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Air pollution dispersion models-special reference to input parameters and application in sustainable urban planning

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ABSTRACT

Air pollution dispersion models have different applications including in sustainable urban planning. It is a model showing picture of reality and is widely used to make predictions thereby solve problems and make compatible strategies for the management of specific environmental problems. The output of a model is precisely dependent on source strength of pollutants, meteorology, topography, dispersion coefficients, and plume rise and so on so forth. An effort has been made in the present paper by the authors to precisely estimate the source strength, dispersion coefficients, plume rise etc along with type of air diffusion models and their relevance on urban planning.

Keywords: Air pollution, atmospheric dispersion models, source strength, urban planning, atmospheric conditions

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1.0 Introduction:

The air pollution has assumed greater and alarming proportion in urban , industrial & pockets where cluster of air polluting industries are in existence .Various air pollutants , namely , Carbon Monoxide (CO), sulphur dioxide (SO2), oxides of nitrogen (Nox),suspended particulate matter, Respirable suspended particulate matter(PM10, PM2.5, PM1.0), Hydrogen Sulphide(H2S), Methane, Hydrocarbons(HC), Benzene, Aldehydes, 1-3 Butadiene, PAH, Mercaptans, Carbon disulphide(CS2) , Fluorine based gases and so on so forth are emitted out from these sources. These pollutants are caused on account of vehicular emissions, industrial, Mining, Commercial and Household fuel burning. These pollutants when released in the atmosphere are subjected to transportation, dispersion, transformation, fall out and wash out and finally reach the ground level at a particular distance. Emissions from stacks are subjected to plume rise which again is dependent on force of buoyancy and momentum. The higher is the plume rise or stack, the lesser will be Ground level Concentration(1)

The relationship between the source of emissions and its magnitude with the ground level concentrations at different receptor points is governed by air dispersion models which takes into account the source strength , plume rise, Atmospheric Stability, mixing height, wind velocity, terrain and other meteorological conditions.

Various air dispersion models have been developed world over for different applications under different scenarios. Applications of such models have been made mandatory within the framework of environmental impact assessment (EIA) notification, 1994, as amended from time to time. It has therefore assumed greater importance for the academicians, consultants and regulatory authorities(2).

2.0Air dispersion models:-

Air dispersion models are system tools to predict ground level concentrations over a period of time and space from any point, multiple point, and line and area sources. It requires input data in the form of source strength for each pollutant from a given source along with meteorological parameters, topography, terrain features, stack details and so on so forth. A dispersion model is a set of mathematical equations that simulates the release and dispersion of air pollutants in the atmosphere. Atmospheric dispersion model is also a mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere .It also determine as to how air pollutant dispersed in to atmosphere. It is performed with computer programs, called dispersion model, that solve the mathematical equations and algorithms which simulate the pollutant dispersion (3).

2.1 Types of air dispersion models:-

Various air dispersion models have been or are being used under different scenarios. Broadly these models can be classified under following categories.

- Gaussian models
- Statistical models
- Numerical models

Gaussian models are used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Models may also be used for predicting the dispersion of non-continuous air pollution plumes (called *puff models*).

A statistical model is a formalization of relationships between variables in the form of mathematical equations. A statistical model describes how one or more random variables are related to one or more random variables. In mathematical terms, a statistical model is frequently thought of as a pair (Y,P) where Y is the set of possible observations and P the set of possible probability distributions on Y.

A Numerical model expressed in mathematical formulas and solved approximately on a computer. Numerical models are mathematical models that use some sort of numerical time-stepping procedure to obtain the models behavior over time. The mathematical solution is represented by a generated table and/or graph.

Usually in practice, Gaussian models are being use widely all over the world. However there are different types of Gaussian models which are being used presently in different parts of the world under different conditions(4).

