MODULE 1

INTRODUCTION

ISI definition for air pollution IS-4167(1966)

"Air pollution is the presence in ambient atmosphere of substances, generally resulting from the activity of man in sufficient concentration, present for a sufficient time and under circumstances which interfere significantly with the comfort, health or welfare of persons or with the full use or enjoyment of property".

American Medical Association

"Air pollution is the excessive concentration of foreign matter in the air which adversely affects the well being of the individual or causes damage to property".

Engineers Joint Council (U.S.A)

"Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke, or vapour, in quantities, with characteristics, and of durations such as to be injurious to human, plant, or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property".

1. Classification of air pollutants:

Air pollutants can be classified as follows:

1. Natural contaminants

   e.g., natural fog, pollen grains, bacteria and products of volcanic eruption.

2. Aerosols (particulates)

   e.g., dust, smoke, mists, fog and fumes

3. Gases and vapours

The various gases and vapours, which are important air contaminants are given in table 1.

Table 1: Air contaminants

Sl No	Group	Examples
1.	Sulphur compounds	SO_3, SO_2, H_2S, mercaptants
2.	Nitrogen compounds	NO, NO_2, NH_3
3.	Oxygen compounds	O_3, CO, CO_2
4.	Halogen compounds	HF, HCl

5.	Organic compounds	Aldehydes, hydrocarbons
6.	Radioactive compounds	Radioactive gases

1.1 Natural contaminants

Among natural contaminants pollen is important because of its peculiar properties irritating to some individuals. Pollen grains are discharged into the atmosphere from weeds, grasses and trees. From the point of view of pollution, air-borne pollutants are significant because of the allergic responses produced in sensitive individuals. Many people suffer from asthma or hay fever, while most victims have an uncomplicated type of hay fever in which the symptoms disappear at the end of the pollen season; some develop bronchitis, bronchial asthma and dermatitis.

1.2 Aerosols

Aerosols refer to the dispersion of solid or liquid particles of microscopic size in gaseous media such as dust, smoke or mist. An aerosol can also be defined as a colloidal system in which the dispersion medium is a gas and the dispersed phase is solid or liquid.

The term aerosol is used during the time it is suspended in the air. After it has settled either by virtue of its weight, by agglomeration, or by impact on a solid or liquid surface, the term no longer applies. Thus, particulate matter is an air pollutant only when it is an aerosol. However, it is a nuisance both as an aerosol(visibility reduction) and as settled or deposited matter(soiling of surfaces, corrosions).

1.2.a Dust:

Dust is made up of solid particles predominantly larger than those found in colloids and capable of temporary suspension in air or other gases. They do not tend to flocculate except under electrostatic forces: they also do not diffuse but settle under the influence of gravity. Dust is produced by the crushing, grinding of organic and inorganic materials.

1.2.b Smoke:

Smoke consists of finely divided particles produced by incomplete combustion. It consists predominantly of carbon particles and other combustible materials. Generally the size of the particles is less than 1µ.

1.2.c Mist:

Mist refers to a low concentration dispersion of liquid particles of large size. In meteorology, it means a light dispersion of minute water droplets suspended in the atmosphere. Natural mist particles formed from water vapour n the atmosphere are rather large, ranging from 500-40µ n size. The particles may coalesce.

1.2.d Fog:

Fog refers to visible aerosols in which the dispersed phase is liquid. Formation by condensation is usually implied. In meteorology, it refers to dispersion of water or ice in the atmosphere near the earth's surface reducing visibility less than half kilometer. In natural fog the size of the particles ranges from 40-1µ.

1.2.e Fumes:

These are solid particles generated by condensation from the gaseous state, generally after volatilization from melted substances, and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce.

1.3 Gases

Following are the gases in air pollutants:

1.3.a Sulphur Dioxide:

This is one of the principal constituents of air pollutants. The main source of SO_2 is the combustion of fuels, especially **coal**. Its concentration in the atmosphere depends upon the sulphur content of the fuel used for heating and power generation. The sulphur content of fuels varies from less than 1% for good quality anthracite to over 4% for bituminous coal. During the smelting of many ores like zinc, copper and lead, sulphur dioxide is evolved in stack concentrations of 5-10% (SO_2). But, this can be recovered in the form of sulphuric acid. Among the miscellaneous operations releasing sulphur dioxide into the atmosphere are sulphuric acid plants and paper manufacturing plants. The quantities are usually low and therefore easily amenable to control measures. The open burning of refuse and municipal incinerators also contribute some amount of sulphur dioxide to the atmosphere.

1.3.b Hydrogen Sulphide:

H_2S is a foul smelling gas. The sources of its natural emission include anaerobic biological decay processes on land, in marshes and in oceans. Volcanoes and natural water springs emit H_2S to some extent. One of the major sources of H_2S is the Kraft pulp industry, which uses a sulphide process for manufacturing paper. The other industrial sources of H_2S are petroleum refineries, coke-oven plants, viscose rayon plants, and some chemical operations. Other sulphur compounds that are of interest in air pollution, principally because of their strong odours, are methyl mercaptants (CH_3 SH), dimethyl sulphide (CH_3 S CH_3), dimethyl disulphide (CH_3 SS CH_3) and their higher molecular homologs. The mercaptants are emitted in mixtures of pollutants from some pulp mills, petroleum refineries, and chemical manufacturing plants.

1.3.c Hydrogen Fluoride:

The major sources of fluorides are manufacture of phosphate fertilizers, the aluminium industry, brick plants, pottery, and ferro-enamel works. Small amounts are also emitted from other metallurgical operations, such as zinc foundries and open-hearth steel furnaces. Small amounts are also liberated in the burning of coal, which normally contains about 0.01% fluorine. Hydrogen fluoride is an important air contaminant even in extremely low concentrations of 0.001-0.1ppm by volume. In these concentration levels, hydrogen fluoride is more important in terms of injury to vegetation and animals than in terms of injury to humans. The high degree of toxicity of fluorine compounds renders the control of such emissions imperative for industries manufacturing aluminium and phosphate fertilizers.

1.3.d Chlorine and Hydrogen Chloride:

Chlorine is found in polluted atmosphere as the element itself(chlorine), as hydrogen chloride, as chlorine-containing organic compounds such as perchloroethylene and as inorganic chlorides. The last mentioned compounds are solids and hence found in particulate form: the other materials mentioned are present as gases.

The most common sources of chlorine in the atmosphere are from operations in which it is manufactured or used to produce other chemicals. Also as chlorine is used in water purification plants, in sewage plants and in swimming pools, equipment failure sometimes leads to leakage of chlorine into the atmosphere.

Hydrogen chloride is evolved in numerous industrial chemical processes, but it is so easy to recover, that little reaches the atmosphere.

The main effects of chlorine and its compounds are respiratory irritation from chlorine, corrosion by hydrogen chloride, and damage to vegetation from chlorine & hydrogen chloride.

1.3.e Oxides of Nitrogen:

The highest concentration of nitrogen oxides in gaseous emissions occurs in effluents from industries where nitric acid is produced or used in chemical reactions. The next highest concentration is in automobile exhausts. Then come effluents from large power plants, and then to a small extent those from low heat burners and furnaces.

Out of seven oxides of nitrogen (N_2O, NO, NO_2, NO_3, N_2O_3, N2O4, N_2O_5), only nitric oxide and nitrogen dioxide arise from many human activities and are classified as pollutants. In atmospheric analyses, they are usually reported as total oxides of nitrogen or NO_x. it is a standard practice in the chemical industry to absorb and recover significant quantities of oxides of nitrogen.

Ammonia and ammonium salts are not important air contaminants.

1.3.f Carbon Monoxide:

It is an odourless and colourless gas has its major origin in incomplete combustion of carbonaceous materials. It is a highly poisonous gas and is generally classified as an asphyxiant. The chief source of CO in the atmosphere is combustion, especially due to automobile exhausts.

Certain industrial operations, such as electric and blast furnaces, gas manufacturing plants, some petroleum refining operations and coal mines are potential contributors of CO.

1.3.g Ozone:

The origin of ozone that is found in the air has not been clarified, but it is likely that combustion and sunlight are involved in its production. Ozone is poisonous and smelly. It exists in great abundance under natural conditions in the upper atmosphere.

GENERAL DEFINITION FOR AIR POLLUTION

"Air Pollution is the pollution is the presence of undesirable material in air, in quantities large enough to produce harmful effects".

ISI DEFINITION FOR AIR POLLUTION [ISI-IS:4167(1966)]

"Air pollution is the presence in – ambient atmosphere of substances, generally resulting from the activity of man in sufficient concentration, present for a sufficient time and under circumstances which interfere significantly with the comfort, health or welfare of persons or with the full use or enjoyment of property"

DEFINITION BY AMERICAN MEDICAL ASSOCIATION (AMA)

"Air pollution is the excessive concentration of foreign matter in the air which adversely affects the well being of the individual causes damage to property"

CLASSIFICATION AND PROPERTIES OF AIR POLLUTION

CLASSIFICATION: The variety of matter emitted into the atmosphere by natural and anthropogenic sources are so diverse that it is difficult to classify air pollutants neatly at easily.

However usually they are divided into two categories

1. Primary pollutants
2. Secondary pollutants

PRIMARY POLLUTANTS	SECONDARY POLLUTANTS

• Primary pollutants are those that are emitted directly from the sources. • Typical pollutants are particulate matter such as ash, smoke, dust, fumes and mist; inorganic gases such as SO_2, H_2S, , nitric oxide, ammonia, CO, CO_2, hydrogen fluoride, olefinic and aromatic hydro carbons and also radio carbon and also radioactive components. • Of the large number of primary pollutants into the present in sufficient – concentration to be of immediate concern. • These are 5 major types particulate matter, sulphur dioxide, oxides of nitrogen hydrocarbons. • CO_2 is generally not considered because of its increased global concentration, its influence on the global climate patterns is of great concern.	• Secondary pollutants are those formed in the atmosphere by chemical reactions between primary pollutants and normal atmospheric constituents. • Pollutants such as SO_3, NO_2 Peroxy acetyl nitrate (PAN), ozone, aldehydes, ketones and various sulphate and nitrate salts are included in this category. • Secondary pollutants are formed from the chemical and photo chemical reaction in the atmosphere. • The reaction mechanisms are influenced by concentration of reactants at pollutants, the amount of moisture contents, degree of photo activation, meteorological forces and local photography.

PROPERTIES OF AIR POLLUTION

(1) <u>PARTICULATE MATTER</u>: In general the term particulate refers to all atmospheric substances that are not gases. They can be suspended droplets at solid particles at mixtures of the extremely reactive materials ranging in size from 100μm down to 0.1μm and less. The inert – materials do not react readily with the environment nor do they exhibit any morphological changes as a result of combustion or any other process, whereas the reactive materials could be with the environment as a result of combustion or any other process, whereas the reactive materials could be further oxidized at may react chemically with the environment.

The classification of various particulates one as follows:

DUST: It contains particles of size ranging from 1 to 200 μm. These are formed by natural disintegration of rock and soil at by the mechanical processes of grinding and spraying. They have large settling velocities and one removed from the air by gravity and other inertial processes. Fine dust particles act as centres of – catalysis for many of the chemical reactions taking place in the atmosphere.

SMOKE: It contains fire particles of the size ranging from 0.01 to 1 μm, which can be liquid at solid and are formed by combustion at chemical processes, smoke may have different colours depending on nature of materials burned.

