

UNIT-3

SAMPLING

Air Sampling

capturing the contaminant from a known volume of air; measuring the amount of contaminant captured and expressing it as a concentration.

- The air is passed through a filter medium [normally a paper for solid & liquid contaminants and a sorbent for gases]
- The volume of air is measured against the amount of contaminant captured. This gives the concentration, which is expressed either as milligrams per cubic metre (mg/m^3) or parts per million (PPM).
- The volume of air is calculated by multiplying the flow rate through the filter medium by the time in minutes.

Air pollution sampling

- Related to analysis of pollutants in a given volume of air.

Types of Contaminant

→ According to their physical properties

- 1) Particulates
- 2) Vapours
- 3) Gases

→ Particulates can be further subdivided into 5 types

- 1) Aerosols
- 2) Dusts
- 3) Fumes
- 4) Smokes
- 5) mists

Aerosols:

→ Dispersion of solid particles of microscopic size in air

Dust:

→ Solid particulate capable of temporary suspension in air

Fume:

→ Solid particles produced by condensation from the gaseous phase

→ Fumes are usually derived from the heating of a solid to its melting point & the subsequent cooling of the gas produced.

Smoke:

- Particles resulting from the incomplete combustion of organic matter consisting predominantly of carbon & oxides of carbon

Mist:

- Dispersion in air of liquid droplets usually large enough to be seen by the naked eye.

Vapour:

- Gaseous phase of substance that usually exists as a liquid / solid at normal room temp & pressure

Gas:

- A substance which doesn't normally exist as a liquid / solid at normal room temp & pressure

Air sampling calculation:

- An air sample requires 3 basic measurements
 - 1) Amount of pollutant collected
 - 2) Flow of air through the medium
 - 3) The run time in minutes

Air sampling methods:

- Air pollutant sampling are of 2 types
 - 1) Air sampling based on particulate pollutant
 - 2) Air sampling based on gaseous & vapour pollutant

Air Sampling based on Particulate pollutant

→ The following are the air sampling techniques for particulate pollutants

1) sedimentation

2) Filtration

3) Impingement

4) Precipitation → a) Thermal precipitation

b) Electrostatic precipitation

I) Sedimentation:

→ It is used to collect settleable particulate that settle out of the atmosphere as a result of the gravitation force.

→ Particulate pollutant having size of 10 micro meter can be collected with 99% efficiency

→ The sampler consists of sample dust jar fitted with a funnel. (20-32 cm high & 10-15 cm Ø @ base)

→ A liquid is added to collector to prevent the solids blown out from the jar by air.

→ Collected dust is evaporated to dryness & then weighed in mg

→ Sampling period is 30 days.

→ The total solids collected are expressed as weight per unit area per 30 days.

2) Filtration :

- This technique is used in the collection of air pollutants of size smaller than 10 micro meter in diameter.
- The particulates are removed from the air sample by suction apparatus through a porous filter where particulates are deposited.
- The glass fiber filter of porous size less than 0.1 μ m is used in high volume sampler.
- Sampling period is 24 hours
- Air volume sucked : 2000 m^3
- Particulate concentration : $1 \mu\text{g}/\text{m}^3$ (microgram/ m^3)

3) Impingement:

- It is based on inertial technique, in which particles are collected from the high velocity air stream directed towards the obstacles placed across the path of air stream.
- The particulates collide with the obstacle & air changes its direction
- If the obstacle are adhesive surface then particles are impacted on it & this is known as dry impingement.
- If obstacle is wet by any liquid then it is called wet impingement.

- The efficiency of collection by impingement/impaction is high for particles whose dia is 1 μ or greater.
- For collection of Submicron particles, the impinger should be operated at high velocities.
- Examples for wet collectors are "Greenburg-Smith Standard impinger" and "midget impinger".
- In Greenburg-Smith's impinger, the air sample is drawn through an orifice of 2.3 mm in dia and impinges against a flat surface of 5 mm distant, with a jet velocity of about 113 m/s at a sampling rate of 28.3 l/min.
(For fig, refer textbook, Page 93) by MN RAO
- In the midget type, the air is drawn at a rate of 2.8 l/min through an orifice of 1 mm in dia and impinges against a flat surface of 5 mm distant, at a jet velocity of about 60 m/s
(For fig, refer textbook, Page 94) by MN RAO
- The collection efficiency is low for particles less than 0.7 μ in dia.
- Dry cascade impactors/impingers are also available and are useful for simultaneous collecting and size differentiating of an aerosol.

4) Precipitation

→ Precipitation is of two types

- 1) Thermal Precipitation
- 2) Electro-static Precipitation

1) Thermal Precipitation

→ It based on the principle that the particles move towards the lower temp. region when subjected to a strong temp. gradient.

→ The temp. gradients are normally of the order of $3000^{\circ}\text{C}/\text{cm}$

→ This technique is used to collect the particle size of 0.001 micrometer with high efficiency.

→ Detailed Process :- If a gas containing particles in suspension is brought into contact with a heated surface, a dust free space develops b/w the surface & particles, owing to the action of thermal force that causes the particles to migrate from a zone of high temp to zone of low temp.

2) Electrostatic Precipitation

- These type of Precipitators are an electrically charged to force radioactive particulates to migrate out the air steam onto a collection surface.
- In this precipitators, two electrodes are used one is positive and other one is negative.
- When the air steam with particulates pass through the electrodes, the particles which have negative charge and migrate towards inner post of the precipitators where got discharged and deposited on the positive electrodes.
- The most imp mechanism in the charging of Particles [whose dia $> 2\text{ }\mu$] is Bombardment by ions.
- For Particles [whose dia $< 2\text{ }\mu$], the controlling mechanism is "charging by ion diffusion" or the motion of ions induced by thermal motion of the surrounding gas molecules.
- Both the mechanisms are effective in collecting particles [whose dia is 0.2 to $2\text{ }\mu$].