2.2 Common features of Gaussian plume models:-

Characteristics of steady-state Gaussian models that make them convenient tools include the fact that they(5):

- do not require significant computer resources − they can be run on almost any desktop PC and can usually process a complete year of meteorological data in a matter of minutes
- are easy to use – they come with user-friendly graphical user interfaces (GUIs) and a relatively small number of input variables are required are widely used – well developed knowledge due to many users and results can easily be compared between different studies
- have simple meteorological data requirements – an input data set can be developed from standard meteorological recordings.
- have conservative results for short (<100 m) or low-level sources − overseas validation shows these models are more likely to over- rather than under-predict ground-level concentrations, which offers some degree of safety in the regulatory environment when assessing discharges from short or low-level sources.

2.3 Air dispersion models currently in use:-

There are several air dispersion models currently in use and are based on Gaussian approach. These models have different applications. The lists of some of such models are given here under(6):

- AERMOD
- ISC3 (ISC)
- SCIPUFF
- CAL3QHCR
- SLAB
- OBODM
- FARM (The Flexible Air quality Regional Model)
- STACKS (The Netherlands)
- CAR-International
- LOTOS-EUROS
- EK100W (Poland)
- POLGRAPH (Portugal)
- INPUFF-U (Romania)
- MODIM (Slovak Republic)
- CTDMPLUS

2. 4 Gaussian plume model equations:

The turbulent diffusion equation is a partial differential equation that can be solved with various numerical methods. Assuming a homogenous, steady-state flow and a steady-state point source, equation can also be analytically integrated and reveal the well-known Gaussian plume distribution

$$C(x,y,z,t) = \frac{Q}{2\pi . u . \sigma_y . \sigma_z} . \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z-H_{eff})^2}{2\sigma_z^2}\right)\right] + \exp\left(-\frac{(z+H_{eff})^2}{2\sigma_z^2}\right)$$

Where

X is a concentration at a given position,

Q is the source term,

x is the downwind,

y is the crosswind and *z* is the vertical direction

u is the wind speed at the *h* height of the release.

The σ_y, σ_z deviations describe the crosswind and vertical mixing of the pollutant

The above equation describes a mixing process that reveals a Gaussian concentration distribution both in crosswind and in vertical direction, centered at the line downwind from the source as depicted in figure 1 below and the last term of above equation expresses a total reflection from the ground, therefore this formula does not count with dry and wet deposition. Adding a third vertical component to the equation, total reflection from an inversion layer can also be computed where as gravitational settling and chemical or radioactive decay is neglected(7).

H_{eff} is the effective stack height used in the above equation which can be calculated from from various equations, but in the present case Holland equation is used to determine the effective stack height as under

Holland equation

H = Vs.d /u [1.5+ 2.68 * 10^-3 pd (Ts – Ta)/ Ts]