FUMES: These are solid particles of the size ranging from 0.1 to 1 μm and are normally released from chemical at metallurgical processes

MIST: It is made U.P. of liquid droplets generally smaller than 10μ which are formed by condensation in the atmosphere or released from Industrial operation

FOG: It is the mist in which the liquid is water and is sufficiently dense to obstruct vision.

AEROSOL: Under this category are included all air borne suspensions either solid at liquid. These are generally smaller than 1 μm.

Particulates in the size range 1 to 10 μm have measurable settling velocities but are – readily disturbed by air movements, where as particles of size 0-1 to 1μm have small settling velocities. Those below 0.1μ a sub microscopic size found in urban all, undergo random – Brownian motion resulting from collision among individual molecules. Most particulates in urban all have sizes in the range 0.1 to 10μ. The finest and the smallest particles are the ones which cause significant damage to health.

(2) <u>OXIDES OF SULPHUR:</u> The most important emitted by pollution sources is SO_2 [sulphur] It is a colourless gas with a characteristic, pungent odour. It is moderately soluble in water [11.3 gm / 100ml] Forming weak acidic sulphurous acid (H_2SO_3). It is oxidized slowly in clean air to sulphur trioxide (SO_3). In a polluted atmosphere, SO2 reacts photo chemically at catalytically with other pollutants at normal atmospheric constituents to form SO3, H2SO4 and salts of H_2SO_4. SO_3 is generally emitted along with SO_2 at about 1-5% of SO_2 concentration, SO_3 rapidly which has a low dew point. Both SO_2 and SO_3 are relatively quickly washed out of the – atmospheres by rain at settle out as Aerosols.

(3) <u>NITROGEN OXIDES</u>: Of the six or seven oxides of nitrogen only three – nitrous oxide (N_2O), Nitric in any appreciable quantities in the atmosphere. Nitrous oxide (N_2O) is a colour less, odourless, non toxic gas present in the natural atmosphere major sources of N2O, in the natural atmosphere in relatively large concentration (0.25 ppm). The major sources of N_20 in the atmosphere is the biological activity of the soil and there are no anthropogenic sources. It has a low reactivity and is generally not considered as an Air Pollutant. Nitric oxide (NO) is a colour less, odourless, gas produced largely by fuel combustion. It is oxidized to NO_2 through photo chemical – secondary reactions. NO_2 is a brown pungent gas with an initiating odour which can be detected at concentrations of about 0.12 ppm. It absorbs sunlight and initiates a series of photo chemical reactions. NO_2 is probably produced by the oxidation of NO by ozone. NO_2 is of major concern as a pollutant and is committed by fuel combustion and Nitric acid plants.

(4) CARBON MONOXIDE (CO): It constitutes the single largest pollutant in the urban atmosphere CO is colourless, odourless and tasteless and has a boiling point of 0.192oc. It has a strong affinity towards Hemoglobin and is a dangerous pollutant. The rate of oxidation of CO to CO_2 in the atmosphere seems to be very slow, mixtures of CO and O_2 exposed to sunlight remain almost uncharged CO is present in small concentrations, 0.1 ppm in the natural atmosphere and has a residential time of about months. The main sources of CO in the urban air are smoke, exhaust fumes of many devices, burning coal, gas or oil.

(5) <u>HYDRO CARBONS:</u> The gaseous and volatile liquid hydrocarbons are of particular interest as air pollutants. Hydro carbons can be saturated or unsaturated, branched or straight chain or can have a ring structure as in the case of saturated class, methane is by far the most abundant hydrocarbons constituting about 40-80% of the total hydrocarbons present in an urban atmosphere. The unsaturated class includes alkenes (olefines) and acetylenes. Among alkenes the prominent pollutants are ethylene and propenes. The First member of aromatic class is benzene, but most of its substituted derivatives such as toluene and M-xylene are usually present in larger concentration in the urban atmosphere. Tarpenes are a particular class of volatile hydrocarbons emitted largely by a natural source: These are cyclic non-aromatic hydrocarbons found in pine for and other wood sources. The Hydrocarbons in air by themselves alone cause no harmful effects. They are of concern because the hydrocarbons undergo chemical reaction in the presence of sunlight and nitrogen oxides forming photochemical oxidants of which the predominant one is ozone. Methane has a very low photo chemical activity as compared to that of other hydrocarbons for this reason. He is the non methane hydrocarbons concentration is of interest while considering air pollution.

EMISSION SOURCES

The source of air pollution is numerous they can be grouped according to:

i) A variety of methods including type of source.

ii) Number of spatial distribution of sources

iii) Types of emissions:

SOURCE TYPE: Source type refers to natural and anthropogenic sources as well as to additional sub classifications within each group. Natural sources include wind blow dust, pollen grains, sea salt nuclei, volcanic gas and ash, smoking and trace gases from forest fires and tarpenes from forest. Anthropogenic sources cover a wide spectrum of types.

CLASSIFICATION OF ANTHROPOGENIC AID POLLUTION SOURCES

SOURCE TYPE	CATEGORY	IMPORTANT SOURCES	TYPICAL POLLUTANTS
Combustion	a) Stationary	Power plants, industrial boilers, diesel generations, municipal and industrial incineration refused	Oxides of sulphur, NOx, co, smoke fly ash, trace metal oxides.
	b)Mobile	Motor vehicles aircraft	CO, HC's, NOx, SO_2, particulars
Roasting and Heating processes	a)Non-Ferrous metallurgical	Roasting, smelting and refilling operations	Dust, Smoke, metal fumes (Cu, pd, Zn) SO_X
	b)Ferrous metallurgical	Materials handling are sintering & palletizing, coke owns, blast furnace, steel furnaces	Smoke, fumes, co odours, H2S2, organic vapours, fluorides
	c) non-metallic minerals	Crushed stone, gravel sand processing, cement glass, refractories and ceramic manufactures etc.,	Mineral and organic SO_2 particulates, NOx, dust fumes
Chemical petroleum	a)Petroleum refilling	Biogas, process heaters, catalyst regenerators, tractors, Store, storage	SO_X, HC's, NOx, particulate matter, CO, aldehydes,

pulp and paper		tanks compressor engines	ammonia, odour
	b) Inorganic chemicals	Sulphuric acid, plants, fertilizer, manufacture, nitric acid and ammonia plants, phosphoric acid manufacture	SO_2, HF, H_2S, NO_x, NH_3, particulate matter H_3PO_4, etc.
	c) Organic chemicals	Plastics, paint and varnish manufacture, synthetic rubber, rayon insecticide, soap and detergent manufacture, methanol, phenol etc	Particulate matter, odours, SO_2, CO, organic intermediates, product gases and vapours, solvent vapours etc.,
	d) Pulp and paper (Kraft process)	Digester below system pulp washers, recovery furnace, evaporators, oxidation towers	Particulate matter, odours sulphur, compounds (H_2S Methyne,,. Dimethyl sulphide and SO_2 (sulphite process)
Food and Agriculture	a) Food processing	Drying, preserving and packaging	Vapours, odours dust
	b) Crop spraying and dusting	Pest and weed control	Organic phosphates Chlorinated HC arsenic, lead
	c) Field burning	Refuse burning	Smoke, Fly ash and soot

ACCORDING TO NUMBER AND SPATIAL DISTRIBUTION

(EMISSION INVENTORY SOURCE CLASSIFICATION)

Air pollution sources can also be grouped – according to number and spatial distribution.

These include

i) Single at point sources (large stationary sources)

ii) Area sources (small stationary sources and mobile sources with indefinite routes)

iii) Line sources (mobile sources with definite routes)

TOTAL SOURCES

Sl .no	Stationary Sources		Mobile Sources	
	Point sources	**Area sources**	**Line sources**	**Area sources**
1.	Industrial processing	Residential	High way	Motor Vehicles

		heating (coal, gas at oil)	vehicles	light duty, medium duty, heavy duty
2.	Power plants	Institutional and commercial heating (coal, oil & gas)	Rail road coco motives	Rail yard locomotives
3.	Fuel Combustion (Industrial	On site incineration	Channel vessels	Port vessels
4.	Solid waste disposal (Municipal incinerators, open burning)	Open burning (large scale)		Airports
5.	Miscellaneous	Evaporative losses		Miscellaneous

TYPE OF EMISSIONS

Another source grouping by the type of emissions, with particulate and gaseous emissions being the major divisions.

CONCENTRATION OF POLLUTANTS (SCALES OF POLLUTANTS)

The concentration of a pollutant in the atmosphere can be expressed in a number of ways involving units of weights at volume/ unit weight at volume of air.

Four concentration scales are generally used to describe the concentrations of either gaseous at particulate pollutants.

1st SCALE OF CONCENTRATION: The first is the mass concentration (W_P) defined as the ratio of mass of pollutant to the mass of air + mass of pollutant i.e.,

$W_p = (m_p / m_a + m_p)$

Where,

m_p= mass of the pollutant

m_a= mass of pure air in a given volume of air pollutant mixture

2nd SCALE OF CONCENTRATION: The second concentration scale is column concentration (y_p) defined as the ration of the volume of pollutant to the volume of air + volume of pollutant i.e.,

BEHAVIOUR AND FATE OF AIR POLLUTANTS

Although large amounts of pollutants are discharged into the atmosphere, the very fact that their ambient levels have remained very much the same throughout the world suggests that there are certain pathways of exchange from the atmosphere to the earth, whereby the pollutants are continuously removed. These pathway or the scavenging process, as they are called may be grouped as follows for both particulates and gases.

I. **FOR PARTICULATES** :

a) Wet removal by precipitation

b) Dry removal by sedimentation, impaction and diffusion.

II. **FOR GASES:**

a) Wet removal by precipitation

b) Chemical reaction in the atmosphere to produce aerosols and/or absorption on aerosols with subsequent removal.

c) Absorption or reaction at Land and ocean surfaces.

WET PRECIPITATION:

Wet precipitation has two distinct Mechanisms- rain out and washout. The first includes various processes taking place inside clouds where the containments serve as condensation nuclei on which droplets condense. The second Mechanism repairs to the removal of pollutants below the cloud level by falling rain wet precipitation is one the most effective scavenging process for both particulates and gaseous pollutants in a global sense.

DRY DEPOSITION:

Particulate matter smaller than 0.1 often coagulates through mutual collisions and forms larger aggregates which are effectively removed by gravitational settling. Brownian motion is the major mechanism of coagulation, although atmospheric turbulence also enhances the diffusive motion of particles Atmospheric turbulence is particularly effective for coagulating larger particles whose Brownian motion is less pronounced. The rate of the settling of particles depends on their settling velocities according to the **STOKE'S LAW**.

STOKE’S LAW

$Vt=\{2gdp/18\mu a\}(\rho_p-\rho_a)[1+2c/d_pP]$

Where,

Vt=terminal settling velocity

dp=particle dia in cm

$\rho_p,\rho_{a=\text{density of particle}}$ and air

μa= viscosity of air

P= air pressure millibars

C=constant=0.0084

From the above equation, it is seen that the rate of sedimentation is strongly influenced by the particle size. Particles larger than 10mm have high settling rates and hence have short resident time in the atmosphere.

CHEMICAL REACTIONS IN THE ATMOSPHERE

Many of the gaseous pollutants undergo chemical reactions within the atmosphere and from either new compounds or aerosols. This made of removal is of great importance for SO_2 A large part of SO_2 in the atmosphere is oxidized to SO_2 which quickly combines with moisture to form H_2SO_4 mist. The overall reaction is represented as:

$$2\ SO_2+2H_2O+O_2\rightarrow 2H_2SO_4$$

This process has been catalyzed by metal salts such as iron and manganese commonly, found in the fly ash. These particle serve as nucleation sites for droplet formation and the sulphuric acid droplet may in turn react with metal salts, metal oxides such as MgO, Fe_2O_3.

