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Review Article

A REVIEW ON THEORETICAL AIR POLLUTANTS DISPERSION MODELS

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ABSTRACT

Pollution is the most predominate cause that is effecting every living and nonliving organisms on earth. While the main reason behind this is man activities for his existence, comforts and needs. Due to these a wide range of pollutants are being evaluated daily in to the atmosphere, in order to prevent pollution and to study the effect of those, several theory's and strategies are evolved which can give use virtual results according to the date given with predefine conditions and limitations which are included in them. By using these models we can know the minimum effluent concentration that can be discharge into atmosphere and we can able to take the preventive measure. Abundantly used models are Box Model, Gaussian Model, Eulerian Model, Lagrangian Model, CFD Model and Dense Gas Model. Every model is briefly described and discussed its own postulates and drawback which are being discussed here, while they can't predict the environmental impacts accurately.

Keywords: Pollution, Health Effects, Dispersion models, Plume Rise, Plume Stability.

1. INTRODUCTION

The atmospheric composition on Earth is largely governed by the by-products of the every life that it sustains. Earth's atmosphere contains roughly (by molar content/volume) 78.08% Nitrogen, 20.95% Oxygen, a variable amount (average around 1.247%) water vapor, 0.93% Argon, 0.038% Carbon dioxide, and traces of Hydrogen, Helium, and other noble gases[1].

The word pollution 'pollution' has been derived from a Latin word, 'pollutionem,' which means to make dirty (Pollution is the process of making the environment. i.e., the land, water and air dirty by adding harmful substances to it). Pollution causes imbalance in the environment. This imbalance has threatened the every survival of life. It is a threat to the whole world. Environmental pollution is a serious problem. Nearly 35 percent of India's total land area is subjected to serious environmental pollution[2].

2. Types of major pollutions

In present we are suffering with four major pollutions. They are (a) Water Pollution, (b) Air Pollution, (c) Soil Pollution and (d) Noise Pollution. Air pollution is the most dangerous form of pollution. Land and water pollution have worsened the situation. Pollution causes several types of harmful disease. We must control pollution for our survival. The industrial development and the Green Revolution have adversely affected the environment. People have converted the life supporting systems of the entire living world into their own resources and have vastly disturbed the natural ecological balance. Serious degradation and depletion have been caused thought overuse, misuse and mismanagement of resources to meet the human greed.

Three fourths of the earth consists of water, yet there is a scarcity of potable water. In India, all the sources of water like rivers, lakes, ponds and wells have been polluted and are unfit for drinking. As a result of the increased use of fertilizers, the rivers, seas and oceans have become contaminated with harmful pollutants. It is estimated that more than 500 tons of mercury enters the ocean every year. Pollution caused by the flow of industrial waste, sewage and fertilizer have also threatened the aquatic life.

Soil pollution usually results from the disposal of solid and semi-solid wastes from agricultural practices and from unsanitary habits. The soil is heavily polluted day-by-day by hazardous materials and microorganisms, which enter the food chain or water and create numerous health problems[2].

In simple terms, noise is unwanted sound. Sound is a form of energy which is emitted by a vibrating body and on reaching the ear causes the sensation of hearing through nerves. Sounds produced by all vibrating bodies are not audible. The frequency limits of audibility are from 20 HZ to 20,000 HZ. A noise problem generally consists of three inter-related elements- the source, the receiver and the transmission path. This transmission path is usually the atmosphere through which the sound is propagated, but can include the structural materials of any building containing the receiver[3].

Noise induces a severe impact on humans and on living organisms. Some of the adverse effects are Annoyance, Physiological effects, Loss of hearing, human working performance, effect on Nervous system, Sleeplessness and Damage to building material. Some of the techniques employed for noise control are Control at source, Control in the transmission path and using protective equipment[4].

The migration of rural population to the cities in search of work has created an unhealthy environment. It has led to overcrowding, establishment of slum areas. Towns and cities are full of smoke, fumes, dirt, dust, rubbish, gases, foul smell and noise. Air, water and land pollution have further worsened the very survival of human beings.