Where,

p= Atmosphere pressure in milli bars

Vs. = exit gas velocity in m/s

d = Stack diameter in meter

u = wind speed at stack height in m/s

Ts= Stack gas temperature

Ta= Ambient air temperature

H= Plume rise in meters

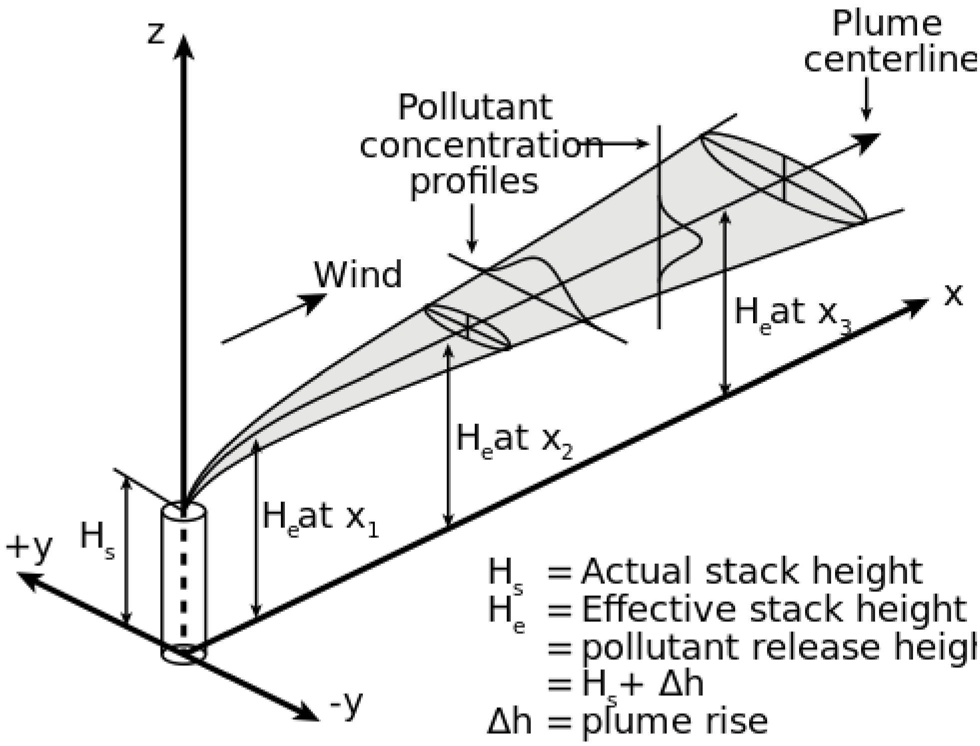

Figure: 1 Schematic figure of a Gaussian plume

2.5 Estimation of diffusion coefficients:

Diffusion co-efficient (σz)

The vertical deviations, σz is a function of the downward position x as well as the atmospheric stability conditions. Diffusion co-efficient estimated for different downwind distances by using following equation and taking values of constants as per table 1 below (8)

$$\sigma z = c\ x \wedge d + f$$

Table 1: Stability classes

Stability	when x < 1 km				b
	a	c	d	f	
A	213	440.8	1.941	9.27	0.894
B	156	106.6	1.14	3.3	
C	104	61	0.911	0	
D	68	33.2	0.725	-1.7	
E	50.5	22.8	0.678	-1.3	
F	34	14.35	0.74	-0.35	
when x > 1km					0.894
A	213	459.7	2.094	-9.6	
B	156	108.2	1.098	2	
C	104	61	0.911	0	
D	68	44,5	0.516	-13	
E	50,5	55,4	0.305	-34	
F	34	62.6	0.18	-48	

2.6 Estimation of source strength:

Source strength is worked out based on amount of fuel consumption, raw materials, emission factors, actual monitored observations of air pollutant emissions. The more precise is source strength of air pollutants, more compatible will be the predicted concentration of air pollutants on receptor locations using well established air dispersion models since these models help in understanding the relationship between the magnitudes of emissions at source with the Concentrations at different receptor points at ground level. Source strength is very important for any air dispersion model to predict reproducible results with least degree of variation. Its estimation should therefore be highly precise and accurate under all operating conditions. The units for source strengths are different for line, point and area sources. They are as under:

Sources Units:

- Point sources g/second
- Line sources g/m. second
- Area sources g/sq.meter.second

(A) Estimation of source strength from point sources:

The source strengths from point sources can be estimated with the use of following three criteria's.

- Based on volumetric concentration of pollutants (mg/Nm3)
- Based on composition of combustible fuel.
- Based on Emission factors of industry specific

Based on volumetric concentrations (mg/Nm3).

In this case, the concentrations of pollutants are to be monitored at the site under all operating conditions and with full capacity of the plant. Preferable, hourly or 3 hourly monitoring over a span of 24 hours should be done including the

Monitoring during start-up period. The maximum concentration observed should be considered for the air dispersion model as an input. Following formula may be used for estimation of source strength:

$$S = C \times V \times 10{-}3\ g/s$$

where S is the source strength in g/s, C the volumetric concentration of pollutant in

Mg/Nm3 and V is the volume of gases in Nm3/second.

Based on composition of combustible fuel.

The source strength based on composition of fuel is estimated as per the formula below:

$$S = 0.2315\ P \times Q$$

where S is the source strength of SO_2 in g/s, P the total quantity of fuel used in tons/day, and Q is the sulfur content in fuel in percent.