Air sampling based on Gaseous pollutants & vapours

→ The gaseous sampling can be done by any one of the following methods

- Absorption
- Adsorption
- Condensation

a) Absorption

→ In this process, Effluent gases are passed through absorbers (scrubbers) which contain liquid absorbents that removes the one or more of the pollutants in the gas stream.

→ The resultant liquid is analyzed for the desired pollutant.

→ The efficiency of this process depends on

- Amount of surface contact b/w gas & liquid
- Contact time
- Concentration of the absorbing medium
- Speed of reaction b/w the absorbent & the gases.

→ Absorbents are being used to remove SO_2 , H_2S , SO_3 & NO_x .

→ The different types of devices used for Absorption

- Simple bubblers
- Midget impinger
- Greenburg-smith standard impinger
- Fluted absorbers
- Spiral type absorbers.

b) Adsorption

- In this process, the effluent gases are passed through adsorbents which contain solids of porous structure.
- The different types of adsorbents used in adsorption sampling are activated carbon, silica gel, activated alumina & activated Earth, etc..
- The factors affecting the adsorption of gaseous pollutants are:

- Concentration of pollutant in the air :- The higher the concentration of pollutant in the air, the greater the adsorption.
- Surface area of the adsorbent :- The large surface area of the adsorbents help to distill out impurities in air sample.
- Temperature :- The room temperature is considered to be ideal for the adsorption of pollutants in gases & vapours.
- Properties of Adsorbate :- High molecular weight compounds are easy to physically adsorb, while low molecular weight gaseous compounds are difficult to physically adsorb.

However low molecular weight gaseous compounds such as formaldehyde, ammonia & hydrochloride are adsorbed chemically.

c) Condensation

- the conversion of a volatile or gas to a liquid
- Freeze out/condensation/cryogenic sampling is the ideal method for collection of gaseous pollutants in the form of volatile organic compounds at extremely low concentration.
- The cryogenic trap is designed in a manner so as to allow progressive cooling of air in 2 or 3 stages by the use of coolants such as ice, dry ice, liquid air & liquid oxygen.
- As the gaseous pollutant pass through the different temp range of condensers where the temp is below the boiling point, the gaseous pollutant will trap in the liquid.

Stack Sampling

- Stack sampling/source sampling is a method of collecting representative samples of pollutant laden air/gases at the place of origin of pollutants to determine the total amount of pollutants emitted into the atmosphere from a given source in a given time.

→ The purpose of stack sampling:-

- a) To have an accurate data of the quality & quantity of different pollutants emitted from stacks.

- b) To device various methods for pollution control
 - c) To analyze the efficiency of control measures
 - d) To evaluate the efficiency of various pollution control devices.
- e) To check the compliance of the emissions with the help of emission standards.
 - f) Preparation of emission inventories.

selection of sampling location

- The sampling point should be as far as possible from any disturbing influence such as elbows, bends, transition pieces, baffles or other obstructions.
- The sampling point, wherever possible should be at a distance of 5 to 10 diameters downstream from any obstructions and 3 to 5 diameters upstream from similar disturbances.

size of sampling point

- For collection of samples, an opening has to be made to an extent of accomodating the probe.
- The size of sampling point may be made in the range of 7 to 10 cm in dia.
- A flange may be inserted so that the opening may be closed during the non-sampling period.

Traverse point

- For the sample to become representative, it should be collected at various points across the stack.
- This is essential as there will be changes in velocity & temp across the c/s of stack.
- Transverse points have to be located to achieve this and are to be located @ the centre of each of a no. of equal areas in the selected c/s. of the stack.

Diameter / C/S Area	<12	<20	<30	<48	>48
No. of Traverse Points	4	6	8	10	12

- For rectangular stacks, the area is divided into 12 to 25 equal areas & traverse points are det.

Isokinetic Conditions

- The flue gas & particulates from the stacks have high temperature & high velocity
- In order to obtain a true representative sample, the velocity of the gas stream must be equal to the velocity of gas @ the nozzle of the probe. This condition is referred as the "ISOKINETIC" condition.
- This condition can be achieved when the velocity of the gas in the stack is equal to the velocity of the gas at nozzle of the probe. Such sample is said to be more representative for measuring the particulates.

Monitoring of sulphur dioxide:

The stack monitoring of SO_2 by west gaekc method

→ In this method, SO_2 gas in stack sample

reacts with Para-rosaniline, methyl sulphuric acid to form a "red coloured complex"

→ The colour formed is read in "spectro-photometer" at 575 nm.

Reagents required

a) Para-rosaniline hydrochloride (0.04% /w/v)

b) Sodium tetrachloromercurate (0.1M)

c) Iodine solution (0.01N)

d) Sodium sulphite solution

e) Formaldehyde solution (0.2%)

f) Starch solution

Procedure

→ 1) 10 ml of Sodium tetrachloromercurate [absorbing solution] is taken in a test tube & air sample is allowed to flow into it.

→ 2) 1 ml of Para-rosaniline solution, 1 ml of formaldehyde solution is added to the test tube

- 3) A blank sample is taken using 10 ml of sodium tetrachloromercurate in another test tube and labelled as blank.
- 4) A stock solution is prepared by adding 2 ml of standard sodium sulfite solution to 100 ml of Sodium tetrachloromercurate
- 5) This stock solution is diluted to prepare a calibration curve b/w absorbance & volume of SO_2 (ml)
- 6) The SO_2 in the stack sample in the experimental tube is measured spectrophotometrically at 575 nm.
- 7) The amount of SO_2 in the sample per 10 ml of Sodium tetrachloromercurate is calculated from the graph.

Calculations

The amount of SO_2 in stack sample

$$= \frac{\mu\text{l of } \text{SO}_2}{\text{Volume of air sample}}$$

Analysis of SO_2 by Hydrogenperoxide method

→ The SO_2 in air sample is absorbed by Hydrogen peroxide solution at pH 5.0 to get oxidized to sulphuric acid.

