Tuijin Jishu /Journal of Propulsion Technology
ISSN:1001-4055
Vol. 44 No. 04 (2023)

Three-Dimensional Analytical Mathematical Diffusion Model of Air Pollutant in a Mixing Layer With Chemical Reaction and Wet Deposition of Larger Particles of Pollutants Due to a Point Source

K. Lakshminarayanachari[1,2] , K. Ravindranath[1,3] , C. Bhaskar[2]

[1] *Research and Development Centre, Bharathiar University, Coimbatore 641046, India*

[2] *Department of Mathematics, Sai Vidya Institute of Technology, Rajanukunte, Bengaluru 560064, India*

[3] *Department of Mathematics, M.S.Ramaiah College of Arts,Science and Commerce, Bengaluru 560054, India*

Abstract: A three dimensional analytical mathematical diffusion model of air pollutant in a mixing layer $z_r \leq z \leq H_l$ with chemical reaction and wet deposition of larger particles of pollutants due to a point source at $z = z_s$ is furnished to investigate the primary pollutant concentration in a protected sector and it is above the earth surface layer of the earth's atmosphere. The pollutants are assumed to be emitted only from a ceaseless source in surface layer. The physical phenomenon of the above problem is reduced to advection diffusion partial differential equation and is solved by using the method of Fourier's technique. The effect of rate of chemical reaction of pollutants and rate of wet deposition of pollutants on the concentration of dispersed pollutants is investigatedfor both stable and neutral atmospheric situations. Concentration contours are plotted and the results are analysed for air pollutants in stable and neutral atmospheric situations. In the upper part of the mixing layer pollutants concentration is less in stable atmospheric condition for smaller roughness length and moderate geostrophic wind speed.

Key words: *analytical method; mathematical model; point source; chemical reaction of pollutants; wet deposition of pollutants.*

1. Introduction

In our day-to-day life, air pollution keeps on increasing in the atmosphere which is because of our lifestyle. To study the influence of air pollution on human being and living things, one of the efficient tools is mathematical air pollution model. Now a days the study of concentration of air pollution modelling creates curiosity in prognosticating of the dispersion of air pollution which is released from point source. Industries, domestic needs and transportation are the major source to produce air pollution. The dispersion of pollutants caused due to diffusion and advection in the air near the earth's surface. We have presented a three-dimensional analytical mathematical model to study the impact of different removal mechanisms on concentration distribution discharged from a point source. Most of the models presented are one dimensional and time dependent in nature. These results are valid in the case of area sources, and they are very confining to gauge the impact of point source on environment. Thus, one has to consider three dimensional models in the case of point source. There are different removal mechanisms to reduce air pollution particles which are settling of particles due to gravitational force, leakage of pollutants, wet deposition and so on. Many K-theory models constructed by Pal and Khan (1990b),Lakshminarayanachari and SudheerPai (2012), Lakshminarayanachari. K and Suresha(2014), Lakshminarayanachari.K and Bhaskar.C(2021), R.Latha,K.Lakshminarayanachari **and** C.Bhaskar(2023)are studied extensively the scattering of air pollutants which are liberated from area source and point source numerically.

There are quite a large number of three-dimensional analytical models (Ku et al 1987 and Lee 1980 Rao 1981) are framed to compute the contiguous distribution of pollutant's concentration due to the emissive source taking into consideration of different removal mechanisms. All these analytical models consist of constant eddy-diffusivity and velocity profiles. These mathematical models consider only dry deposition phenomenon. The gravitational settling and absorption of pollutants cannot be ignored and this atmospheric transport problem is discussed by Calder (1961). Using the same type of formulation as proposed by Calder,

atmospheric transport equation solutions are obtained for many cases(Smith 1962, Heines and Peters 1974).

These solutions have not been used significantly, presumably due to their complicated nature or the difficulty in applying them under different atmospheric stability conditions. Another removal mechanism know as chemical reaction is of prime importance for the case of reactive pollutant emitted from a point source. Alam and Seinfeld (1981) developed a three-dimensional model considering this aspect. But the model does not take care of settling of larger particles. In this model we discussed both the removal mechanisms wet deposition and chemical reaction. Moreover, in all the models discussed, the height of mixing layer has been taken as arbitrary constant. With the conformity of real situation we take the height of mixing layer as function of Monin-obukhov stability length L and friction velocity u_* .