INVERSION

If the cold layer of air at ground level is covered by warmer air at a higher level, the phenomenon is called inversion. During inversion, the vertical air movement is stopped and pollutants are concentrated in the inversion layer below. In this state, the atmosphere is stable and very less turbulence or mixing takes place. As a result, the pollutants in the air do not disperse. Inversion occurs typically in the months of October to February. The accumulation of smoke and other pollutants aggravates the problem of pollution by preventing the sun's rays from heating the ground and adjacent air. Fog is generally associated with inversions. Narrow valleys are favorable to inversions as horizontal air movement is restricted. During inversions visibility is greatly reduced and contaminant concentration is maximum.

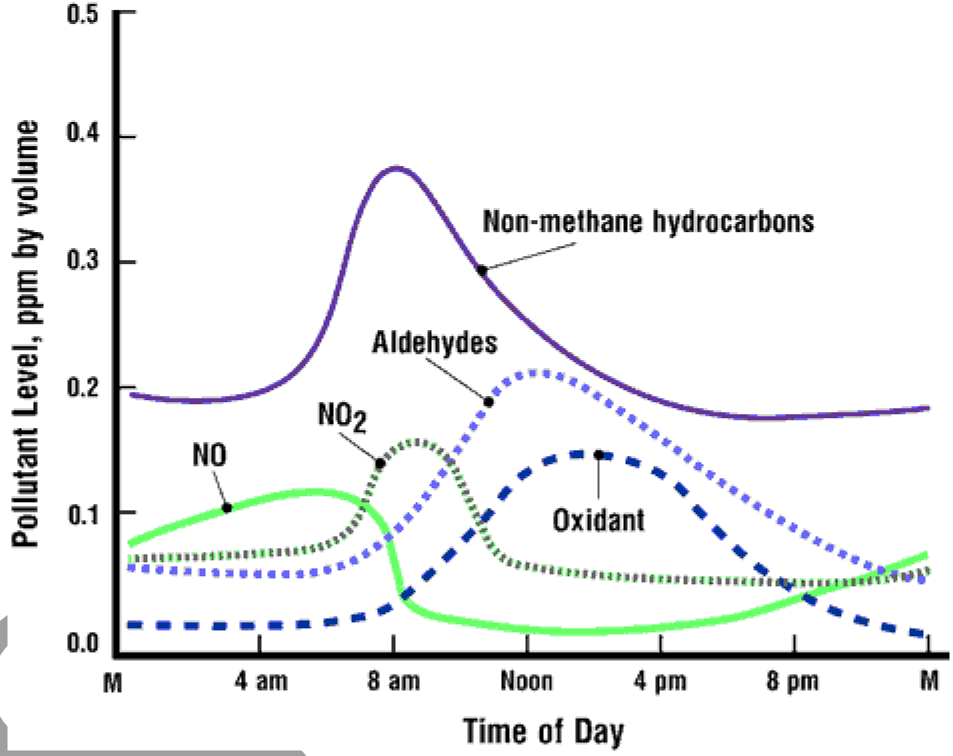
TYPES OF INVERSION

1. Radiation inversion
    - This type of inversion occurs at night, when the earth loses heat by radiation and cools the air in contact with it.
    - It occurs when the vertical movement of air is stopped until the sun warms the lower air, next morning.
    - Fog forms in this type of inversion if air is moist and temperature is below the dew point
    - It is common in winter due to longer nights
    - It frequently occurs in valley areas because of the restriction of horizontal air movement by surrounding high ground, may frequently have such inversions.
2. Subsidence inversion
    - This type of inversion occurs at modest altitudes and remains for several days
    - It is caused due to sinking of air in high pressure areas surrounded by low pressure areas
    - As the air sinks, it is compressed and gets heated to form a warm dense layer that prevents upward movement of contaminants
    - Inversion height varies from ground layer to a height of 1600 m.
    - At inversion height of 200 m, extreme pollution occurs.

If radiation and subsidence inversion occur simultaneously, the phenomenon is called "double inversion".

PHOTOCHEMICAL SMOG

Photochemical smog is formed due to photochemical oxidation of hydrocarbons and nitrogen oxides. The substances that react with nitrogen oxides to form oxidants (the final product of photochemical smog) are trace hydrocarbons (from incomplete combustion) and the hydroxyl radical. The necessary ingredients for photochemical smog formation are (1) nitrogen oxides, (2) sunlight, and (3) hydrocarbons. Photochemical smog formation proceeds through a sequence of reactions, all involving a free radical mechanism. Free radicals are generated by photo dissociation of nitrogen dioxide, a process that generates ozone and oxygen atoms. Oxygen atoms react with water to form hydroxyl radicals, which in turn react with hydrocarbons to form hydrocarbon radicals. Oxidation of hydrocarbons by the hydroxyl radical leads to the formation of aldehydes. The aldehydes are oxidized further to form aldehyde peroxides and aldehyde peroxyacids. These final substances are the compounds that are so irritating to sensitive biological tissues and cause most of the health problems associates with photochemical smog. Figure 40.3, shown below, is a diagram showing the changes in atmospheric concentrations for nitrogen oxide, nitrogen dioxide, non-methane hydrocarbons, aldehydes, and oxidants. Analysis of the data shown in figure led to the equations for photochemical smog formation (equations 1-8, shown below).



eq. 1 $NO_2 + h\nu \rightarrow NO + O$

eq. 2 $O + O_2 + M \rightarrow O_3 + M$ *Make O_3 and O*

eq. 3 $NO + O_3 \rightarrow NO_2 + O_2$

eq. 4 $O^{\bullet} + H_2O \rightarrow 2\,OH^{\bullet}$

This is a cyclic process that needs light and nitrogen oxides to generate oxygen atoms. Once formed, the oxygen atoms react with water to form hydroxyl radicals. The hydroxyl radicals then react with hydrocarbons according to equations 5 through 8 to form peroxyacyl nitrates (or PAN).

$$\text{eq. 5} \quad \left[\begin{array}{l} RH + OH^{\bullet} \rightarrow H_2O + R^{\bullet} \\ R^{\bullet} + O_2 \rightarrow RO_2^{\bullet} \text{ very fast} \end{array} \right.$$

$$\text{eq. 6} \quad \left[\begin{array}{l} RO_2^{\bullet} + NO \rightarrow NO_2 + RO^{\bullet} \\ RO^{\bullet} + O_2 \rightarrow R'CHO + HO^{\bullet}_2 \text{ very fast} \end{array} \right.$$

$$\text{eq. 7} \quad \left[\begin{array}{l} R'CHO + OH^{\bullet} \rightarrow R'CO^{\bullet} + H_2O \\ R'CO^{\bullet} + O_2 \rightarrow R'C(O)\,O_2^{\bullet} \text{ very fast} \end{array} \right.$$

$$\text{eq. 8} \quad R'C(O)O_2^{\bullet} + NO_2 \longrightarrow R'C(O)_2NO_2$$

EFFECTS OF VARIOUS POLLUTANTS ON HUMAN HEALTH, MATERIALS AND VEGETATION

INTRODUCTION:

All the impurities in the inhaled air do not necessary cause harm. Depending upon the chemical nature of the pollutants, some may be harmful when pleasant in the air in small concentrations and others only if they are present in high concentrations. The duration of exposure of the body to polluted air is also an important factor, therefore prime factors affecting human health are:

1) Nature of pollutants
2) Concentration of the pollutants
3) Duration of exposure
4) State of Health of the receptor
5) Age group of the receptor

Susceptibility to the effects of air pollution is more in case of infants and also elder people and those who are suffering from diseases. Those with Chronic diseases of lungs or heart are thought to be at great risk. The effect of air pollution on human health is worst during the winter seasons, when pollution levels reach a maximum. An objectionable odour, visibility reduction, eye intimation or vegetation damage are useful guides to the health effects.

VARIOUS HEALTH EFFECTS DUE TO AIR POLLUTION

1) Eye irritation
2) Throat and Nose irritation
3) Irritation of the respiratory tract
4) Bases like H_2S, NH_3 and mercaptants cause odour nuisance even at low concentrations.

5) Increase in mortality rate and morbidity rate.

6) A variety of particulates particularly pollens, initiates asthmatic attacks.

7) Chronic pulmonary diseases like bronchitis and asthma are aggregates by a high concentration of SO_2, NO_2, particulate matter and PCS.

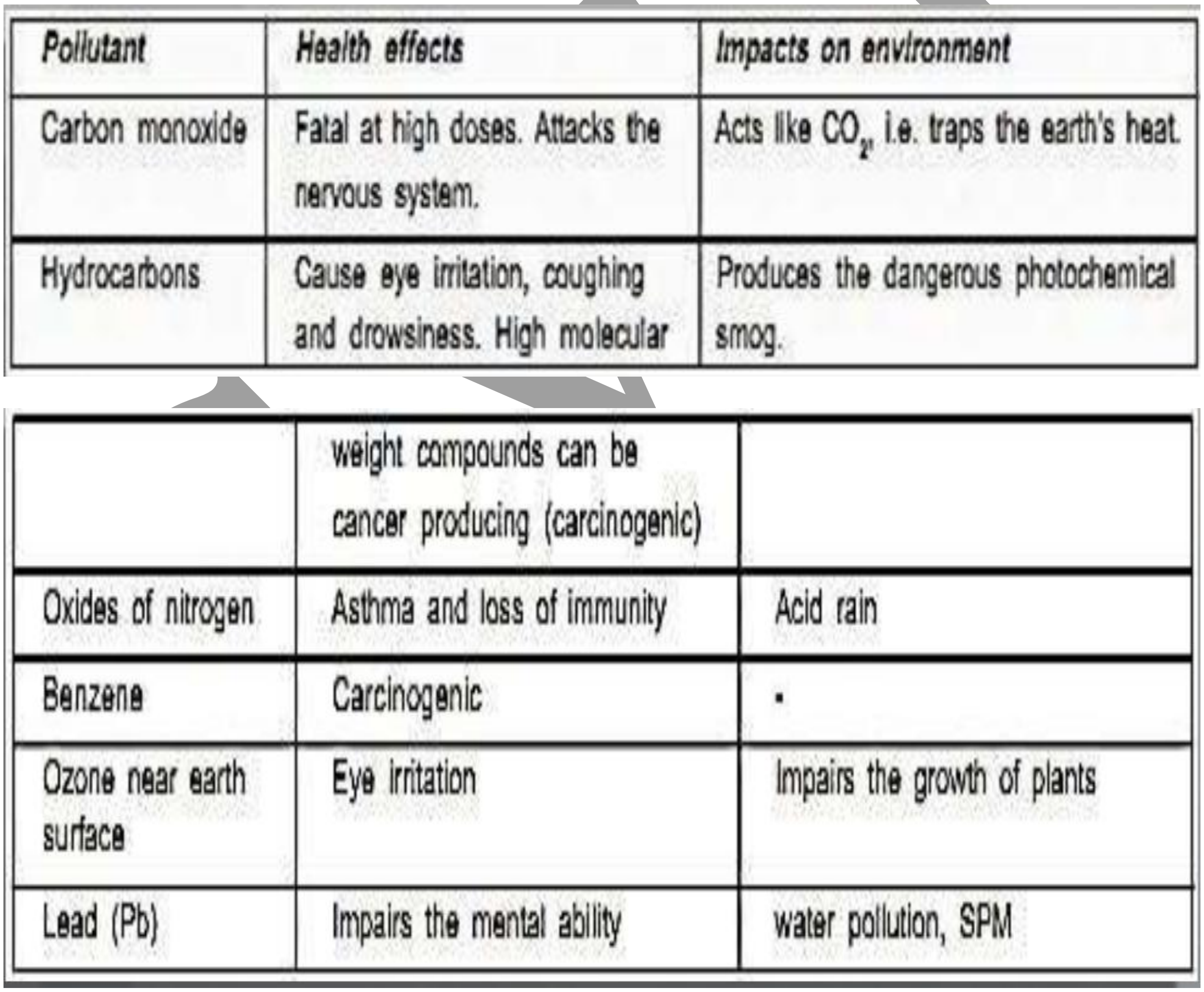
8) CO combines with the haemoglobin in the blood and consequently increases stress on those suffering from CARDIOVASCULAR and PULBONARY DISEASES.