Reagents required

- Hydrogenperoxide solution [0.03N @ pH 5.0]
- Sulphuric acid (0.002N)
- Sodium hydroxide solution (0.002N)
- Indicator solution (Bromocresol green & methyl red)

Procedure

- Hydrogenperoxide solution [absorbing solution] is taken in a conical flask and air sample is allowed to pass into it.
- 75 ml. of the above sample [containing Hydrogenperoxide & air sample] is taken in a conical flask and 3 drops of indicator solution is added.
- This solution mixture is titrated with standard solution of sodium hydroxide till the change in colour is observed i.e from red to green colour.

→ The blank reagent is also titrated in the similar manner and the observed values are subtracted from the sample titre.

Monitoring of oxides of carbon :

→ The CO₂ present in the flue gas can be analyzed by "Titrimetric method"

→ In which the gas is allowed to pass through alkali hydroxide solution to form alkali carbonates, followed by titration with acid

→ The CO in flue gas is analyzed by "Non-dispersive infrared (NDIR) spectroscopy" method.

→ The NDIR sensor consists of the following parts:

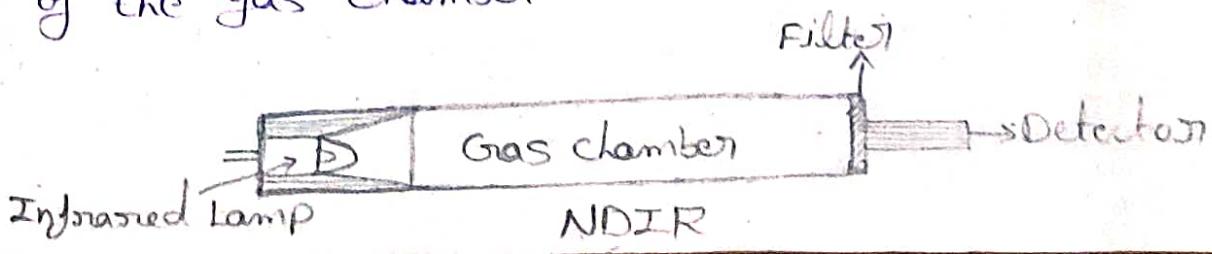
a) Infrared lamp

b) Gas sample chamber

c) wavelength filter

d) Infrared detector

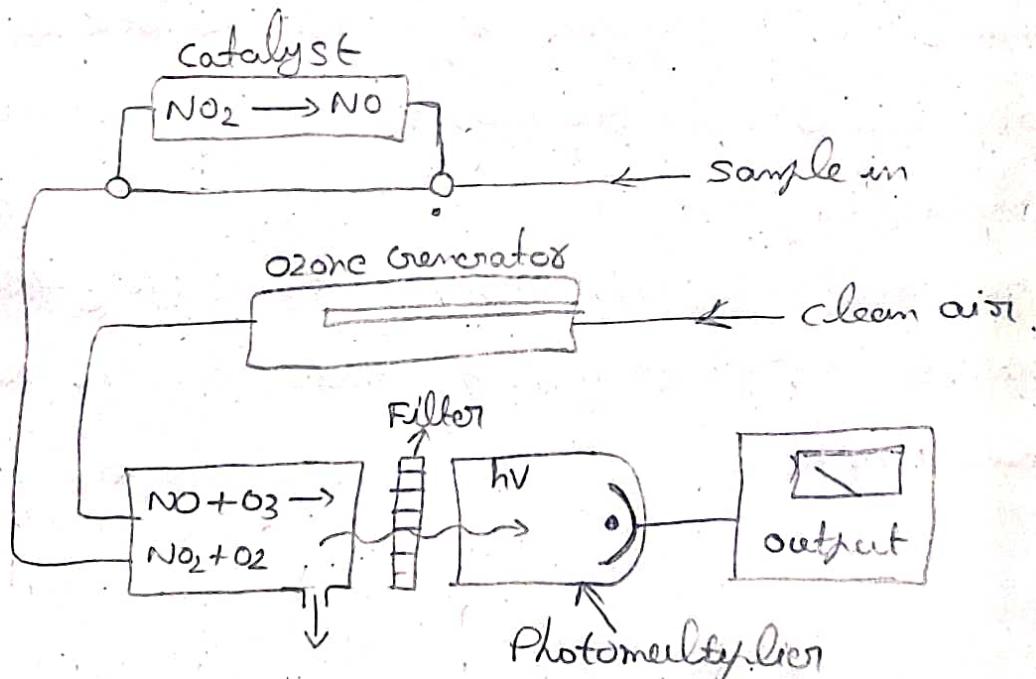
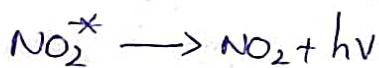
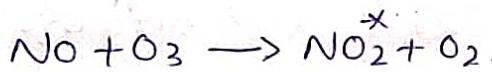
→ The Infrared lamp gives out a beam of infrared light which can be measured by the infrared detector placed at the opposite end of the gas chamber.



- When a gas sample is allowed to pass into the gas chamber, the CO_2 gas in particular absorbs a specific wavelength of energy within the infrared spectrum ($\sim 900 \text{ nm}$ to $10,000 \text{ nm}$)
- While the other gases in the sample do not absorb that wavelength.
- The wavelength filter located just before the infrared detector allows only that wavelength of light that has not been absorbed by the CO_2 gas, which is then detected by the infrared detector.
- When there is a negligible CO_2 gas in the sample chamber, all the infrared wavelength reach the detector.
- When the concentration is high in the sample chamber, the infrared light is absorbed by the CO_2 gas.
- Hence less infrared light reaches the detector.
- The sensor calculates the concentration of CO_2 gas in the air sample in Parts per million (PPM).