We considered the entire atmospheric boundary layer as the region of interest. The model is steady state three-dimensional. For the sake of simplicity we consider constant diffusivity throughout the boundary layer. To take into account the leakage of pollutant through the super jacent layer, we employ a leakage velocity boundary condition at the top of the boundary layer or mixing layer. We have considered only primary pollutant in this model. This model can be considered as the generalization of the model of Alam and Seinfeld (1981) for the case of primary pollutant when settling phenomenon cannot be neglected. In addition to that, our model incorporates the variational form of mixing layer height with stability and several meteorological parameters.

2. The Model Formulation

The substantial problem comprises of an elevated continuous point source of atmospheric pollutant discharging into a horizontally semi-infinite and vertically elevated layer. We considered constant wind along x-axis, horizontal cross wind in the direction of y-axis and vertical cross wind along z-axis. The point source is situated at the point$(0,0,z_s)$.

The pollutant emitted from the source is bounded below by the earth's ground surface. To study thedifferent removal mechanisms on pollutant's concentration in the atmospheric boundary layer above the ground surface. we have made the following assumptions:

[i] The first order chemical reaction rate transforms the chemically reactive pollutant into a secondary pollutant.

[ii]Turbulent eddies carry the air contaminants downstream and disperse them laterally and vertically.

[iii] Under certain atmospheric condition a part of atmospheric pollutants appear in particleform on which the gravitational acceleration effect cannot be neglected. So, pollutants are end up on the ground by means of gravitational settling.

[iv] Carry away of pollutants may occur by dry deposition onto the surface of the earth as a result of ground absorption by soil, vegetation etc.

[v] The pollutants are assumed to be driven by a constant horizontal wind speed.

[vi] There may be removal of pollutants due to wet deposition.

The equation for pollutants concentration of this model is described by the turbulent advection-diffusion equation

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = K_x\frac{\partial^2 C}{\partial x^2} + \frac{\partial}{\partial Y}\left(K_Y\frac{\partial C}{\partial Y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right) + W_s\frac{\partial C}{\partial z} - (K_c + K_w)C \quad (1)$$

Where C represents concentration of air pollutants. t represents time and (x,y,z) represents space co-ordinates. K_x , K_y , $K_z$represents eddy diffusivity , horizontal diffusivity and vertical diffusivity respectively. W_s , K_c , $K_w$represents rate of settling velocity, chemical reaction rate of pollutants concentration and rate of wet deposition respectively.u,v represents mean wind velocity components.

In addition to the assumptions madeabove, we use the following assumptions:

[a] Since the wind is unidirectional (along the x axis) and sufficiently large and hence the diffusive transport in the x-direction $K_x\frac{\partial^2 C}{\partial x^2}$, will be neglected when compare to advective transport.

[b] The cross wind horizontal eddy-diffusivity $K_Y$is assumed constant in the boundary layer.

[c] For the simplicity we assume that the vertical eddy-diffusivity coefficient is constant.

[d] Assume gravitational settling velocity of larger size particle-pollutant is negligible in this model i.e.$W_s = 0$.

Assumption (a) makes the x-component of the pollutant particle velocity a constant. Thereforewe use Taylor's hypothesis. Consequently, only steady state case needs to be considered. Under the above assumption (a) takes the form:

$$u\frac{\partial C}{\partial x} = K_y\frac{\partial^2 C}{\partial y^2} + K_z\frac{\partial^2 C}{\partial z^2} - (K_c + K_w)C \quad (2)$$

The boundary and source conditions are:

[i] Continuous point - source of constant strength Q is situated at (0,0,Z_s) so that.

$$C(x,y,z) = \frac{Q}{U}\delta(y).\delta(z - z_s)atx = 0 \quad (2.a)$$

[ii] The pollutant's concentration approaches zero far from the source in the lateral direction. That is

$$C(x,y,z) = 0 \quad \text{at } y \to \pm\infty \quad (2b)$$

[iii] The rate of pollutant's deposition on the ground occurs which is proportional to the local concentration. This can be expressed as

$$K_z\frac{\partial C}{\partial z} = V_d Catz = z_r \quad (2c)$$

[iv] There will be leakage of some amount of pollutant at the top of the mixing layer. The flux of the pollutant at the top of the mixing layer is assumed proportionalto the local concentration. The proportionality constant is known as leakage velocityγ_l. Then we have

$$K_z\frac{\partial C}{\partial z} = -\gamma_l Catz = H_l \quad (2d)$$

Here, Q is the emission rate of pollutant, V_d the deposition velocity, Z_r is the reference height of lower boundary and H_l is the height of the mixing layer from the ground surface.