9) Hydrogen Fluoride causes disease of the bone [Fluorosis] and mottling of teeth.

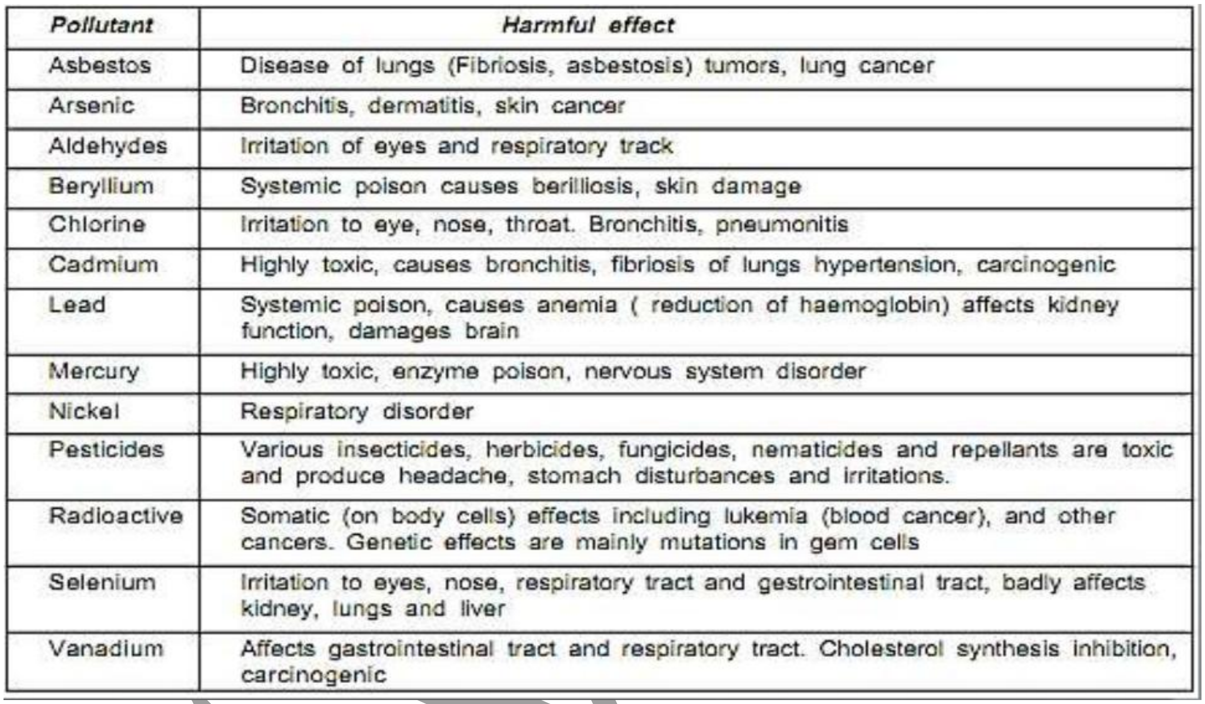
10) Carcinogenic agents cause cancer.

11) Dust particles cause respiratory diseases. Diseases like Silicosis, asbestosis etc. result from specific crusts.

12) Certain heavy metals like lead may enter the body through the longs and cause poisoning.



Pollutant	*Health effects*	*Impacts on environment*
Carbon monoxide	Fatal at high doses. Attacks the nervous system.	Acts like CO_2, i.e. traps the earth's heat.
Hydrocarbons	Cause eye irritation, coughing and drowsiness. High molecular weight compounds can be cancer producing (carcinogenic)	Produces the dangerous photochemical smog.
Oxides of nitrogen	Asthma and loss of immunity	Acid rain
Benzene	Carcinogenic	-
Ozone near earth surface	Eye irritation	Impairs the growth of plants
Lead (Pb)	Impairs the mental ability	water pollution, SPM



Pollutant	*Harmful effect*
Asbestos	Disease of lungs (Fibriosis, asbestosis) tumors, lung cancer
Arsenic	Bronchitis, dermatitis, skin cancer
Aldehydes	Irritation of eyes and respiratory track
Beryllium	Systemic poison causes berilliosis, skin damage
Chlorine	Irritation to eye, nose, throat. Bronchitis, pneumonitis
Cadmium	Highly toxic, causes bronchitis, fibriosis of lungs hypertension, carcinogenic
Lead	Systemic poison, causes anemia (reduction of haemoglobin) affects kidney function, damages brain
Mercury	Highly toxic, enzyme poison, nervous system disorder
Nickel	Respiratory disorder
Pesticides	Various insecticides, herbicides, fungicides, nematicides and repellants are toxic and produce headache, stomach disturbances and irritations.
Radioactive	Somatic (on body cells) effects including lukemia (blood cancer), and other cancers. Genetic effects are mainly mutations in gem cells
Selenium	Irritation to eyes, nose, respiratory tract and gestrointestinal tract, badly affects kidney, lungs and liver
Vanadium	Affects gastrointestinal tract and respiratory tract. Cholesterol synthesis inhibition, carcinogenic

MECHANISM OF ACTION OF POLLUTANTS

The effect of pollution on human health generally occurs as a result of contact between the pollutants and the body. Normally, bodily contact occurs at the surfaces of skin and exposes membranes contact with exposed membranous surfaces is of utmost important because of their absorptive capacity, compared to that of dry skin. Air borne gases, vapours, mist and dust may cause imitation of the membranes of the eyes, nose throat, larynx, tacheo-brochial tree and lungs some imitates even reach the mucosa of the digestive tract.

CASE STUDY IN ALLERGIC ANGENTS IN BANGALORE CITY

The garden city of Bangalore known for its fine climate is also known as the city of Asthma for many people. The incidence of Bronchial Asthma is particularly high in this city. Instances have been cited where people who have never exhibited tendencies earlier, have on coming to

Bangalore has attacks of Asthma. Further those who have had only mild attacks elsewhere experienced severe once here, Also it has been recorded that the percentage of asthmatics who reported relief when they left Bangalore is as high as 37.6%.

The survey undertaken by the asthma research society revealed that housewives [37.01%] and office workers [40.31%] are more susceptible to asthma attacks than industrial workers [7.11%] and retired persons [11.29%]. This suggests that as a casual factor for asthma and that attention should be focused on pollens, spores and dust particles. Some industrial operation may add to the allergens. Industrial operations like cotton, milling, for processing, hair processing, father processing, jute processing, leather processing, floor processing, wood working and tobacco processing may be included under this category.

EFFECTS ON VEGETATION

Pollution has been long known to have adverse effects on plants. At first is only sulphur dioxide that was considered a dangerous pollutant. Now with the advent of various pesticides and new industrial processes the range of harmful pollutants has multiplied tremendously.

STRUCTURE OF A NORMAL LEAF

Knowledge of a structure of a Leaf will help us to understand why damage occurs to examined, one will normally see a network of cleanser structures, the veins, all inter connected to the base or stem of the leaf. The leaf veins act as the transport system, for water and food just like blood vessels in animals. The leaf tissue is in layers with a skin or epidermis on top and bottom and photosynthetic cells in between. The stomata are the entrances in the leaves [top or bottom] through which CO_2 enters to play its role in photosynthesis. These openings are protected by pairs of specialized guard cells which open and close to all gases to enter or leave the leaf. Such gases also include pollutants like SO_2

EFFECT OF ENVIRONMENT ON PLANTS:

The primary factor which controls gas absorption by the leaves is the degree of the opening of the stomata. When the stomata are wide open absorption is maximum and vice versa. Consequently some conditions that enhance the absorption of the gas [CO_2 for photosynthesis] predispose the plant to injury [by absorption a pollutant like SO_2] conditions that cause the stomata to open are

1) High Light intensity [morning hours]
2) High relative humidity
3) Adequate moisture supply to the roots of the plants.
4) Moderate temperatures

LIST OF AIR POLLUTANTS AFFECTING PLANTS

i) SO_2
ii) Fluoride compounds
iii) Ozone
iv) Chlorine
v) Hydrogen Chloride
vi) Nitrogen oxides [NO, NO_2…….]
vii) Ammonia
viii) Hydrogen Sulphide
ix) Hydrogen Cyanide
x) Mercury
xi) Ethylene
xii) PAN
xiii) Herbicides
xiv) Smog

FORMS OF DAMAGE TO LEAVES

Damage to leaves takes several forms

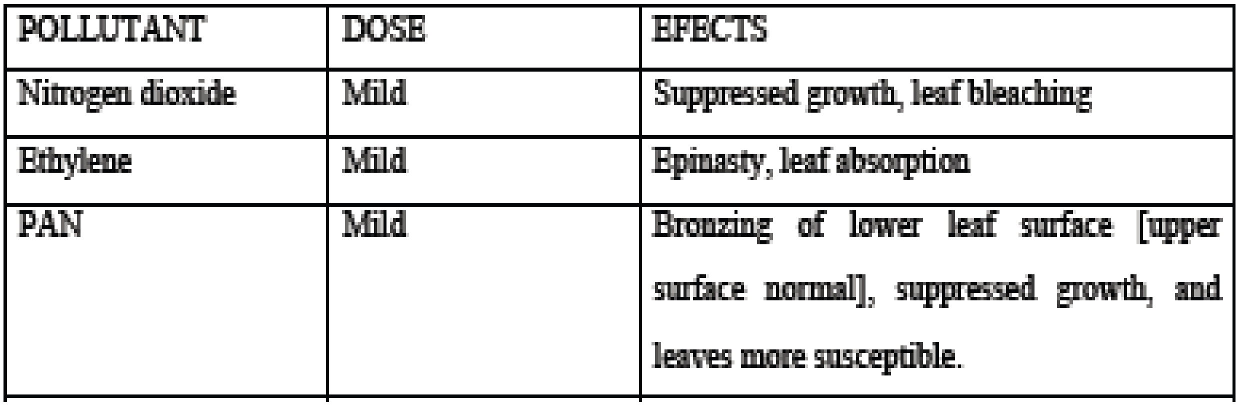
1) **NECROSIS:** Necrosis is the killing or collapse of tissue.

2) **CHLOROSIS:** It is a loss or reduction of the green plant pigment [chlorophyll]. The loss of chlorophyll usually results in a pale green or yellow pattern. Chlorosis generally indicates a

deficiency of some nutrient required by the plant. In many respects it is analogous to anemia in animals.

3) **ABSCISSION:** Leaf abscission is dropping of leaves.