Monitoring of NOx

- The NOx concentration is measured by a "chemiluminescence analyzer" for the NO, NO₂ & NOx concentration measurement.
- The principle of this method stands on the nitrogen molecule excitation by ozone
- with the conversion of the molecule into the basic energetic level, liberation of radiation as chemiluminescence occurs.
- This radiation is detected by a photomultiplier
- The analyzer design makes possible the acquisition of information on NO, NO₂, NOx concentrations.
- The reaction b/w NO & O₃ is an example



Chemiluminescence Layout

- The ozone is generated by UV irradiation of clean air & mixed in a reaction chamber with the sample air.
- Light from the reaction passes through an optical filter and is detected with a photomultiplier tube.

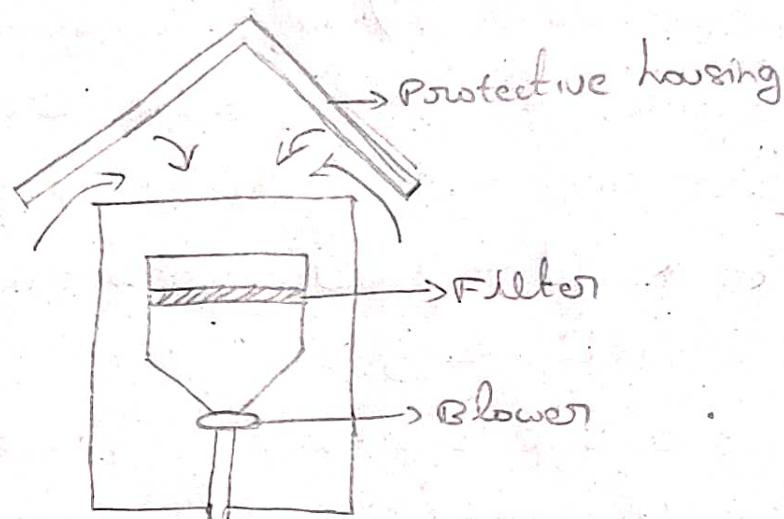
Monitoring of NH₃

- The measurement of NH₃ can be done by chemiluminescence analyzer using the same principle as a NO_x analyzer, but with an ammonia converter.
- In which, the sample gas is passed through the converter which converts NH₃ & NO_x to NO, producing the total oxides of nitrogen (NO_x).
- In the next cycle, the sample is routed through a photolytic converter which converts nitrogen oxides to NO, producing the NO_x reading.
- The difference b/w these readings (NO_y-NO_x=NH₃) provides a reading proportional to the NH₃ concentration.

monitoring of PM_{2.5} & PM₁₀

- Traditionally SPM is measured by sucking air through a filter & determining the weight of dust collected.
- The equipment used is known as High-volume Air sampler [@ high flow rates typically $1.13 \text{ m}^3/\text{min}$ or $40 \text{ ft}^3/\text{min}$]
- The air is drawn into the sampler & through a glass fiber or quartz filter by means of a blower so that particulate material collects on the filter surface.
- without a size selective inlet , particles of $100 \mu\text{m}$ size & less enter the sampling inlet & are collected on the downstream filter.
- the results are referred to as total suspended particulate (TSP)
- For the collection of particulates of size 100 to $0.1 \mu\text{m}$ or less, the glass fiber filters can be used and are ordinarily collected.
- For the collection of PM₁₀ , PM_{2.5} or PM₁ Quartz filters can be used with a size-select inlet.
- The volume of air sample is determined by a flow-rate indicator

- The high volume air sampler consists of
- Protective housing
 - An electric motor
 - A high speed, high volume blower
 - A filter holder
 - A flow controller



→ The air is drawn through a pre weighed filter at a known rate which collects particles on the surface.

→ the filter is weighed again to determine the mass of particles collected

$$\rightarrow TSP = \frac{(w_f - w_i) \times 10^6}{v}$$

where w_i = initial wt. of clean filter in (g)

w_f = final wt. of exposed filter in (g)

v = volume of sampled air = Qxt

Q = avg sample flow rate @ ambient temp & pressure in m^3/min

t = sampling time in min

$\times 10^6$ = conversion of gram to mg

Air quality modeling

→ Air quality models use mathematical & numerical techniques to simulate the physical & chemical processes that affect air pollutants as they disperse & react in the atmosphere.

Purposes:

- 1) Establishing emission control legislation
- 2) Evaluating proposed emission control techniques & strategies
- 3) Selecting location of future sources of pollutants in order to minimize their environmental impacts.
- 4) Planning the control of AP episodes
- 5) Assessing responsibility for existing AP levels

Factors to be considered:

→ In AP dispersion modeling, 5 major physical processes are simulated

- a) Pollutant advection
- b) Diffusion
- c) Deposition
- d) Chemical reaction (i.e transformation)
- e) Emission

