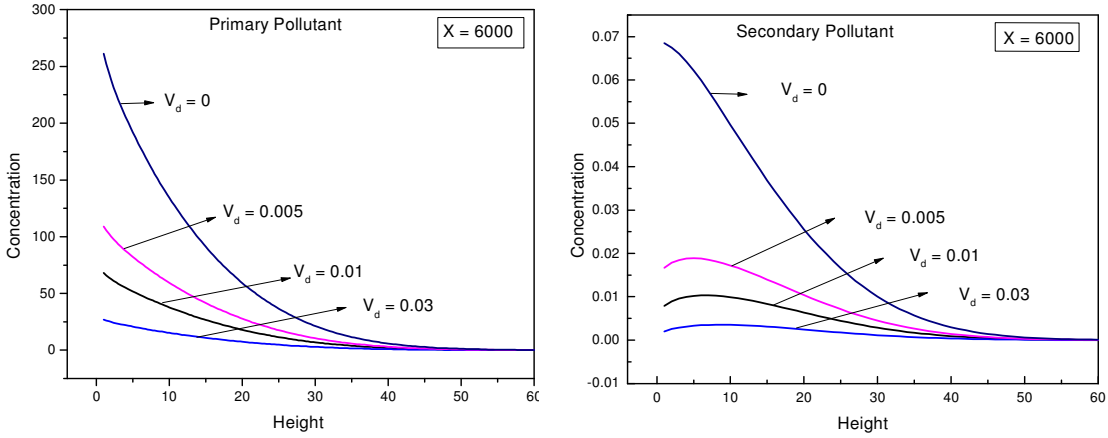

Fig. 4. Variation of ground level concentration with respect to height of the primary and the secondary pollutant with different values of dry deposition velocity for the stable case**.**

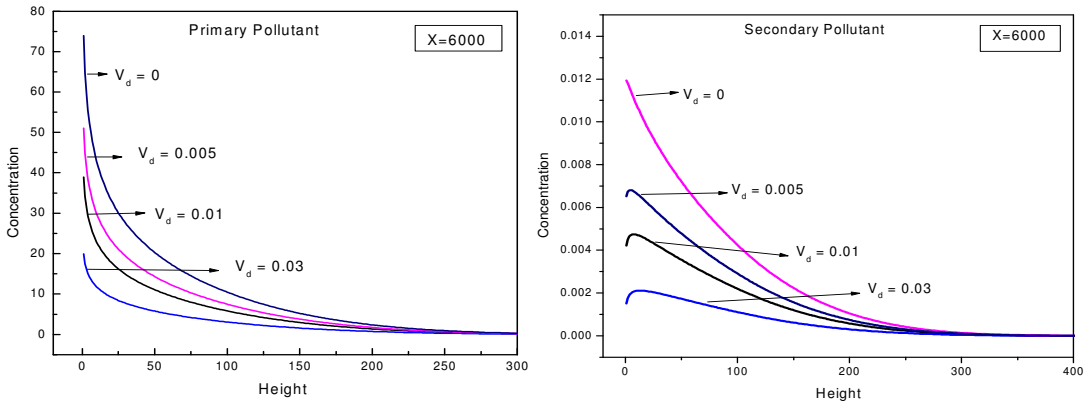

Fig. 5. Variation of ground level concentration with respect to height of the primary and the secondary pollutant with different values of dry deposition velocity for the neutral case

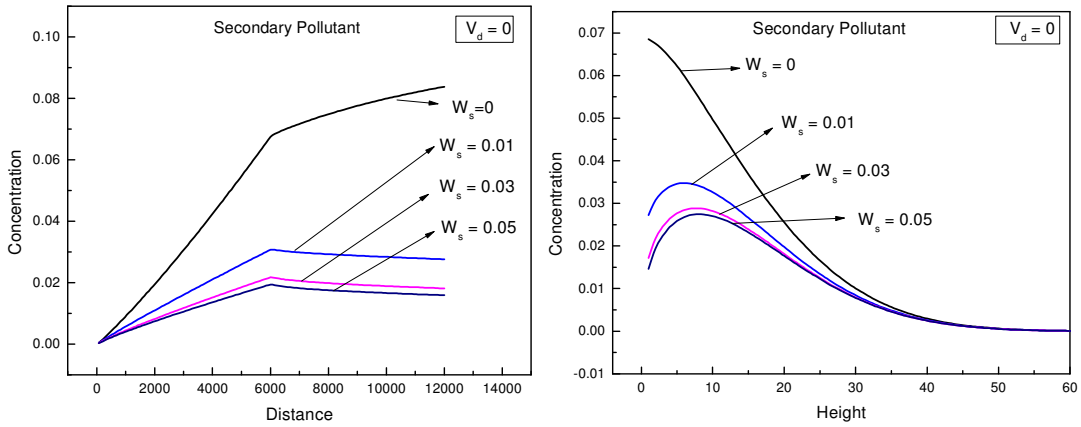

Fig. 6. Variation of ground level concentration with respect to distance and height of the secondary pollutant with different values of the settling velocity for the stable case**.**