3. Air pollution

Air pollution is the most dangerous form of pollution. The major air pollutants are SO_X, NO_X, CO, Particulate matter etc. It results from gaseous emission from industry, thermal power stations, domestic combustion etc. Due to air pollution, the composition of air is changing all over the world. Most of the gases and air pollutants are produced by burning fuels. Burning of coal produces carbon dioxide, sulfur dioxide etc. which are responsible for acid rain. Chlorofluorocarbons are widely used as propellants and as refrigerants which cause ozone depletion. Noise is also one of the major pollutants, which includes in air pollution. The general noise level in the cities is rising alarmingly. Nuclear explosions and nuclear tests also pollute the air. The TajMahal in Agra is affected by the fumes emitted by the Mathura refinery. Reports estimate that the monument would get defaced with a span of twenty years because of the harmful effluents of the mission from the refinery. The emission of greenhouse gases has led to climatic changes. The increase in pollution has resulted in global warming. Global warming is an average increase in the Earth's temperature due to greenhouse effect as a result of both natural and human activity. The term climate is often used interchangeably with the term global warming. The ice-caps in the Polar Regions have begun to melt fast. This has resulted in the rise of the water level of the seas and oceans. Grass sprouting in Antarctica and snowfall in the desert of the United Arab Emirates are all the warning signals of global warming. These are caused by the Greenhouse Effect[5].

Air pollution causes allergies, asthma, lung cancer and bronchitis. Radioactive pollutants cause respiratory problems, paralysis, cancer, and other diseases. Excessive noise pollution can lead to deafness, anxiety, stress, increase in the rate of heart beat and other health problems. The depletion of the ozone layer can also result in skin diseases. In order to fight this menace of pollution, vigorous efforts should be made. The Anti-pollution law should be strictly practiced. Trees should be planted everywhere and vehicles should be made eco-friendly[6].

4. Modeling

Modeling or simulation is a process whereby a system is created to simulate a real-life situation. Pollutants are continuously released from numerous sources into the atmosphere. The pollution sources could be point sources (e.g., stacks or vents), area sources (e.g., landfills, ponds, storage piles), or volume sources, (e.g.: conveyers, structures with multiple vents). The dispersion of the pollutants in the atmosphere emitted from these sources depends on various factors. These factors are given in the table 1[7].

Table 1: Factors affecting the dispersion of the pollutants

Source characteristics	Meteorological Conditions
Emission rate of pollutant	Wind velocity
Stack height	Wind direction
Exit velocity of the gas	Ambient temperature
Exit temperature of the gas	Atmospheric stability
Stack diameter	Mixing height

5. Objectives of modeling

The purpose of a dispersion model is to provide a means of calculating ambient ground-level concentrations of an emitted substance given information about the emissions and the nature of the atmosphere. The amount released can be determined from knowledge of the industrial process or actual measurements. However, predictive compliance with an ambient air quality objective is determined by the concentration of the substance at ground level. Air quality objectives refer to concentration in the ambient air, not in the emission source. In order to assess whether an emission meets the ambient air objective it is necessary to determine the ground-level concentrations that may arise at various distances from the source. This is the function of a dispersion model[8].

6. Types of dispersion models

Different types of dispersion models available, from simple box type models to complex fluid dynamics models are outlined and the suitability of the different approaches to dispersion modeling within different environments, in regards to scale, complexity of the environment and concentration parameters is assessed. Finally, several major commercial and non-commercial particle dispersion packages are reviewed, detailing which processes are included and advantages and limitations of their use to modeling particle dispersion[9].

(a) Box Models

The box model is the simplest of the modeling algorithms. It assumes the air shed in the shape of a box. The box model is represented using following equation

$d(CV)/dt = Q*A + u*Cin*W*H - u*C*W*H$

Where,

Q = pollutant emission rate per unit area

C = homogeneous species concentration within the air shed

V = volume described by box

Cin = species concentration entering air shed

A = horizontal area of box

u = wind speed normal to the box

H = mixing height

Although useful, this model has limitations. It assumes the pollutant is homogeneous across the air shed, and it is used to estimate average pollutant concentrations over very large area[10].