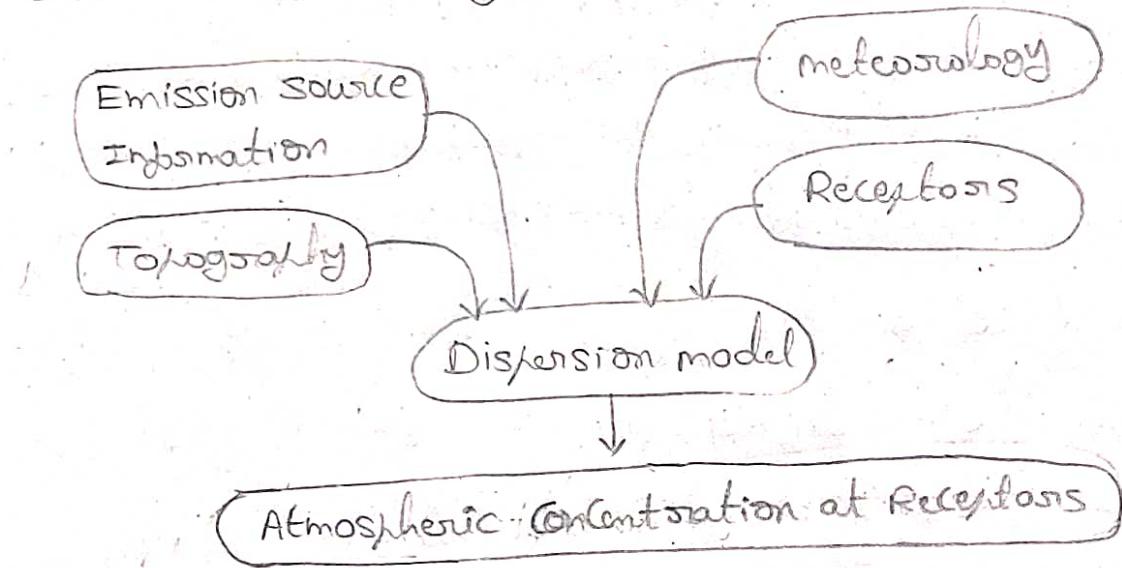
Types of Air quality models

- 1) Dispersion / Diffusion modeling: uses mathematical formulations to characterize atmospheric processes that disperse a pollutant emitted by a source
- 2) Photochemical smog modeling: Long-range air quality models that simulate the changes of pollutant concentrations in the atmosphere due to chemical & physical processes

3) Receptor modeling : mathematical / statistical Procedure for identifying & quantifying the source of air pollutants at a receptor location.

Atmospheric Dispersion model

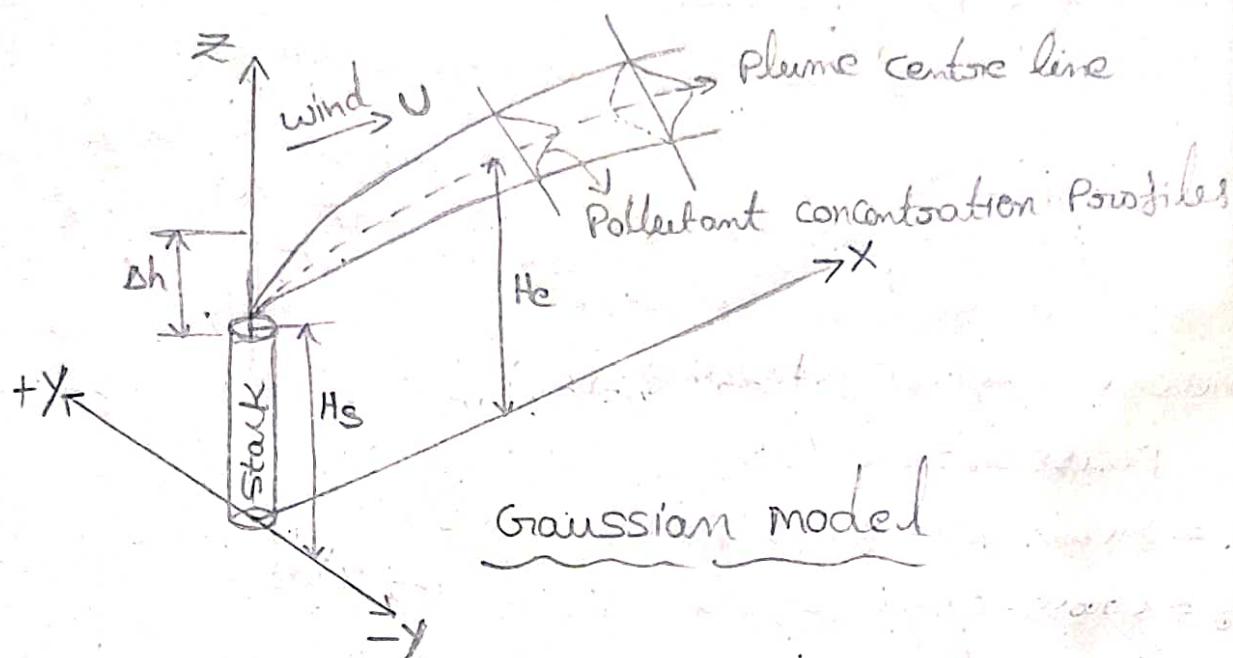
- It is a mathematical simulation of the physics & chemistry governing the transport, dispersion & transformation of pollutants in the atmosphere
- It means of estimating downward air pollution concentrations, given information about the pollutant emission & nature of the atmosphere.



Gaussian Plume dispersion model :

- The dispersion of the pollutant in the atmosphere is explained using "Gaussian Plume dispersion" model.
- It is most widely used method
- It is based on assumption like
 - i) Stagnant gas transported downstream
 - ii) Dispersion in vertical direction is governed by atmospheric stability

- iii) Dispersion in horizontal plane is governed by molecular & eddy diffusion.
- The plume spread & shape vary in response to meteorological conditions.



where H_s = Actual stack height

H_e = Effective stack height = $H_s + \Delta h$

Δh = Plume rise

- The plume in general tries to flow in upward direction due to exit velocity & buoyancy effects
- But due to the prevailing wind, the plume turns into downward direction
- The plume while travelling in downward direction diffuses & assumed to take the shape of the concentration profile given by Gaussian model technique as shown in above fig.
- The concentration decreases in the downward direction (being maximum at centre-line)
- The pollution concentration at any point is given by $C(x, y, z) \propto Q \frac{G}{y}$; G = Normalized gaussian curve in yz Q = Emission flow rate

Gaussian Expression

→ Point source at elevation "H"

→ The concentration of a pollutant at any point (x, y, z) in the 3-D field downwind of the elevated point source of effective height (H) is given as

$$C(x, y, z, H) = \frac{Q}{2\pi U \sigma_y \sigma_z} \left[\exp\left(-\frac{y^2}{2\sigma_y^2}\right) \right] \left\{ \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right] \right\}$$