4**) EPINASTY:** Leaf Epinasty is the downward curvature of a leaf due to higher rate growth on the upper surface



POLLUTANT	DOSE	EFECTS
Nitrogen dioxide	Mild	Suppressed growth, leaf bleaching
Ethylene	Mild	Epinasty, leaf absorption
PAN	Mild	Bronzing of lower leaf surface [upper surface normal], suppressed growth, and leaves more susceptible.

TIME CONCENTRATION EQUATIONS:

The effect of concentration versus time is an important variable in assessing damage. A high dose for a short time may cause an ACUTE INJURY [eg: Bhopal Gas tragedy] whereas the same total dose over a longer time may cause no visible effects at all longer time may cause no visible effects at all.

A concentration time equation may be expressed as,

$$t(C-Co) = K$$

Where,

t = time in hours to produce a certain effect on a certain species.

C = concentration of a specific gas in ppm

Co = Threshold concentration of the gas(ppm) to cause injury.

K = experimentally determined constant

The equation can be re-written as,

$$C = Co + K/t$$

Then, plotting ‘C’ versus 1/t, we get a straight line whose intercept ‘Co’ is the threshold for injury with the exception of some results for sulphur dioxide and ozone, sufficient data is not available at present to determine these parameters assuming that a linear model is accurate.

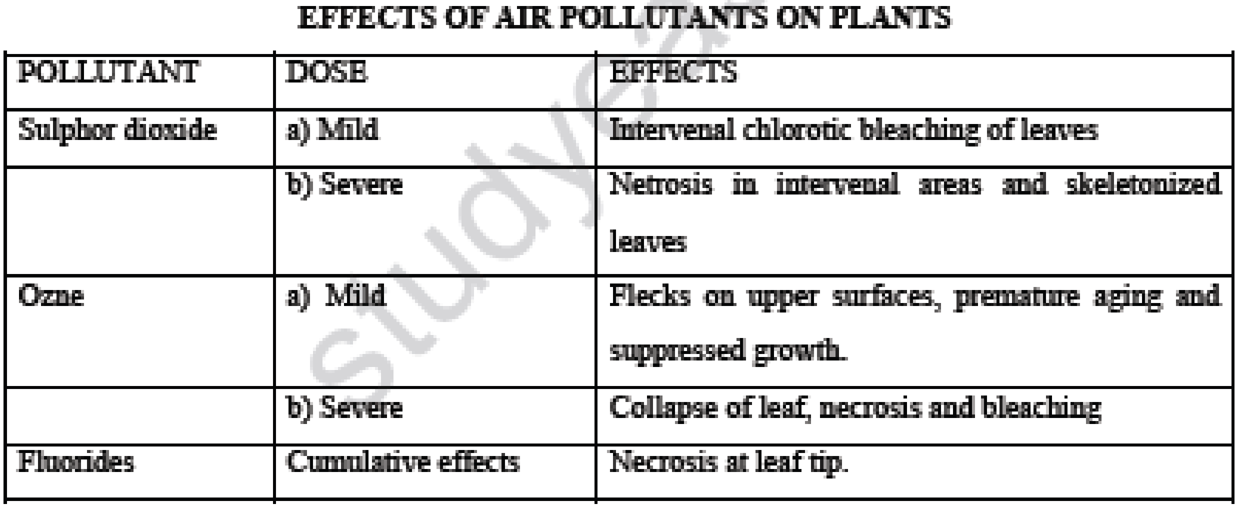
The equation is based on the exposure of a plant for a single pollutant. However in the field, exposures are not due to individual gases, but to an intimate of pollutants whose relative concentrations change as functions of time. Thus there are almost infinite number of possible combinations of pollutants which could be tested and severely injured by air pollutants often has characteristic colour. Bleaching is associated with SO_2, yellowing with ammonia, browning with Fluoride, A silvering or bronzing of the under surface of same leaves is associated with PAN injury PHYTO-TOXICANT is the name given to plant damaging substances..

KINDS OF INJURY TO PLANTS

1) **ACUTE INJURY:** It results from short time exposures to relatively high concentrations, such as might occur under fumigation conditions. The effects are noted within a few hours to few days and may result in visible markings on the leaves due to collapse and death of cells. This leads to narcotic patterns i.e. areas of dead tissues.

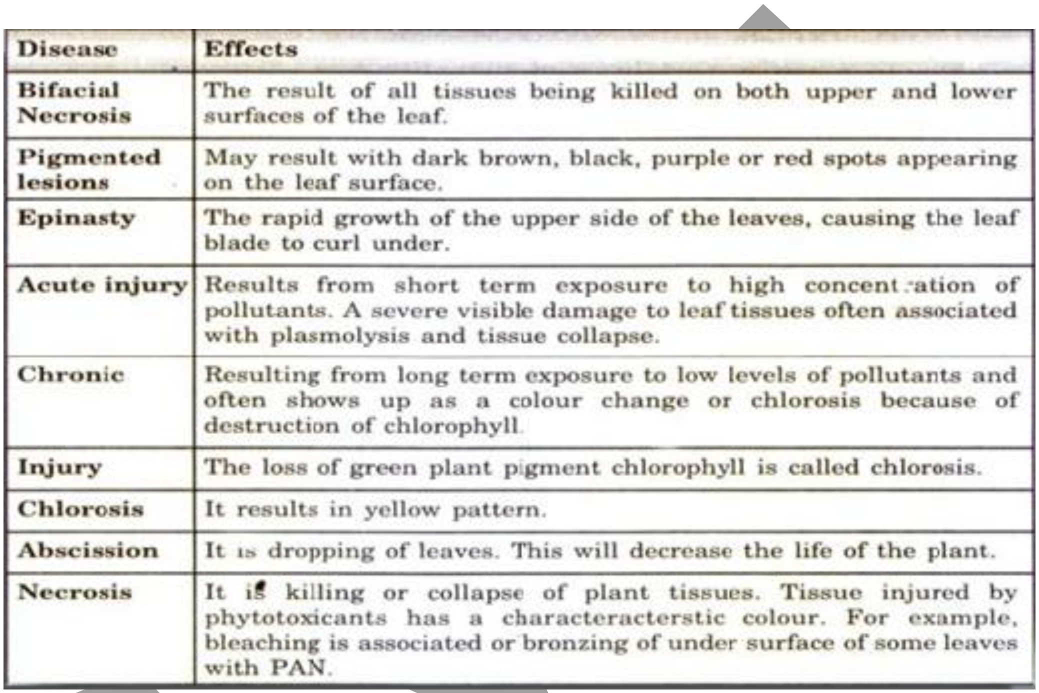
2) **CHRONIC INJURY:** It results from long term low level exposure and usually causes Chlorosis (or) leaf abscission.

3) **GROWTH OR YIELD RETARDATION**: Hare the injury is in the form of an effect on growth without visible markings [invisible injuries]. Usually a suppression of growth or yield occurs.



EFFECTS OF AIR POLLUTANTS ON PLANTS

POLLUTANT	DOSE	EFFECTS
Sulphor dioxide	a) Mild	Intervenal chlorotic bleaching of leaves
	b) Severe	Netrosis in intervenal areas and skeletonized leaves
Ozne	a) Mild	Flecks on upper surfaces, premature aging and suppressed growth.
	b) Severe	Collapse of leaf, necrosis and bleaching
Fluorides	Cumulative effects	Necrosis at leaf tip.



Disease	Effects
Bifacial Necrosis	The result of all tissues being killed on both upper and lower surfaces of the leaf.
Pigmented lesions	May result with dark brown, black, purple or red spots appearing on the leaf surface.
Epinasty	The rapid growth of the upper side of the leaves, causing the leaf blade to curl under.
Acute injury	Results from short term exposure to high concentration of pollutants. A severe visible damage to leaf tissues often associated with plasmolysis and tissue collapse.
Chronic	Resulting from long term exposure to low levels of pollutants and often shows up as a colour change or chlorosis because of destruction of chlorophyll
Injury	The loss of green plant pigment chlorophyll is called chlorosis.
Chlorosis	It results in yellow pattern.
Abscission	It is dropping of leaves. This will decrease the life of the plant.
Necrosis	It is killing or collapse of plant tissues. Tissue injured by phytotoxicants has a characteracterstic colour. For example, bleaching is associated or bronzing of under surface of some leaves with PAN.

EFFECTS ON MATERIALS

MECHANISM OF DETERIORATION

Air pollution cause damage to materials by 5 mechanisms

1. **ABRASION:** Solid particles of sufficient size and travelling at high velocities can cause abrasive action.

2. **DEPOSITION AND REMOVAL:** Solid and liquid particles deposited on a surface may not damage the material itself but it may spoil its appearance

3. **DIRECT CHEMICAL ATTACK:** Some air pollutants react directly and irreversibly with materials to cause deterioration.

Eg: The bleaching of marble by SO2, tarnishing of silver by H2S, etching of metallic surface by an acid mist

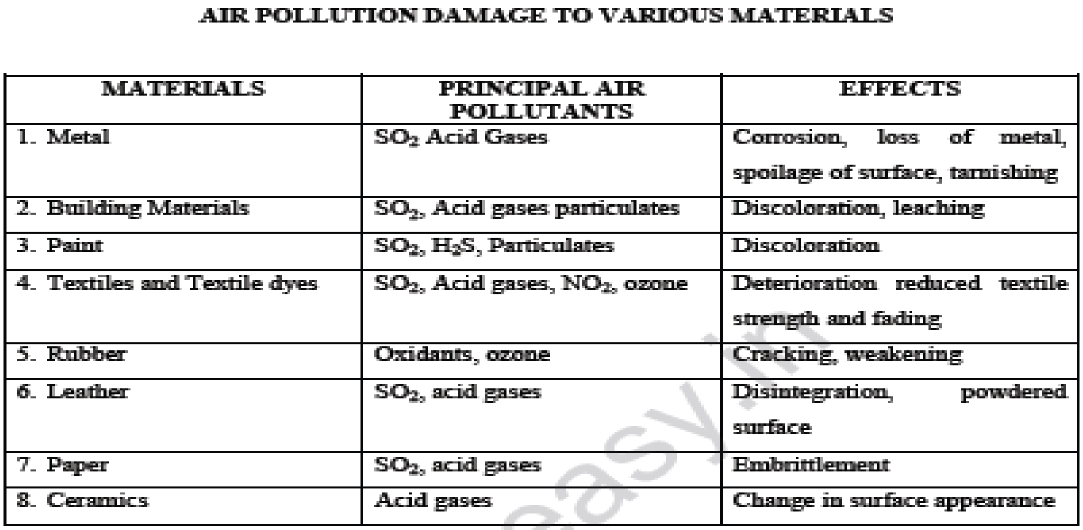
4. **INDIRECT CHEMICAL ATTACK:** Certain materials absorb some pollutants and get damaged when the pollutants undergo chemical changes.

5. **CORROSION:** The atmospheric deterioration of famous metals is by an electrochemical process i.e. corrosion. This is due to the action of air pollutants facilitated by the presence of moisture.

FACTORS INFLUENCING ATMOSPHERIC DETERIORATION:

1. **MOISTURE:** The presence of moisture in the atmosphere greatly helps the process of corrosion. In case of SO2 and various particulars, the rate of corrosion of metals will increase as relative humidity in the air increases.

2. **TEMPERATURE:** Affects the rate of chemical reaction and consequently affects the rate of deterioration.