Non-Dimensionalization

The above equations are non-dimensionalized using characteristic values of length (I_c), speed (U_c) and concentration (C_c) as follows.

$$X = \frac{xK_z}{u_c l_c^2} Y = \frac{y}{l_c} Z = \frac{Z - Z_r}{l_c}$$

$\bar{C} = \frac{C}{C_c} \overline{K_z} = \frac{K_z}{K_z} N = \frac{V_d l_c}{K_z} \beta = \frac{K_y}{K_z}$ (3)

Here

$u_c = uC_c = \frac{Q}{u(H_c - z_r)^2} l_c = H_l - z_r$ (4)

Which is valid under the assumption of mesoscale dispersion within the confined mixing layer.

Non-dimensionalization of eqn (2), the source conditions & boundary conditions (2a) to (2d), lead to

$\frac{\partial \bar{c}}{\partial X} = \beta \frac{\partial^2 \bar{C}}{\partial Y^2} + \overline{K_Z} \frac{\partial^2 \bar{C}}{\partial Z^2} - (\alpha_c + \alpha_w)\bar{C}$ (5)

$\bar{C}(X, Y, Z) = \delta(y).\delta(z - d_S) at X = 0$ (5a)

$\bar{C}(X, Y, Z) = 0 \quad as Y \to \pm\infty$ (5b)

$\overline{K_z} \frac{\partial \bar{C}}{\partial z} = N\bar{C} at Z = 0$ (5c)

$\overline{K_z} \frac{\partial \bar{C}}{\partial z} = -\overline{\gamma_l}\bar{C} at Z = 1$ (5d)

where

$$d_S = \frac{Z_S - Z_r}{H_l - Z_r} \overline{\gamma_l} = \frac{\gamma_l (H_l - Z_r)}{K_z} \alpha_C = \frac{K_C (H_l - Z_r)^2}{K_z} \alpha_W = \frac{K_W (H_l - Z_r)^2}{K_z}$$

Pollutants Dispersion depends on the atmospheric stability, the surface drag, the total heat flux and also mixing layer height. So better to know precise description of the parameters like atmospheric stability length L, friction velocity u_*, mixing layer height H_1.

3. Meteorological Parameters

Let us know about the meteorological parameters involved in this model before solving equation (5).To find the value of ‘h’ which denotes the thickness of the surface layer, we followed the approach of Pasquill and Smith (1983)and its expression is given by

$\frac{\tau_0 - \tau_z}{\tau_0} = \frac{\mathbf{f\beta_3 h}}{\mathbf{u_g c_g^2}}$ (6)

Where $\frac{\tau_0 - \tau_z}{\tau_0} = 0.09$ (7)

In the above, the terms τ_0, τ_z denotes the shear stress which is at the ground level and at any height z respectively.β_3 denotes the total turning direction of gradient wind in lower part of the atmosphere. To find the value of stability length L we followed the approach of Monin-Obukhov(1954) and it is given by the expression

$L = -\frac{u_*^3.\rho.C_p.T}{K.g.H_f}$(8)

$u_* = c_g u_g$ (9)

The terms U_*, ρ, C_p, T, K, g, H_f represents friction velocity, atmosphere air density, specific heat, temperature, Karman constant, acceleration due to gravity and net head flux respectively.

According to Pal and Sinha (1987) the formula for geostrophic drag coefficientc_g is given by

$$C_g = \begin{cases} 0.6\ c_{gN} & for stable case of atmosphere \\ c_{gN} & for neutral case of atmosphere \end{cases} \quad (10)$$

According to Lettau (1959), in the neutral atmospheric condition the term drag coefficient c_{gN} is given by the formula

$$c_{gN} = \frac{0.16}{[log_{10}(R_0) - 1.8]} R_0 = \frac{u_g}{z_0 f} (11)$$

Here $R_O = u_g/(z_o.f)$ represents Rossby number , f represents earth's Coriolis Parameter.