↓ centre line ↓ Horizontal ↓ vertical

where C = concentration (g/m^3)

Q = emission rate (g/s)

U = mean wind speed @ plume height (m/s)

σ_y = cross-wind dispersion parameter (m)

σ_z = vertical dispersion parameter (m)

x, y, z = location of receptor

Gaussian Equation for specific conditions

1) Ground level concentration ($z=0$)

$$C(x, y, 0, H) = \frac{Q}{\pi U \sigma_y \sigma_z} \left[\exp\left(-\frac{y^2}{2\sigma_y^2}\right) \right] \exp\left[-\frac{H^2}{2\sigma_z^2}\right]$$

2) Ground level centre line concentration ($z, y = 0$)

$$C(x, 0, 0, H) = \frac{Q}{\pi U \sigma_y \sigma_z} \left[\exp\left(-\frac{H^2}{2\sigma_z^2}\right) \right]$$

3) Ground level centreline concentration when source is also at the ground level ($z, y \approx H = 0$)

$$C(x, 0, 0, 0) = \frac{Q}{\pi U \sigma_y \sigma_z}$$

4) max ground level centre line concentration from Elevated source

$$C_{\max}(x, 0, 0, H) = \frac{2Q}{\pi U H^2} \frac{\sigma_z}{\sigma_y}$$

5) For infinite line source

$$c(x, y, 0, H) = \frac{2Q_l}{(2\pi)^{1/2} U \sigma_z} \exp\left[-\frac{H^2}{2\sigma_z^2}\right]$$

where Q_l = Emission rate/unit length

6) For infinite line source located at ground level

$$c(x, y, 0, 0) = \frac{2Q_l}{(2\pi)^{1/2} U \sigma_z}$$

① The emission rate of ethanol from Lane stadium is 100 g/s. At 3km downwind on a clear fall evening, what is the centre-line ground-level concentration of ethanol? The effective plume height is 41m, & the wind speed at this height is 2.5 m/s. At 3km downwind under these conditions, $\sigma_y = 80m$ & $\sigma_z = 30m$.

Sol

Given data

$$\text{Emission rate } (Q) = 100 \text{ g/s}$$

$$x = 3 \text{ km}$$

$$\text{Effective height } (H) = 41 \text{ m}$$

$$\text{Wind speed } (U) = 2.5 \text{ m/s}$$

$$(\sigma_y) = 80m$$

$$(\sigma_z) = 30m$$

$$c(x, y, z, H) = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left[-\frac{(y)^2}{2\sigma_y^2}\right] \times \\ \exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]$$

(If $y=0, z=0$ then the formula becomes)

$$= \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left[-\frac{(0)^2}{2\sigma_y^2}\right] \times$$

$$\exp\left[-\frac{(0-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(0+H)^2}{2\sigma_z^2}\right]$$

centre-line ground level concentration;

In this condition; $z=0$ & $y=0$

$$\text{Hence } c(x, 0, 0, H) = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left[-\frac{(H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(H)^2}{2\sigma_z^2}\right]$$

$$c(3, 0, 0, 41) = \frac{100}{2\pi \times 2.5 \times 80 \times 30} \exp\left[-\frac{(-41)^2}{2 \times 30^2}\right] + \exp\left[-\frac{(-41)^2}{2 \times 30^2}\right]$$

$$c = 0.0021 \text{ g/m}^3 = 2.1 \text{ mg/m}^3$$

SEWAGE DISPOSAL AND AIR POLLUTION ENGINEERING
Table 18.3. Pasquill Stability Types

Surface wind speed in m/sec	Day			Night	
	Incoming solar radiation			Mostly overcast	Mostly clear
	strong	moderate	weak		
< 2	A	A-B	B	-	-
2	A-B	B	C	E	P
4	B	B-C	C	D	R
6	C	C-D	D	D	D
> 6	C	D	D	D	D

Category A—extremely unstable
B—moderately unstable
C—slightly unstable
D—neutral
E—slightly stable
F—moderately stable

The maximum ground level concentration occurs where $\sigma_z = 0.707H$, provided $\frac{\sigma_z}{\sigma_y}$ is constant with downwind distance x .

Example 18.1. A coal-fired thermal power plant burns 6.25 tonnes of coal per hour, and discharges the combustion products through a stack having an effective height of 80 m. The coal has a sulphur content of 4.7%, and the wind velocity at the top of the stack is 8.0 m/sec. Atmospheric conditions are moderately to slightly unstable. Determine the maximum ground-level concentration of SO_2 and the distance from the stack at which this maximum occurs.

Solution. Emission rate for SO_2 :

$$\begin{aligned} \text{Coal burnt per hour} &= 6.25 \text{ t} \\ &= 6250 \text{ kg} \end{aligned}$$

Sulphur content of coal = 4.7%

$$\begin{aligned} \therefore \text{Sulphur produced per hr} &= 6250 \times \frac{4.7}{100} \text{ kg} \\ &= 293.75 \text{ kg} \end{aligned}$$

Now, $S + O_2 = SO_2$

ENGINEERING OF AIR POLLUTION, ITS CONTROL, AND MONITORING 777

the molecular mass of both S and O₂ is 32, and they combine on a one to one mass basis.

$$\therefore 293.75 \text{ kg of S} + 293.75 \text{ kg of O}_2$$

$$= 587.5 \text{ kg of SO}_2 \text{ per hour}$$

$$\text{Emission rate of SO}_2 \text{ in gm/sec} = \frac{587.5 \times 1000}{60 \times 60} \text{ gm/sec}$$

$$= 163.19 \text{ gm/sec.}$$

The maximum ground level concentration occurs where $\sigma_z = 0.707 H$, provided $\frac{\sigma_z}{\sigma_y}$ is constant with x .