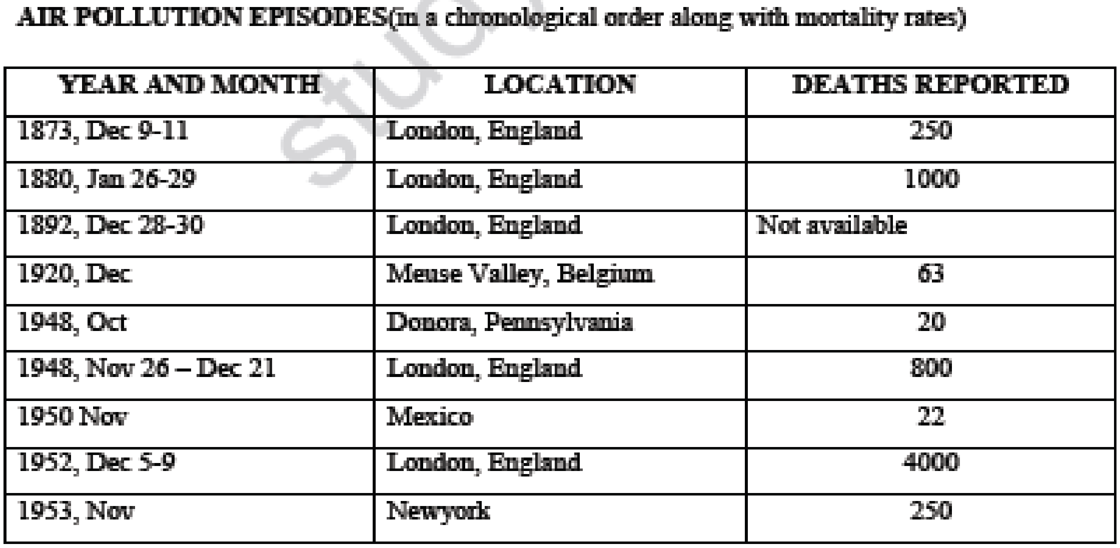


AIR POLLUTION DAMAGE TO VARIOUS MATERIALS

MATERIALS	PRINCIPAL AIR POLLUTANTS	EFFECTS
1. Metal	SO_2 Acid Gases	Corrosion, loss of metal, spoilage of surface, tarnishing
2. Building Materials	SO_2, Acid gases particulates	Discoloration, leaching
3. Paint	SO_2, H_2S, Particulates	Discoloration
4. Textiles and Textile dyes	SO_2, Acid gases, NO_2, ozone	Deterioration reduced textile strength and fading
5. Rubber	Oxidants, ozone	Cracking, weakening
6. Leather	SO_2, acid gases	Disintegration, powdered surface
7. Paper	SO_2, acid gases	Embrittlement
8. Ceramics	Acid gases	Change in surface appearance

3. **SUNLIGHT:** In addition to producing damaging agents such as ozone, PAN through a series of complex photo chemical reactions, sunlight can cause direct deterioration of certain materials.

4. **AIR MOVEMENT:** Wind direction is an important factor to be considered in places where deterioration is caused by pollutants released from nearby factories. Similarly wind speed is also an important factor in determining the impact of air pollutants on the receiving surfaces.



AIR POLLUTION EPISODES(in a chronological order along with mortality rates)

YEAR AND MONTH	LOCATION	DEATHS REPORTED
1873, Dec 9-11	London, England	250
1880, Jan 26-29	London, England	1000
1892, Dec 28-30	London, England	Not available
1920, Dec	Meuse Valley, Belgium	63
1948, Oct	Donora, Pennsylvania	20
1948, Nov 26 – Dec 21	London, England	800
1950 Nov	Mexico	22
1952, Dec 5-9	London, England	4000
1953, Nov	Newyork	250

1956, Jan 3-6	London, England	1000
1957, Dec 2-5	London, England	800
1958	Newyork	!
1959, Jan 26-31	Newyork	250
1962, Dec 5 – 10	London, England	700
1963, Jan 7-22	London, England	700
1963, Jan 9 – Feb 12	Newyork	400
1966, Nov 23-25	Newyork	170
1976, July	Sevesco, Italy	!
A984, Dec – 2	Bhopal, India	2500
1984, April	Chernobal, Ukraine (Reactor Explosion)	2500

EFFECTS ON ANIMALS:

- The cattle grazing on vegetation that has been contaminated with fluorine may develop fluorosis, even when the contaminated plants do not show signs of damage. Symptoms of advanced fluorosis in animals include: lack of appetite, general ill-health due to malnutrition, lowered fertility, reduced milk production and growth retardation.
- Arsenic from dusts and insecticide sprays falling on the plants can similarly be accumulated by the plants and when such contaminated vegetation is eaten by cattle, they may suffer from ARSENIC POISONING, with leading symptoms like salivation, thirst, vomiting, uneasiness, feeble and irregular pulse and respiration.

- The lead contaminated vegetation when eaten by live stock animals may cause **LEAD POISONING**, which may cause symptoms like inability to stand and staggering, prostration; besides complete loss of appetite, paralysis of digestive tract and diarrhea.

MODULE 2

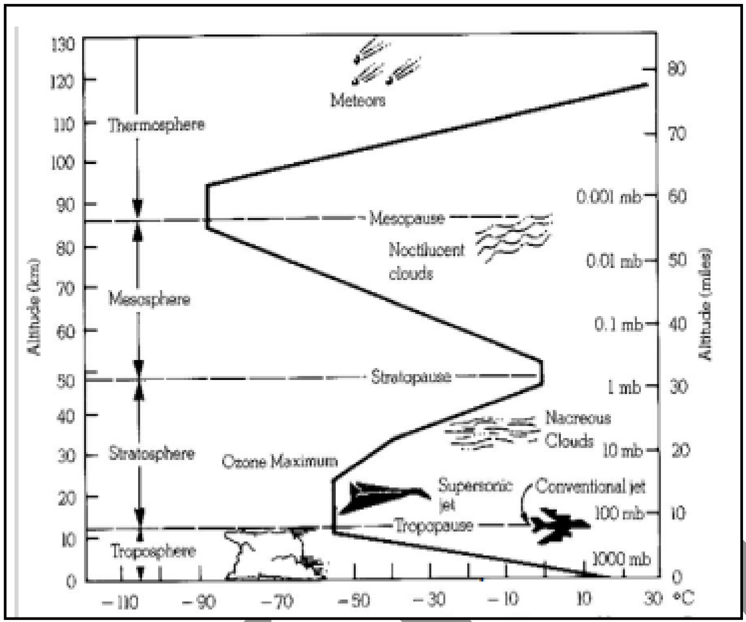
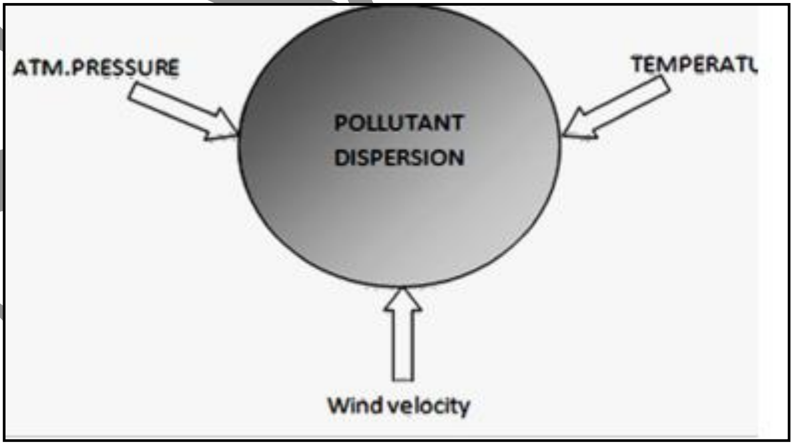


Fig: Structure of the Atmosphere

FACTORS AFFECTING POLLUTANT DISPERSION:

- Wind velocity
- Temperature
- Atmospheric pressure



LAPSE RATE

The temperature of the anbient air normally decreases witvgh increases in the altitude (height), this change of temperature is called lapse rate.

Environmental lapse rate: The prevailing lapse rate at a particular time and the particular place and determined by sending a balloon equipped with thermometer is called environmental lapse rate.

Adiabatic lapse rate: The air parcel moves up, its temperature decreases as its own heat energy is expanded due to increase in the volume of parcel, this rate of change in temperature with height is called adiabatic lapse rate.

Dry adiabatic lapse rate: expand and cooling at 9.8ºC / km.

Wet adiabatic lapse rate: expand and cooling at 6ºC / km.

The three major relative position:

(a) When ELR >ALR = the environment is said to be unstable & super adiabatic lapse rate.
(b) When ELR<ALR = the environment is said to be stable & sub adiabatic lapse rate.
(c) When ELR = ALR = the environment is said to be neutral.

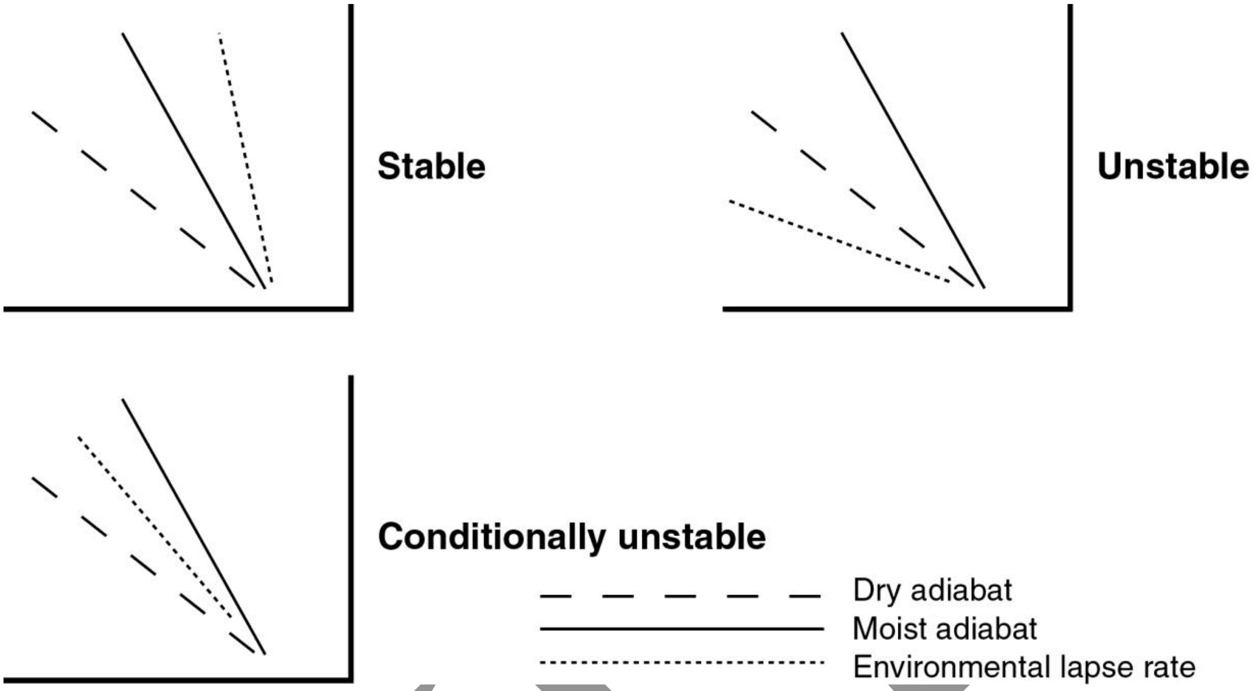
IMPACT OF WIND ON DISPERSION OF POLLUTANT