(b) Gaussian Models

The Gaussian models are the most common mathematical models used for air dispersion. They are based upon the assumption that the pollutant will disperse according to the normal statistical distribution. Gaussian distribution equation is given by

$C_{x,y,z} = Q/2\pi u\sigma_y\sigma_z \{\exp[-(z-h)^2/2\sigma_z^2] + exp[-(z+h)^2/2\sigma_z^2]\}\{\exp(-y)^2/2\sigma_y^2\}$

Where,

$C_{x,y,z}$ = Pollutant concentration as a function of downwind position (x, y, z)

Q = mass emission rate

u = wind speed

σ_y= standard deviation of pollutant concentration in y (horizontal) direction

σ_z = standard deviation of pollutant concentration in z (vertical) direction

y = distance in horizontal direction

z = distance in vertical direction

H = effective stack height

The Gaussian distribution determines the size of the plume downwind from the source. A schematic representation of the Gaussian Plume is shown in Figure 1. The plume size is dependent on the stability of the atmosphere and the dispersion of the plume in the horizontal and vertical directions. These horizontal and vertical dispersion coefficients (σ_y and σ_z respectively) are merely the standard deviation from normal on the Gaussian distribution curve in the y and z directions. These dispersion coefficients, σ_y and σ_z, are functions of wind speed, cloud cover, and surface heating by the sun. The Gaussian distribution requires that the material in the plume be maintained.

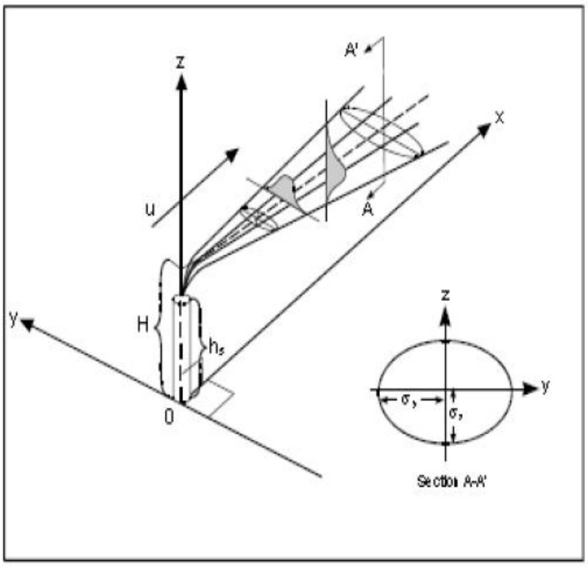

Fig. 1: Schematic Representation of Gaussian Plume

In order for a plume to be modeled using the Gaussian distribution the following assumption must be made:

- The plume spread has a normal distribution
- The emission rate (Q) is constant and continuous
- Wind speed and direction is uniform
- Total reflection of the plume takes place at the surface
- The terrain is relatively flat, i.e., no crosswind barriers

Plume Behavior

The mixing of ambient air into the plume is called entrainment. As the plume entrains air into it, the plume diameter grows as it travels downwind. A combination of the gases' momentum and buoyancy causes the gases to rise. This is referred to as plume rise and allows air pollutants emitted in this gas stream to be lofted higher in the atmosphere. The final height of the plume, referred to as the effective stack height (H), is the sum of the physical stack height (h_s) and the plume rise (Δh). Plume rise is actually calculated as the distance to the imaginary centerline of the plume rather than to the upper or lower edge of the plume (Figure2.)