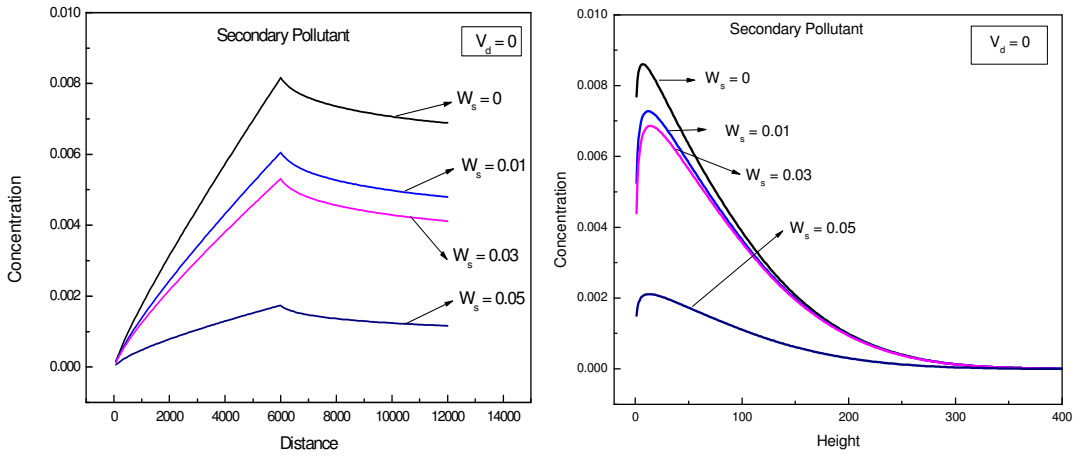

Fig. 7. Variation of ground level concentration with respect to distance and height of the secondary pollutant with different values of the settling velocity for the neutral case.

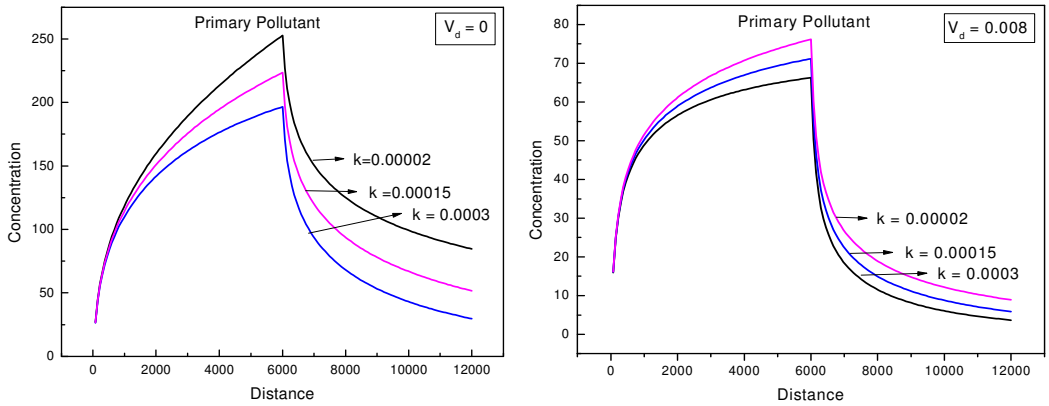

Fig. 8. Variation of ground level concentration with respect to distance of the primary pollutant with various *v*alues of the chemical reaction coefficients for the stable case.

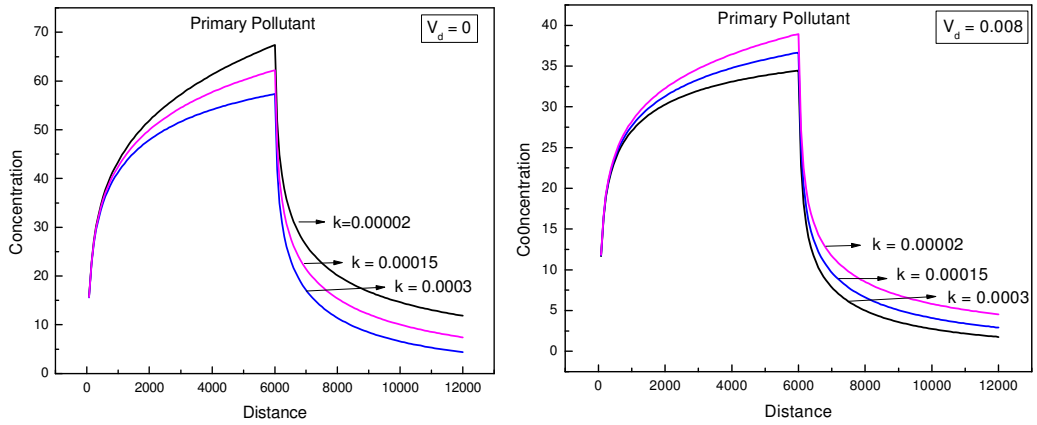

Fig 9. Variation of ground level concentration with respect to distance of the primary pollutant with various *v*alues of the chemical reaction coefficients for the neutral case.

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