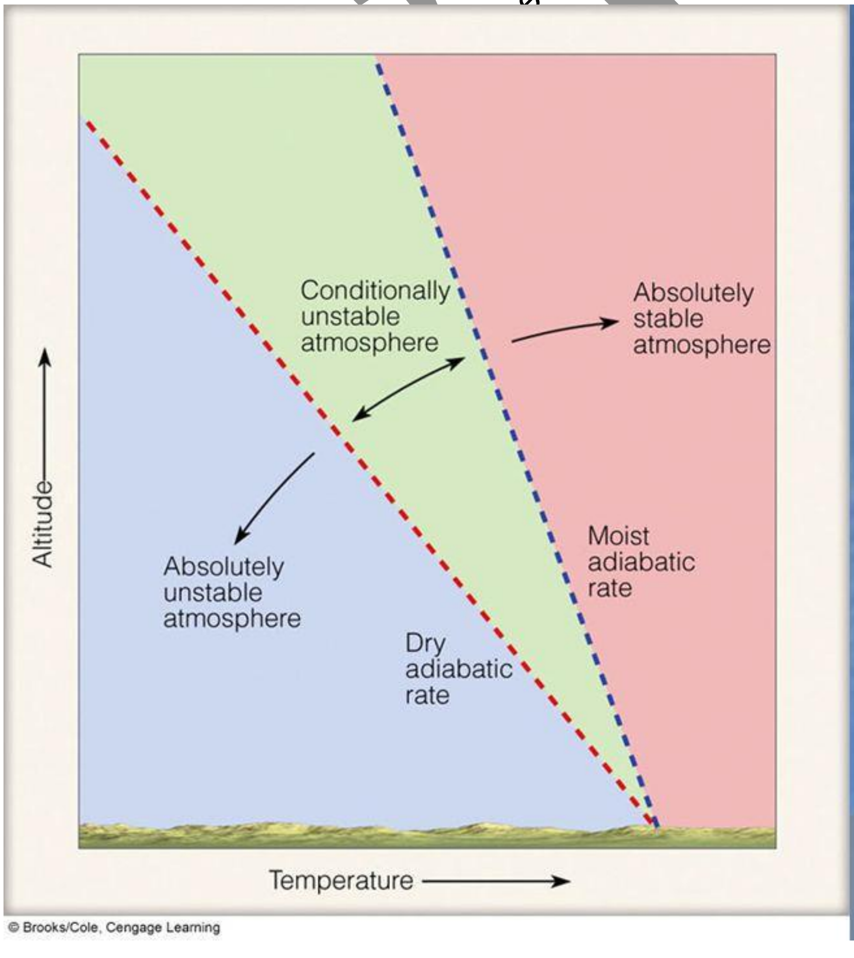
The moving air is called wind, such a movement caused by the unequal distribution of temperature and pressure on earth surface. A critical relationship exists between atmospheric stability and pollutant concentrations. Pollutants that cannot be transported or dispersed into the upper atmosphere quickly become trapped at ground level and pose a significant risk to human health and the environment. This relationship can be visualized in the behaviour of emission plumes from industrial smoke stacks.

Six types of air pollution plumes illustrate the relationship between atmospheric stability and pollutant emissions: looping plumes, fanning plumes, coning plumes, lofting plumes, fumigating plumes, and trapping plumes.

ATMOSPHERIC STABILITY AND TEMPERATURE INVERSIONS LAPSE RATE:

In well mixed air which is dry for every 100m MCI case in altitude, the temperature decreases by about 1^o C. This vertical temperature gradient is known as dry adiabatic lapse rate (DALR). Ambient and adiabatic lapse rates are a measure of atmospheric stability. Since the stability of the air reflects the susceptibility of rising air parcel to vertical motion, consideration of atmospheric stability or instability is essential in establishing the dispersion rate of pollutants. The atmospheric is said to be unstable as long as a rising parcel of air remains warmer than the surrounding air. Conversely, when a rising parcel of air arrives at an altitude in a colder and denser state than the surrounding air, the resultant downward buoyancy force pushes the parcel of air downward (Earthward) and away from the direction of displacement. Under such conditions atmosphere is said to be stable.





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-When the environmental lapse rate is *greater* than the dry adiabatic rate, the atmosphere is ***absolutely unstable***.

- When the environmental lapse rate is *less* than the moist adiabatic rate, the atmosphere is ***absolutely stable.***

- When the environmental lapse rate lies <u>*between*</u> the dry adiabatic rate and the moist adiabatic rate (shaded green area), the atmosphere is ***conditionally unstable***.

Stability is a function of vertical distribution of atmospheric temperature and plotting the ambient lapse rate can give an indication of the stability of the atmosphere. Though dry, moist or wet adiabatic lapse rate may be used, in such a comparison, the DALR issued as the measure against which several possible ambient lapse rates are plotted. Thus the boundary line between the stability and instability is DALR

When ALR exceeds DALR, the ALR is said to be SUPER – ADIABTIC and the atmosphere is highly unstable. When the two lapse rate are exactly equal, the atmosphere is said to be neutral. When the ALR is less than the DALR, the ALR is termed SUB-ADIABATIC and the atmosphere is stable. If air temperature is constant throughout a layer of atmospheric, ALR =O, the atmospheric layer is described as isothermal and the atmosphere is stable.

When temperature of the ambient air increases rather than decrease with attitude, the lapse rate is negative or inverted from the normal state. Negative lapse rate occurs under conditions, commonly referred to as an INVERSION, a state in which warmer air blankets colder air.

INVERSIONS:

When the reverse or negative lapse rate occurs, a dense cold stratum of air at ground level gets covered by lighter warmer air at higher level, this phenomenon is known as INVERSION. During inversion vertical air movement is stopped and pollution will be concentrated beneath the inversion layer i.e. in the denser air at ground level. As a result, during temperature inversion, the atmospheric is stable and very little turbulence or mixing takes place under such conditions pollutants in the air do not disperse. Inversion is a frequent occurrence in the autumn and winter months and the accumulation of smoke and other contaminants further aggravates pollution by preventing the sunrays from warming the ground and adjacent air. Fog is commonly associated with inversions; narrow valleys are favorable to inversions. The horizontal air movement is restricted. At the time of inversions, visibility is greatly reduced and contaminants are at a maximum. Inversion occurs when dT/dz is +ve, when $n < 1$ i.e. when the temperature of atmosphere increase with elevation instead of decreasing.

TYPES OF INVERSIONS:

Different types of inversions are

1) Radiation inversion

2) Subsidence inversion

3) Double inversion (combination of above two)

And wind turbulences under certain circumstances it may be related to all three.

Surface inversions form on clear, light-wind nights and are strongest around sunrise. They form as air in contact with the ground cools by conduction. Because air is a poor conductor, strong surface inversions tend to be shallow, typically a few hundred feet thick, and can occasionally have a temperature increase with height of up to 10°C from the surface to the top of the inversion. Deeper radiation inversions may extend many hundreds of feet if light turbulent winds mix the very cold surface air into the warmer air above. Figure 4.2 shows the structure of a radiation inversion with a shallow layer of cold air under warmer air.

The rapid decrease in density associated with strong surface radiation inversions can have a noticeable effect on climb performance, especially for light aircraft.

Surface inversions can also be associated with strong wind shear when the less dense air at the top of the inversion tends to flow over the colder air, rather than mixing with it. An aircraft climbing through the top of an inversion may experience a sudden increase in wind speed and/ or direction and turbulence.

Within the inversion layer visibility may be reduced by trapped particles of smoke and dust. Fogs are prone to form within radiation inversion layers.

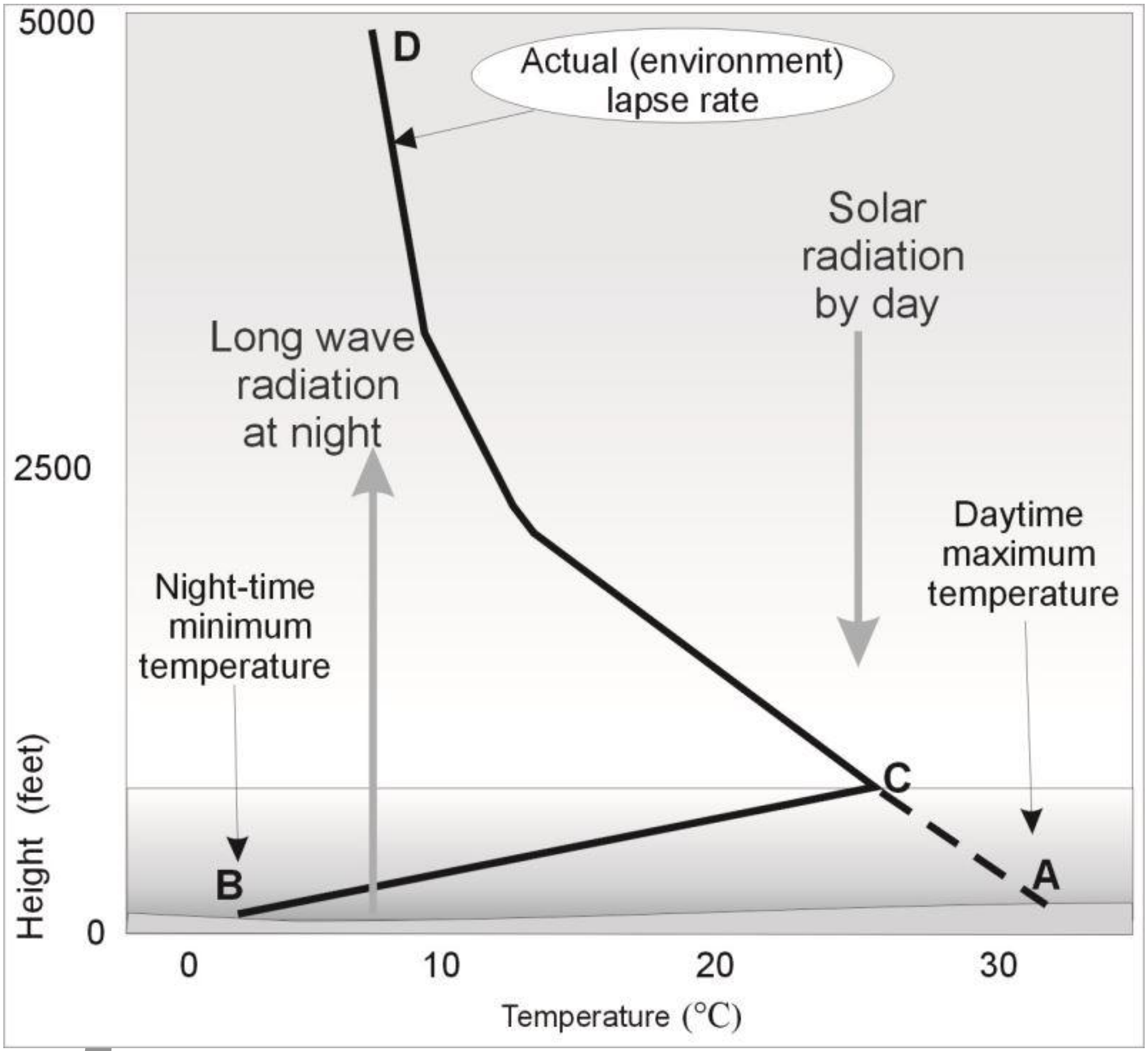


Fig: Radiation Inversion

Subsidence inversions frequently occur with high-pressure systems that cause air in the upper levels to sink and thus warm. When the upper layer warms at a greater rate, an inversion is formed. A typical subsidence inversion in the Australian region occurs at an altitude of 4000 to 6000 feet. Subsidence inversions are strongest and lowest on the eastern flank of high pressure systems.