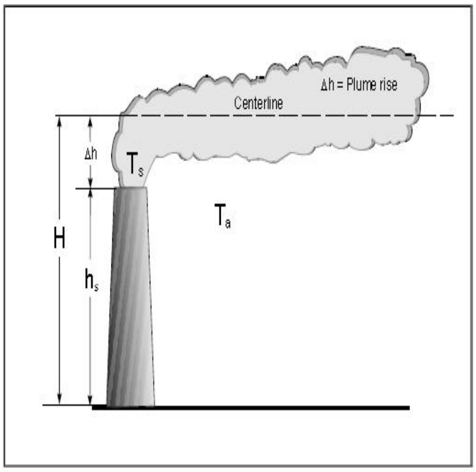

Fig. 2: Plume Rise

The Briggs' plume rise formula (1969) is as follows:

$$\Delta h = \frac{1.6 * F^{1/3} * x^{2/3}}{\bar{u}}$$

Where,
Δh = plume rise (above stack)
F = Buoyancy Flux (see below)
$\bar{u}$ = average wind speed
x = downwind distance from the stack

$$\text{Buoyancy flux} = F = \frac{g}{\pi} V\left(\frac{T_s - T_a}{T_s}\right)$$

g = acceleration due to gravity (9.8 m/s^2)
V = volumetric flow rate of stack gas
T_s = temperature of stack gas
T_a = temperature of ambient air

Plume Stability

Shapes of plumes depend upon atmospheric stability conditions which depend on Environmental Lapse rate (ELR) and Dry Adiabatic Lapse Rate (DALR). The stability conditions based on ELR and DALR is as follows,
ELR > DALR, atmosphere is stable
ELR >>DALR, very stable atmosphere
ELR = DALR, atmosphere is neutral
ELR <DALR, atmosphere is unstable[11-12].

(c) Eulerian Model

It solves a conservation of mass equation for a given pollutant. Equation follows the form:

$$\partial \langle ci \rangle / \partial t = - \bar{U} * \Delta \langle ci \rangle - \Delta \langle ciU' \rangle + D\Delta^2 \langle ci \rangle + \langle Si \rangle$$

Where,
U = Ū + U'
U = wind field vector U(x, y, z)
Ū = average wind field vector
U' = fluctuating wind field vector
c = < c > + c'
c = pollutant concentration
< c > = average pollutant concentration
c' = fluctuating pollutant concentration
D = molecular diffusivity
Si = source term

This equation can be difficult to solve because the advection term $-\bar{U} * \Delta \langle ci \rangle$, is hyperbolic, the turbulent diffusion term is parabolic, and the source term is generally defined by a set of differential equations. This type of equation can be computationally expensive to solve and requires some form of optimization in order to reduce the solution time required[8].

(d)Lagrangian Model

Predict pollutant dispersion based on a shifting reference grid. This shifting reference grid is generally based on the prevailing wind direction, or vector, or the general direction of the dust plume movement. The Lagrangian model has the following form:

$$\langle c(r, t) \rangle = \iint_{-\infty}^{t} p(r, t | r', t') S(r', t') dr' dt'$$

Where,
<c(r, t) > = average pollutant concentration at location r at time t
S(r', t') = source emission term
p(r,t|r',t') = probability function that an air parcel is moving from location r' at time t' to location r at time t

This mathematical model has limitations when its results are compared with actual measurements. This is due to the dynamic nature of the model. Measurements are generally made at stationary points, while the model predicts pollutant concentration based upon a moving reference grid[8].

(e) CFD Models

Resolving the Navier-Stokes equation using finite difference and finite volume methods in three dimensions provides a solution to conservation of mass and momentum. Computational fluid dynamic (CFD) models use this approach to analyze flows in urban areas. In numerous situations of planning and assessment and for the near-sources region, obstacle-resolved modeling approaches are required. Large Eddy Simulations (LES) models explicitly resolve the largest eddies, and parameterize the effect of the sub grid features. Reynolds Averaged Navier Stokes (RANS) models parameterize all the turbulence, and resolve only the mean motions. CFD (large eddy simulation [LES] or Reynolds-averaged Navier-Stokes [RANS]) model can be used to explicitly resolve the urban infrastructure[13].