According to Lettau (1970), surface roughness length z_0 is considered as

$$z_0 = \frac{\overline{H}\overline{a}}{2\,\overline{A}} (12)$$

The terms $\overline{H}$, $\overline{a}$, $\overline{A}$ denotes roughness elements height, frontal area seen by the wind & the lot area respectively.

Pasquill and smith (1983) expressed the value of 'a' which denotes mixing layer height as

$$a = \frac{u_*}{f} F_1 \left(\frac{u_*}{fL}\right) \quad (13)$$

After conducting Minnesota experiment, Smith and Blackall (1979) confirmed that $F_1 = 0.2$ and it is constant for neutral atmospheric condition. Further for stable atmospheric condition it is given by

$$a = \frac{21500\, u_*^2}{\sqrt{\lfloor H_f \rfloor}} \quad (14)$$

Table 01: The roughness parameters z_o under different terrain categories

Terrian Components	**z_o (m)**
Water surface	0.0005
Open field	0.03
Open field with scattered trees and hedges	0.25
Roads/ Railways	0.5
Wood	1.0
Buildings	2.0

4. Solution Of Our Model

Fourier's technique is used to get the solution of eqn(5) with respect to the source and bcs (5a) - (5d). We look for the solution ofeqn (5) in theform

$$\overline{C}(X,Y,Z) = \eta(X,Z)\rho(X,Y).e^{[-(\alpha_C+\alpha_W)X]} \quad (15)$$

Substitutingeqn (15) in (5) and separating the variables, we get

$$\frac{\partial \eta}{\partial X} - \overline{K_z}\frac{\partial^2 \eta}{\partial Z^2} - \overline{W_s}\frac{\partial \eta}{\partial z} = -\eta K_{ll} \quad (16)$$

$$\beta\frac{\partial^2 \rho}{\partial Y^2} - \frac{\partial \rho}{\partial X} = -\rho K_{ll} \quad (17)$$

Where K_{11} is an arbitrary constant.

Using the transformation

$\eta(X,Z) = \eta_2(X,Z).e^{-K_{u}.X} and \rho(X,Y) = \rho_2(X,Y).e^{K_{u}.X}$ (18)

(16)and (17) take the following form:

$\frac{\partial \eta_2}{\partial X} = \frac{\partial^2 \eta_2}{\partial Z^2}$ (19)

$\frac{\partial \rho_2}{\partial X} = \beta \frac{\partial^2 \rho_2}{\partial Y^2}$ (20)

Now we use the transformations (15) and (18) in the source and boundary conditions (5a) - (5d).So we finally get the following systems of equations for $\rho_2 and \eta_2$.

System I:

$\frac{\partial \rho_2}{\partial X} = \beta \frac{\partial^2 \rho_2}{\partial Y^2}$ (21)

$\rho_2(X,Y) = \delta(Y) at X = 0$ (21a)

$\rho_2(X,Y) = 0 \quad as as Y \to \pm\infty$ (21b)

System II:

$\frac{\partial \eta_2}{\partial X} = \frac{\partial^2 \eta_2}{\partial Z^2}$ (22)

$\eta_2(X,Y) = \delta(z - d_s) at X = 0$ (22a)

$\frac{\partial \eta_2}{\partial Z} = N\eta_2 at Z = 0$ (22b)

$\frac{\partial \eta_2}{\partial Z} = -\overline{\gamma}_l \eta_2 at Z = 1$ (22c)

Solution of (21), using (21a) and (21b) can be written as

$\rho_2(X,Y) = \frac{1}{2.\sqrt{\pi\beta X}}.e^{[-Y^2/(4\beta X)]}$ (23)

To solve the system (22), we assume the solution in the form

$\eta_2(X,Z) = e^{-\lambda.X}\, \mathrm{F}(z,\lambda)$ (24)

Where λ is a constant. Due to homogeneity of (22)and homogeneity of boundary conditions (22a) and (22c) the constant λ become eigenvalue of the problem, the pollutant's concentration decreases with X, λ should be non-negative,

ODE satisfied by F (Z, λ) is

$\frac{\mathrm{d}^2\mathrm{F}}{\mathrm{d}z^2} + \lambda F = 0$ (25)

The boundary conditions are:

$\frac{\mathrm{dF}}{\mathrm{dz}} = \mathrm{N}F \quad \text{at } \mathrm{Z} = 0$ (25a)