For the given atmospheric conditions of *moderately to slightly unstable*, we have the stability class as *B* to *C*. (Table 18.3). For conservative designs, let us assume it to be class *C*.

The max. ground level concentration would occur where

$$\begin{aligned}\sigma_z &= 0.707 H \\ &= 0.707 \times 80 \\ &= 56.6 \text{ m.}\end{aligned}$$

From Fig. 18.8, we can find that σ_z will reach a value of 56.6 m at $x = 850$ m (for *C* class of course).

Hence, max. concentration would occur at $x = 850$ m, provided $\frac{\sigma_z}{\sigma_y}$ is constant upto this distance. It can be confirmed from the chart (Fig. 18.8) that for class *C* conditions, $\frac{\sigma_z}{\sigma_y}$ is constant for distances (x) up to 1 km from the stack.

Hence, $x_{max} = 850$ m.

Now, to determine concentration at $x = 850$ m, we use the eqn. (18.4), as

$$C_{(x, 0)} = \frac{Q}{\pi u \cdot \sigma_z \cdot \sigma_y} (e)^{-\frac{1}{2} \left(\frac{H^2}{\sigma_z^2} \right)}$$

From Fig. 18.7, $\sigma_y = 88$ m at $x = 850$ m (*C* class)

$$\begin{aligned}\therefore C_{max} &= \frac{163.19}{3.14 \times 8 \times 56.6 \times 88} (e)^{-\frac{80^2}{2(56.6)^2}} \text{ gm/m}^3 \\ &= 4.8 \times 10^{-4} \text{ gm/m}^3 \\ &= 480 \mu \text{ gm/m}^3. \text{ Ans.}\end{aligned}$$

Example 18.2. From the data given in example 18.1, determine the ground level concentrations at a distance of two km downwind at : (a) The centre line of the plume ; and (b) at a crosswind distance of 0.5 km on either side of the centre line.

Solution. (a) Concentration at $x = 2$ km along centre line of plume, means $y = 0$ and $x = 2$ km. This concentration is given by equation (18.4) as :

$$C_{(x, 0)} = \frac{Q}{\pi u \cdot \sigma_z \cdot \sigma_y} (e)^{-\frac{1}{2} \frac{H^2}{\sigma_z^2}}$$

where $\sigma_z = 130$ (from Fig. 18.6 for $x = 2$ km and C class)

$\sigma_y = 220$ (from Fig. 18.7 for $x = 2$ km and C class)

$$\begin{aligned} \therefore C_{(2, 0)} &= \frac{163.19}{3.14 \times 8 \times 130 \times 220} (e)^{-\frac{80^2}{2 \times (130)^2}} \text{ gm/m}^3 \\ &= 2.27 \times 10^{-4} \times (e)^{-0.189} \text{ gm/m}^3 \\ &= 2.27 \times 10^{-4} \times \frac{1}{(e)^{0.189}} \text{ gm/m}^3 \\ &= 2.27 \times 10^{-4} \times \frac{1}{1208} \text{ gm/m}^3 \\ &= 1.878 \times 10^{-4} \text{ gm/m}^3 \\ &= 187.8 \mu \text{ gm/m}^3. \text{ Ans.} \end{aligned}$$

(b) Concentration at $x = 2$ km and $y = 0.5$ km (i.e., 500 m) is given by eqn. (18.3) as :

$$\begin{aligned} C_{(x, y)} &= \frac{Q}{\pi u \cdot \sigma_z \cdot \sigma_y} \cdot (e)^{-\frac{H^2}{2 \cdot \sigma_z^2}} \cdot e^{-\frac{y^2}{2 \cdot \sigma_y^2}} \\ &= \frac{163.19}{3.14 \times 8 \times 130 \times 220} (e)^{-\frac{80^2}{2 \times (130)^2}} \times (e)^{-\frac{(500)^2}{2 \times (220)^2}} \text{ gm/m}^3 \\ &= (1.878 \times 10^{-4}) \cdot (e)^{-2.583} \text{ gm/m}^3 \\ &= 1.878 \times 10^{-4} \times 0.0755 \text{ gm/m}^3 \\ &= 0.142 \times 10^{-4} \text{ gm/m}^3 \\ &= 14.2 \mu \text{ gm/m}^3. \text{ Ans.} \end{aligned}$$

18.7.1. Effective Height of a Stack. The value of H used in equation (18.3) is the effective height of the stack (chimney) and not its actual height. This effective height consists of actual height (h)

UNIT-II

①

(Gaussian plume Model
Assumptions
 (APC))

Example ①: Determine the ground level concentration at a distance 2km downward for the following locations.

- (i) central line of the plume and
- (ii) At a cross-wind distance of 0.5km on either side of the centre line.

(Given: $\sigma_x = 130\text{m}$ $\sigma_y = 220\text{m}$ Stack height = 80m. Emission rate of $\text{SO}_2 = 163.19 \text{ g/sec}$ avg wind speed = 8 m/s).

Solution

$$\langle P_A \rangle (x, 0, 0H) = \frac{Q}{\pi \sigma_y \sigma_z u} \exp \left[-\frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2 \right]$$

Given data:

$$H = 80\text{m}$$

$$\sigma_y = 220\text{m.}$$

$$z = 0 \text{ (ground level core)}$$

$$x = 2\text{ km} \approx 2000\text{m.}$$

$$Q = 163.19 \text{ g/sec}$$

$$\sigma_x = 130\text{m.}$$

$$u = 8 \text{ m/s}$$

(2)

(i) $y = 0$ (central line of plume
 $\langle p_{SO_2} \rangle (2000, 0, 0, 250)$

$$\langle P_A \rangle (x, 0, 0, H) = \frac{Q}{\pi \delta_y \delta_z \bar{u}} \exp \left[-\gamma_2 \left(\frac{H}{\delta_z} \right)^2 \right]$$