(f) Aerosol Dynamic Models

The numerical simulation of gaseous species is the first component of a CTM (Chemistry Transport Models). For many applications, the modeling of condensed matter is also required. This includes the description of chemical composition and of size distribution of aerosols (particulate matter). Both have an influence for the radioactive behavior of aerosols, for microphysical processes (through the activation of the finest aerosols to generate cloud droplets) and for the assessment of health impact (the most adverse particles are the finest ones). Simulating a poly disperses distribution of aerosols is a challenging task for many reasons (at the numerical level)

- There is a wide range of scales (from a few nanometers to at least 10 µm),
- One has to deal with high-dimensional models (the number of chemical species inside the aerosol mixture has to be multiplied by the number of degrees of freedom chosen to describe the size),
- The processes that affect the size and chemical composition of aerosols are nonlinear and discontinuous (thresholds for phase transition for the hysteresis of deliquescence/crystallization).

The evolution of size distribution and of chemical composition for aerosols is governed by the So-called General Dynamics Equation for aerosols (GDE in the sequel)[14].

(g) Dense Gas Model

Dense gas models are models that simulate the dispersion of dense gas pollution plumes (i.e., pollution plumes that are heavier than air). The three most commonly used dense gas models are

- The DEGADIS model developed by Dr. Jerry Havens and Dr. Tom Spicer at the University of Arkansas under commission by the US Coast Guard and US EPA.
- The SLAB model developed by the Lawrence Livermore National Laboratory funded by the US Department of Energy, the US Air Force and the American Petroleum Institute.
- The HEGADAS model developed by Shell Oil's research division[14].

7.List of software to simulate the theoretical model using a computer

Computer modeling is generally the most inexpensive and versatile method for analyzing a real-life situation and has become prevalent for solving problems related to physical processes, especially in research and development. Simulation generally involves modeling a physical process and analyzing it through the use of a personal computer. This analysis involves trial-and error methods applied to the model and tested with the actual physical process to perfect the model. Once this process is completed, the computer model can be used to identify problematic areas, and efforts can focus on finding solutions to address these particular concerns. Computer modeling of dust dispersion from mine sources can allow for the identification of potential hazard areas surrounding the source from a health and safety standpoint. It can also allow for the evaluation of dust control techniques to determine modifications necessary to improve dust control. The list of simulating software’s for the above discussed theoretical models are listed in table 2[15-20].

Table 2: List of theoretical models and their corresponding software's

S.NO	TYPE OF MODEL	LIST OF SOFTWARE'S
1	Box model	AURORA, PAL2, CPB and PBM
2	Gaussian models	CALINE4, HIWAY2, CAR-FMI, ISC3, OSPM, CALPUFF, AEROPOL, AERMOD, UK-ADMS, FDM and SCREEN3.
3	Eulerian model	GRAL, TAPM, ARIA Regional.
4	Lagrangian model	GRAL, TAPM, ARIA Regional.
5	CFD models	ARIA Local, MISKAM, MICRO-CALGRID
6	Aerosol dynamics	GATOR, MONO32, UHMA, CIT, AERO, RPM, AEROFOR2, URM-1ATM, MADRID, CALGRID and UNI-AERO.
7	Dense gas models	DEGADIS , SLAB , HEGADAS

CONCLUSION
The health of the people might damage significantly because of the continuous exposure to these pollutant concentration for such a long duration. The elders, senior citizens, infants, children and infirm of the population may badly affected because of the high pollutants concentrations. The above discussed models are useful to know the pollutants concentration, and the chemical analysis of the pollutants collected in the area through proper sampling is necessary to know the chemical characteristics. From this we know how these exposed to our health. It may add new dimensions to the existing pollution challenges. By following the precautions like, putting fine mess doors to all opening including ventilators to prevent the entry of particulate pollutants into the living or working space. The people living and working the region should have nose filters/nose masks when they came out of their households in their day to day activity. They should have periodical health checkups to assess the status of their reparative track including lungs, eye vision, skin diseases and so on. The storage and handling of the bulk cargo should not be taken up in open spaces. The transportation of the work material through trucks should be discouraged. Public education and awareness of the relationship between climate change and human health is the key to deal with problems more effectively. General awareness is must to save our planted from destruction. All the nations of the world should work united to control environmental pollution.

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