$\frac{\mathrm{dF}}{\mathrm{dz}} = -\overline{\gamma}_l F \quad \text{at } \mathrm{Z} = 1$ (25b)

The solution of (25) may be written as

$\mathrm{F}(\mathrm{Z},\lambda) = \mathrm{A}\left[\mathrm{cosbz} + \frac{\mathrm{B}}{\mathrm{A}}\mathrm{sinbz}\right] : \mathrm{b} = \sqrt{\lambda}$ (26)

Now the general solution for $\eta_2(X,Z)$can be written in the form:

$\eta_2(X,Y) = \sum_{n=1}^{m} A_n e^{(-\lambda_n X)}.Z_n(z)$ (27)

$Z_n(z) = [\cos b_n z + D_n \sin b_n z] \quad : D_n = \frac{B_n}{A_n}$ (27.a)

$b_n = \sqrt{\lambda_n} \lambda_n = b_n^2$ (27.b)

$D_n = \frac{[b_n \sin b_n - \overline{\gamma_l} \cos b_n]}{[b_n \cos b_n + \overline{\gamma_l} \sin b_n]}$ (27.c)

and b_n can be obtained by solving the transcendental equation.

$\mathrm{Tan} b_n = \frac{b_n(N + \overline{\gamma_l})}{b_n^2 - N\overline{\gamma_l}}$ (27.d)

The constant A_n appeared in solution (27) is obtained using the source condition (22a). That is

$\sum_{n=1}^{m} A_n . Z_n(z) = \delta(z - d_S)$ (27.e)

Multiplying both sides of (27e) by $Z_n(z)$, n = 1,2,...m and integrating between the limits 0 and 1, we get

$\int_0^1 (A_1 Z_1 + A_2 Z_2 + A_3 Z_3 \dots \dots . + A_m Z_m) Z_n dz = Z_n(d_s)$, $n = 1,2,3, \dots \dots m$ (27.f)

Equation (27f) represents system of m linear, non-homogeneous algebraic equation with m unknowns A_1, $A_{2,...}$...A_m . The coefficients of the above system of equations are integrals

$$\int_0^1 Z_i Z_j dz, \quad i,j = 1,2,3, \dots \dots .. m$$

Which have been evaluated in explicit from. Solving these equations by Gauss elimination method we get A_1, A_2 ,...... A_m. Therefore final solution is

$\bar{C}(X,Y,Z) = \frac{1}{2.\sqrt{\pi\beta X}} . e^{[-Y^2/(4\beta X)]} . \sum_{n=1}^{m} A_n . e^{[-(\lambda_n + \alpha_C + \alpha_W)X]} . Z_n(z)$ (28)

Where Z_n (z) is given by (27a) - (27d) , the eigenvalues λ_n are given by (27b) and (27d) and $A_n^{'}$s are obtained by solving (27f).

Table 02: Meteorological Parameters for various atmospheric categories

Parameters		**Stable atmospheric condition** $H_f = -0.06$ langley/min					**Neutral atmospheric condition** $H_f = 0.0$ langley/min				
		u_g (ms^{-1})	U_* (ms^{-1})	L (m)	h (m)	a (m)	u_g (ms^{-1})	U_* (ms^{-1})	L (m)	h (m)	a (m)
For Z_0=0.25 m	Weak Wind	05	0.14	5.5	11	65	05	0.23	∞	31	460
	Moderate Wind	10	0.25	3.5	19	208	10	0.42	∞	53	840
	Strong Wind	20	0.47	218	33	734	20	0.78	∞	91	1560
For Z_0=2.25 m	Weak Wind	05	0.19	14	21	120	05	0.31	∞	59	620
	Moderate Wind	10	0.34	81	35	384	10	0.56	∞	95	1120
	Strong Wind	20	0.61	482	56	1237	20	1.0	∞	155	2000
C_p =0.24 Cal/g (K) , g = 980cm/s , β_3=0.3 radian, ρ=1.25×10^{-3} g/cm^3 , κ = 0.4 , F_1 = 0.2 , T = 278^{0}K , f = 1× 10^{-4}/s											