(ii) $y = 0.5 \text{ km}$ or 500 m

$\langle p_{SO_2} \rangle (2000, 500, 0, 250)$

$$\langle P_A \rangle (x, y, 0, H) = \frac{Q}{\pi \delta_y \delta_z \bar{u}} \exp \left[-\gamma_2 \left(\frac{y}{\delta_y} \right)^2 \right] \exp \left[-\gamma_2 \left(\frac{H}{\delta_z} \right)^2 \right]$$

$$(i) \langle p_{SO_2} \rangle (x, 0, 0, H) = \frac{Q}{\pi \delta_y \delta_z} e^{-\gamma_2 \left(\frac{H}{\delta_z} \right)^2}$$

$$= \frac{163.19 \times 10^6}{\pi \times 8 \times 220 \times 130} e^{-\gamma_2 \left(\frac{80}{130} \right)^2}$$

$$= 227.03 \times 0.8278$$

$$= \underline{\underline{187.94 \text{ Mg/m}^3}}$$

(ii) Formula $\langle p_{SO_2} \rangle (x, y, 0, H)$

$$= \frac{Q}{\pi \delta_y \delta_z} e^{-\gamma_2 \left(\frac{y}{\delta_y} \right)^2} \times e^{-\gamma_2 \left(\frac{H}{\delta_z} \right)^2}$$

$$= \frac{163.19 \times 10^6}{\pi \times 8 \times 220 \times 130} e^{-\gamma_2 \left(\frac{500}{220} \right)^2} e^{-\gamma_2 \left(\frac{80}{130} \right)^2}$$

$$= 227.03 \times 0.0756 \times 0.8278$$

$$= \underline{\underline{14.2 \text{ Mg/m}^3}}$$

(3)

Example 2. A chimney with a design stack height of 250m is emitting SO_2 at the rate of 500 gm/sec on a sunny day in June with moderate wind speed of 6m/sec at stack altitude. Estimate concentration of SO_2 downwind for the following conditions.

(a) $\angle p_{\text{SO}_2} \geq (1000, 0, 0, 250)$

(b) $\angle p_{\text{SO}_2} > (1000, 50, 0, 250)$

(c) $\angle p_{\text{SO}_2} > (1000, 50, 20, 250)$

(d) if $\angle p_{\text{SO}_2} (1000, X, 0, 250)$ is 100 Mg/m^3

What is the value of X ? Assume $\sigma_y = 151 \text{ m}$ and $\sigma_z = 108 \text{ m}$.

Solution

Given data

$$H = 250 \text{ m.}$$

$$Q = 500 \text{ gm/sec}$$

$$U = 6 \text{ m/sec}$$

$$\sigma_y = 151 \text{ m.}$$

$$\sigma_z = 108 \text{ m.}$$

$$\text{(a)} \quad \angle p_{\text{SO}_2} (X, 0, 0, H) = \frac{Q}{\pi U \sigma_y \sigma_z} e^{-\frac{Y^2}{2\sigma_z^2}} \left(\frac{H}{\sigma_z} \right)^2$$

$$\angle p_{\text{SO}_2} (1000, 0, 0, 250)$$

$$= \frac{500 \times 10^6}{\pi \times 6 \times 151 \times 108} \times e^{-\frac{Y^2}{2 \times 108^2}}$$

$$= 1626.6 \times 0.0686$$

$$= 111.6 \text{ Mg/m}^3$$

(4)

$$(b) \quad \text{RPSO}_2 > (x, y, 0, H)$$

$$= \frac{\rho}{\pi \sqrt{\sigma_y \sigma_z}} e^{-y_2} \left(\frac{y}{\sigma_y} \right)^2 \times e^{-y_2} \left(\frac{H}{\sigma_z} \right)^2$$

$$\text{RPSO}_2 > (1000, 50, 0, 250)$$

$$= \frac{500 \times 10^6}{\pi \times 6 \times 151 \times 108} e^{-y_2} \left(\frac{50}{151} \right)^2 e^{-y_2} \left(\frac{250}{108} \right)^2$$

$$= 1626.6 \times 0.9464 \times 0.0686$$

$$= \underline{105.62} \text{ Mg/m}^3$$

$$(c) \quad \text{RPSO}_2 > (x, y, z, H) = \frac{\rho}{2\pi\sigma_z\sigma_z} e^{-y_2} \left(\frac{y}{\sigma_y} \right)^2$$

$$\times \left\{ \left(e^{-y_2} \left(\frac{z-H}{\sigma_z} \right)^2 \right) + \left(e^{-y_2} \left(\frac{z+H}{\sigma_z} \right)^2 \right) \right\}$$

$$= \frac{500 \times 10^6}{2\pi \times 6 \times 151 \times 108} \times e^{-y_2} \left(\frac{50}{151} \right)^2 \times \left(e^{-y_2} \left(\frac{20-250}{108} \right)^2 + e^{-y_2} \left(\frac{20+250}{108} \right)^2 \right)$$

$$= 813.3 \times 0.9464 \times (0.104 + 0.0439)$$

$$= \underline{113.5} \text{ Mg/m}^3$$

(d) Dividing (a) by (b) to get y'

$$\frac{\text{RPSO}_2 > (x, 0, 0, H)}{\text{RPSO}_2 > (x, y, 0, H)} = e^{-y_2} \left(\frac{y}{\sigma_y} \right)^2$$

$$= \frac{(1000, 0, 0, 250)}{(1000, y, 0, 250)} = e^{-y_2} \left(\frac{y}{151} \right)^2$$

$$= \frac{111.6}{100} = C^{\frac{1}{2}} \left(\frac{1}{151}\right)^2$$

$$\therefore \sin(1-116) = \frac{1}{2} \left(\frac{4}{151}\right)^2$$

$$\underline{\underline{y = 7.8 \text{ m. Ans}}}$$

X