And, for particulate matter

$$S = 0.1157\ P \times A$$

where A is the ash content in fuel in percent and S is the source strength of particulate matter in g/s.

Based on Emission factors

The emission factors have been formulated by the U.S.EPA and also by the CPCB in some of the industrial processes along with others in kg/tonne or mg/tonne of product. These emission factors are industry specific and unit operations/processes oriented. The emission factors in respect of the following category of industries with separate sources of emissions have been formulated

Inorganic chemical industry

- Urea plant
- Normal super phosphate
- Triple super phosphate
- Hydrochloric acid (HCL)
- Hydrofluoric acid (HF)
- Nitric acid
- Phosphoric acid
- Sulfuric acid
- Chlor – alkali
- Sulfur recovery

Organic chemical industry

- Paint and varnish
- Plastic
- Polystyrene

Mineral-based industry

- Brick manufacturing
- Calcium carbide
- Ceramic
- Cement
- Phosphate rock processing
- Stone crushers

Metallurgical industry

- Lead smelting
- Zinc smelting
- Gray iron foundries
- Copper smelting
- Ferro alloy furnaces

Refuse combustors other than municipal waste

- Industrial/commercial refuse combustion

Municipal waste

- Open burning of municipal refuse
- Biomedical waste
- Municipal solid waste

Energy based plants

- Power plants
- Boilers (steam generating)
- D.G. sets

The source strength based on emission factors as referred to above are estimated with the following formula in g/s.

$S = 11.574 \times 10^{-3}\, EF1 \times P$ (g/s)

Where S is the source strength of pollutant in g/s, EF1 the emission factor for a pollutant in kg/tons of product, and P is the production capacity of plant in tons/day.

If EF1 is given in mg/tons of product, then,

$S = 11.574 \times 10^{-6} \times EF1 \times P$ (g/s)

3.0 Application of diffusion models in sustainable urban planning:

The application of air dispersion models are quite wide in as much as that it is effectively used for sustainable urban planning which include industrial estate planning, industrial zoning, sitting of industrial project and overall special planning from environmental point of view. It can also be used to forecast the critical air pollution levels in certain areas and during certain periods. It also helps in managing the air pollution control strategies. Models can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program, in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment. Modeling can be used to analyze actual or potential accidents that release contaminants to the atmosphere. Use for determining appropriate stack heights, For managing existing emissions ,Purpose of designing ambient air monitoring networks

,identifying the main contributors to existing air pollution problems, estimating the influence of geophysical factors on dispersion, assessing the risks of and planning for the management of rare events such as accidental hazardous substance releases. Other applications are as under.

- assessing compliance of emissions with air quality guidelines, criteria and standards
- planning new facilities
- determining appropriate stack heights
- Managing existing emissions
- designing ambient air monitoring networks
- identifying the main contributors to existing air pollution problems
- evaluating policy and mitigation strategies (e.g. the effect of emission standards)
- forecasting pollution episodes
- assessing the risks of and planning for the management of rare events such as accidental hazardous substance releases
- estimating the influence of geophysical factors on dispersion (e.g. terrain elevation, presence of water bodies and land use)
- running 'numerical laboratories' for scientific research involving experiments that would otherwise be too costly in the real world (e.g. tracking accidental hazardous substance releases,)
- saving cost and time over monitoring – modeling costs are a fraction of monitoring costs and a simulation of annual or multi-year periods may only take a few weeks to assess.
- Location aspect of green belt development

Conclusions:

Air dispersion or diffusion models are very important tools in the overall integrated environmental planning particularly in urban and industrial areas. It also helps in assessing the possible impacts on different environmental attributes on account of any developmental activity like, industry, urban development, transport sector, and expansion thereof. A location specific air dispersion model needs to be developed and subsequently validated to give reproducible and compatible predictions. Moreover, comprehensive research needs to be encouraged, taken up and applied in the field in order to take judicious decisions on the location of any developmental activity.

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