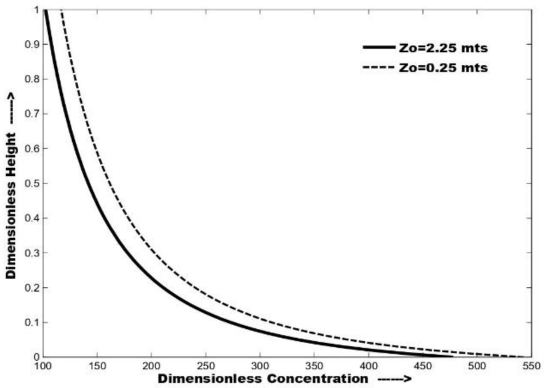

Figure (1) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of surface roughness lengths Z_o in case of Strong Wind under Stable atmospheric condition at larger travel time

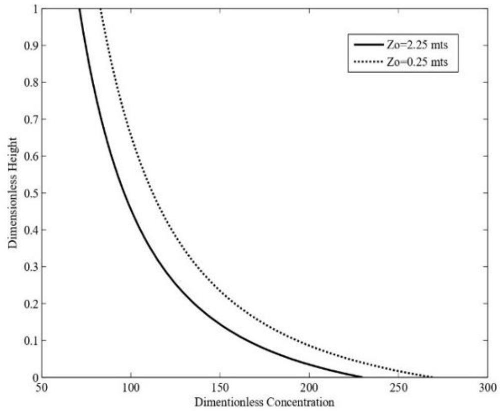

Figure (2) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of surface roughness lengths Zo in case of Moderate Wind under Stable atmospheric condition at larger travel time

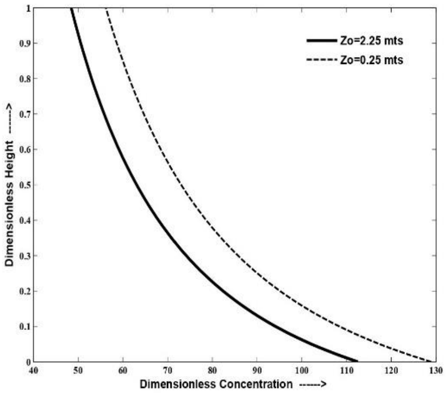

Figure (3) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of surface roughness lengths Z_o in case of Weak Wind under Stable atmospheric condition at larger travel time

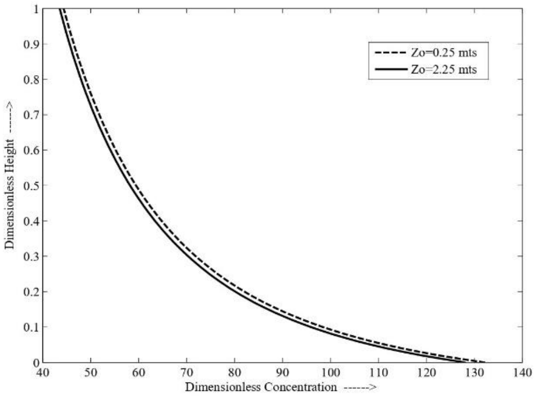

Figure (4) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of surface roughness lengths Zo in case of Weak Wind under Neutral atmospheric condition at larger travel time

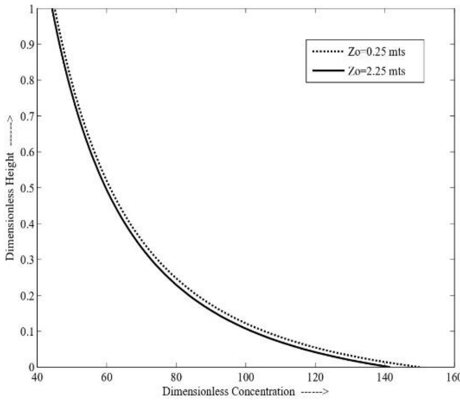

Figure (5) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of surface roughness lengths Zo in case of Moderate Wind under Neutral atmospheric condition at larger travel time

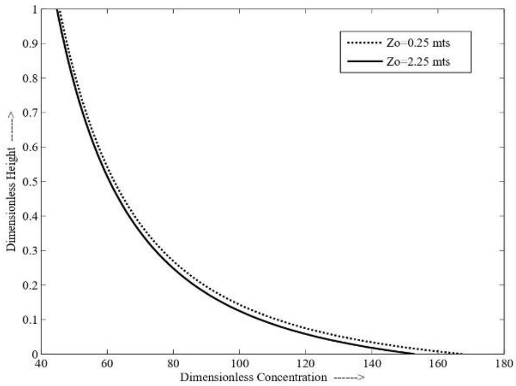

Figure (6) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of surface roughness lengths Zo in case of Strong Wind under Neutral atmospheric condition at larger travel time

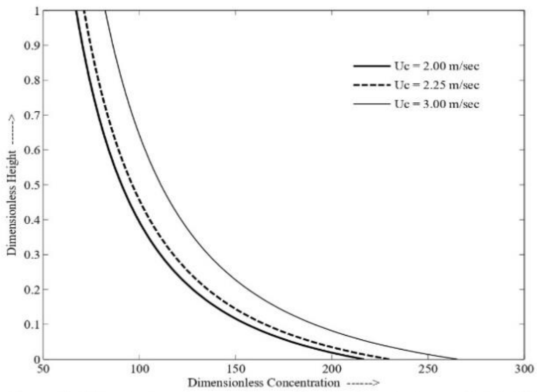

Figure (7) Dimensionless Concentration profiles Vs. dimensionless vertical height for different values of wind velocities in case of Strong Wind under Stable atmospheric condition at larger travel time

5. Results And Discussions

A three-dimensional analytical mathematical model has been presented for concentration distribution of air pollution particles released from a point source $z = z_s$ in mixing layer $z_r \leq z \leq H_l$. This model includes various phenomena like diffusion, transport and different removal mechanisms including deposition of air pollution particles by wet deposition due to washout, surface terrain, chemical reaction and leakage of air pollutants to the space through the top of the mixing layer. The distribution of air pollution concentration in atmospheric boundary layer strongly based on the atmospheric stability and different meteorological parameters. To obtain the stability dependent concentration distribution we have considered the vertical height of the mixing layer as a function of Monin-Obukhov stability parameter L, friction-velocity u_*& radiating net flux H_F . The formula used for the mixing layer height has been tested by Smith and Blackall (1979) using the data drawn from Minnesota experiment.

The mathematical model has been solved by quasianalytic approach. The results have been analysed for various situation of deposition discussed in formulation of the model. For various atmospheric categories listed in Table 02 the computation has been carried out for ambient concentration of chemically reactive primary pollutant. Various aspects of the results are explained graphically using the Figures (1) to (7)

For computation, we took values of roughness length (z_o) as 0.25 mts and 2.25 mts. The friction velocity u_* and stability length L values under different atmospheric conditions have been summarized in Table 02 for typical case of geostrophic wind speed 2.0 m/s,2.25 m/s and 3.0 m/s. The value of radiating net heat flux H_f is taken as -0.06 langley min^{-1} for stable atmospheric condition. The height of the mixing layer is calculated using the formula (13) for different atmospheric conditions and values are summarised in table 02 . The value of leakage-velocity is cosidered as 0.0m/s in this model. The value of wind velocity u is 2.25m/s and reference height Z is 1.00m fixed such that $0 \leq z \leq 1$. The rates of wet deposition and chemical reaction are 0.05 h/r, 0.005h/r respectively. The typical value of horizontal diffusivity $K_z$is taken as 17.08 m^2/s and the value of vertical diffusivity K_y is 17.08m^2/s. Source height for all graphs is d_s=0.7. Figures (1) to (7) are the plot of non-dimensional horizontal concentration profiles along non-dimensional vertical height.

When settling of larger particles is negligible, it can be seen from the figure(1) that the concentration is higher in the lower part of the boundary layer and the concentration decreased in the upper part of the mixing layer.In figure(2) under stable atmospheric condition, in the lower part of the boundary layer the concentration of the air pollution decreased as the surface roughness length increased and the same thing happened in the upper part of the mixing layer. In figure(1) and (3) for same surface roughness length, at the bottom of the surface layer the pollutant concentration is more in figure(1) when compare to figure(3), this is because of stable atmospheric condition.

In figure(4) for different surface roughness length, the concentration of air pollution is almost same is due to neutral atmospheric condition.In figure(5) and (6) for different wind speed at larger travel time , the pollutant concentration is almost same which is due to neutral atmospheric condition. In figure(7) for different wind velocities in case of strong wind speed, the air pollution concentration is higher in the lower part of the mixed boundary layer and the concentration decreased in the upper part of the mixing layer is due to neutral atmospheric condition at larger travel time.

6. Conclusion

This model provides a proper approach to represent stability dependence concentration profile using surface layer height and mixing layer height with Monin-Obukhov stability parameter L. The effect of both rate of roughness parameters and rate of wind velocity of pollutants on the concentration of dispersed air pollutants is analysed for both stable atmospheric condition and neutral atmospheric condition. The air pollutants concentration in the upper part of the mixing layer is less in stable atmospheric situation for smaller roughness length of terrain and moderate geostrophic wind speed.

References

[1] Lakshminarayanachari and Bhaskar (2021) “Numerical model for primary and secondary air pollutants emitted from an area and point source in an urban area with chemical reaction and removal mechanisms”Materials Today: Proceedings,2021 – Elsevier Volume 37,part2, 2021, page 2961-2967

[2] Latha.RLakshminarayanachari **.K** Bhaskar.C “An Analytical Model for Point Source Pollutants in an Urban Area with Mesoscale and Removal Mechanisms” Int J Env Health Eng 2023;12:21.

[3] K.LakshmiNarayanachari, C.M. Suresha, M. Siddalinga Prasad, C.Pandurangappa.(2014) “Time dependent advection diffusion model of air pollutants with removal mechanism” International Journal of Environmental Sciences , volume 5, Issue 1, 34, 2014.

[4] K.LakshmiNarayanachari. K.L. SudeerPai, M. Siddalinga Prasad, C. Pandurangappa. (2012) “A two dimensional numerical model of primary pollutant emitted from an urban area source with mesoscale wind, dry deposition and chemical reaction. Atmospheric Pollution” Research 4 (2013) 106-116.

[5] Pal. D. and Khan S.K (1990b) “Unsteady conjugated atmospheric dispersion model” Intern. J. Environmental Studies 36, 265.

[6] Pal,D. and Sinha ,D.K ”An Area source numerical model on atmospheric dispersion with chemical reaction and Deposition” Intern.J.Environmental studies 29,269-280(1987).

[7] Pasquill F, Smith F.B, “Atomspericdiffusion” John Wiley and sons , pp.89-115 (1983).

[8] Alam, M.Khaairul and Seinfeld, John.H 1981 “ Solution of the study state, three dimensional atmospheric diffusion equation for sulfur dioxide and sulphate dispersion from point sources” Atmospheric Environment 15, 1221.

[9] Jia-Yeong Ku, S.Trivikrama Rao 1987 “Numerical simulation of air pollution in urban areas: Model Development” Atmospheric Environment (1967) : Volume 21, Issue 1, 1987, Pages 201-212

[10] Lee, H.N. 1980 “A study of analytical mesoscale model for atmospheric transport, diffusion and removal of pollutants. Symposium on Intermediate Range Atmospheric Transport processes and technology Assessment” pp 289-297, Gatlinburg, Tenn, 1-3 Oct. 1980.

[11] Rao, K.S 1981 “Analytical solutions of a gradient-transfer model for plume deposition and sedimentation” NOAA Technical Memorandum ERL ARL-109 ATIN Contribution 81/14.

[12] Smith F.B and Blackall R.M, “The application of field experimental data to the parameterization of the dispersion of plumes from ground level and elevated sources, Mathematical Modelling of Turbulent Diffusion in the Environment” C.J. Harris Academic Press (1979)

[13] Smith, F.B. 1962 “The problem of deposition in atmospheric diffusion of particulate matter” J.Atmos. Sci. 19, 429.

[14] Heines, T.S. and Peters, L.K. 1974 “The effect of ground level absorption on the dispersion of pollutants in the atmosphere” Atmospheric Environment 8, 1143.

[15] Lettau, H.H.(1970), Physical and meteorological basis for mathematical models of urban diffusion processes. Proceedings of symposium on multiple Source urban Diffusion Models” USEPA publication AP-86.

[16] Calder, K.L. 1961 “Atmospheric diffusion of particulate material, considered as a boundary value problem” J. Meteor. 18, 413.

[17] Lettau, H.H.(1959), “Wind profile , surface stress and geostrophic drag coefficients in the atmospheric surface layer” Advances in Geophysics, Academic press, New York, 6, p.241.

[18] Monin, A. S., Obukhov, A. M. (1954), “Basic laws of turbulent mixing in the ground layer of the atmosphere” Dokl .Akad. SSSR, 151, pp 163-187.