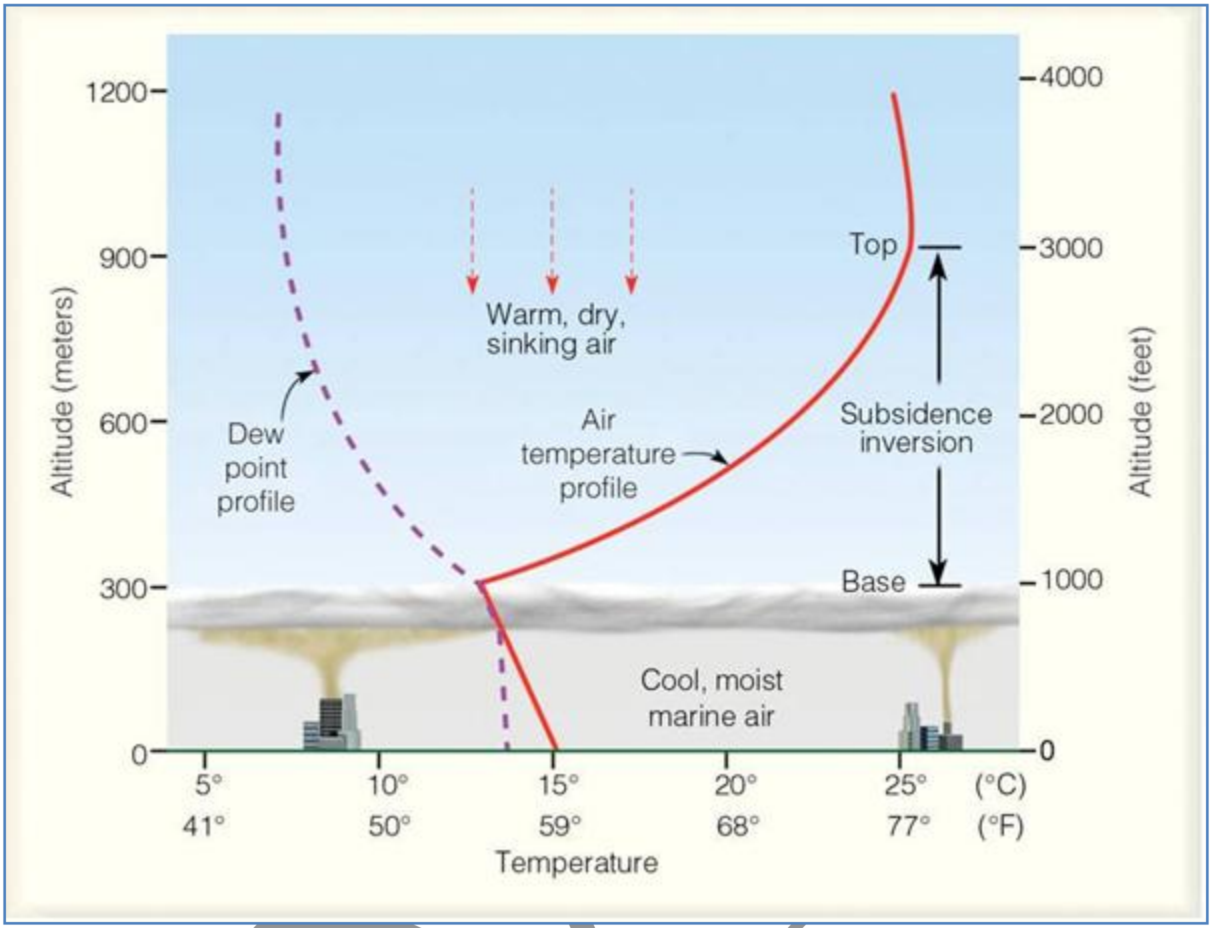


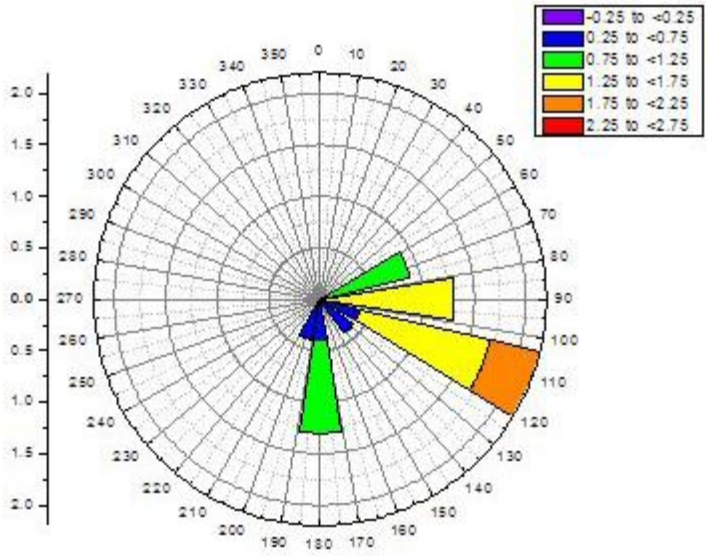
Fig: Subsidence Inversion

Subsidence inversions can be of significance to aviation because:

- thick haze and smoke can be trapped beneath the inversion so that descent through the inversion is coincident with markedly reduced visibility;
- Convective currents are inhibited so that low-level convective clouds are limited in their vertical development. Cloud tops therefore spread out below the inversion to form stratocumulus cloud. With slow moving high-pressure systems this cloud layer may persist for several days especially during winter (sometimes referred to as anticyclonic gloom);
- persistent low stratus cloud may form, if surface conditions are moist and light winds mix the air to saturation below the inversion;
- they provide ideal environments for fog because:
  - the atmosphere is generally clear above the inversion;
  - winds below the inversion are light;

  - pollutants are trapped within the inversion layer providing an abundance of condensation nuclei;
  - humidity is often high;
  - Conditions are favourable for radiation inversions to form below a subsidence inversion.

- **WINDROSE DIAGRAM:** It is defined as any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period. In other words the wind rose shows the prevailing direction of the wind. The most common form consists of a circle from which eight or sixteen lines Cinergy, one for each direction. The length of each line is proportional to the frequency calm conditions are centered in the centre. There are many variations in the construction of wind roses. The wind rose diagram is prepared using an appropriate scale to represent percentage frequencies of wind directions and appropriate index shades, lines etc… to represent various wind speeds observation corresponding to wind speed below 1 lm/hr are recorded as CALM.



- **POLLUTION ROSES :**
- Special wind roses are sometimes constructed like,
- 1. Precipitation wind rose
- 2. Smoke wind rose
- 3. SO_2 wind rose
- 4. Hydrocarbons wind rose
- Instead of wind speed, the parameters of precipitation, smoke SO_2 hydrocarbons etc., are attached to the wind direction, these are known as POLLUTION ROSES.

PLUME BEHAVIOUR:

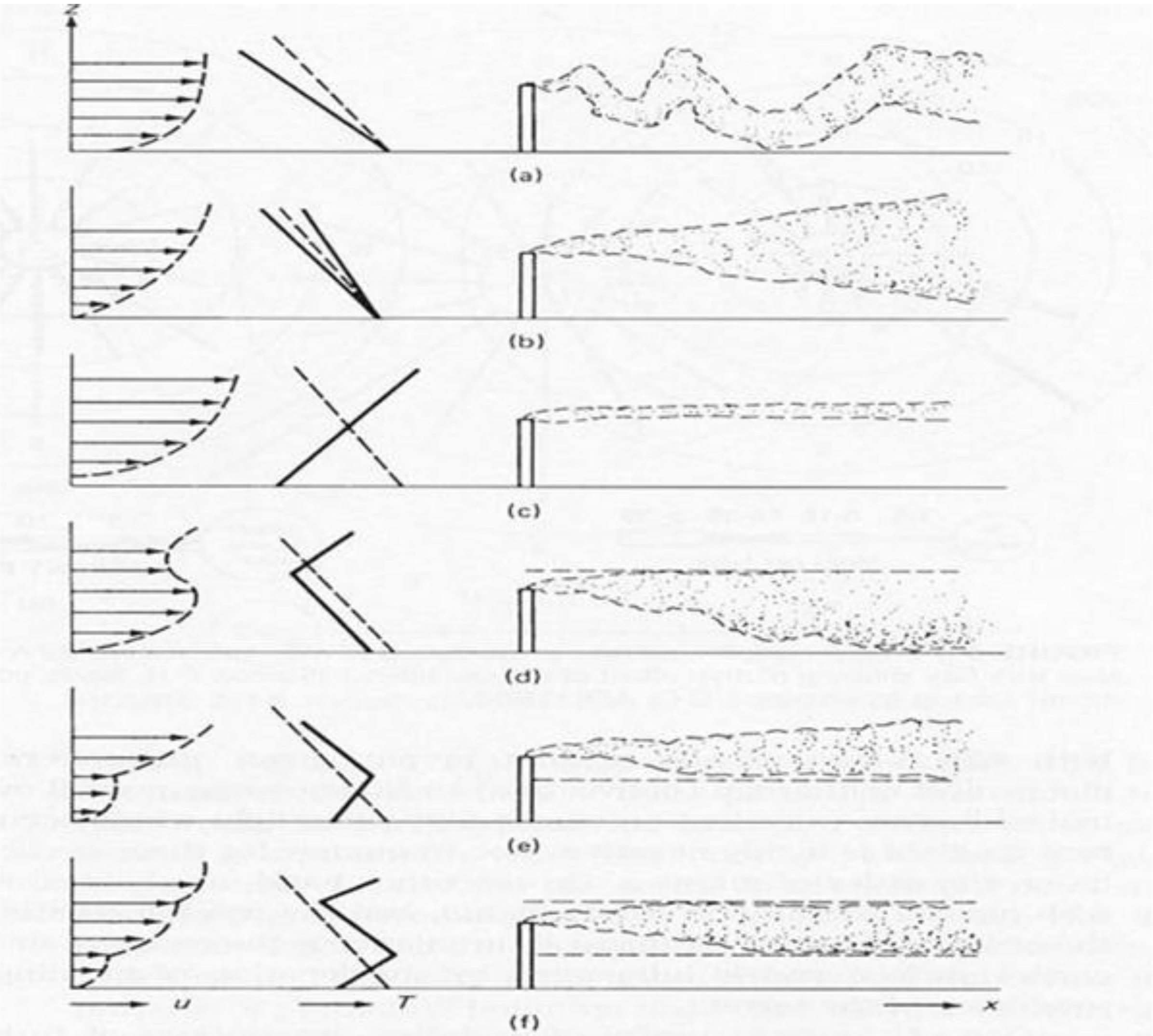
Plume refers to the path and extent in the atmosphere of the gaseous effluents released from a source usually a stack (chimney). The behavior of a plume emitted from any stack depends on localized air stability. The Geometric forms of stack plumes are a function of the vertical temperature and wind profiles, vice versa, by looking at the plume one can state stability condition and dispersive capacity of atmosphere. The behavior and dispersion of a plume entirely depend on the environmental lapse rate (ELR).

Effluents from town stacks are often injected to an effective height of several 100m above ground because of the cumulative effects of buoyancy and velocity on plume rise other factors influencing the flume behavior are the diurnal (seasonal) variations in the atmospheric stability and the long term variations which occur with change in seasons.

Six types of plume behavior are shown in the figure below, the spread of the plume is directly related to the vertical temperature gradient as shown in the figure.

i) Looping
ii) Coning
iii) Fanning
iv) Lofting
v) Fumigation
vi) Trapping

- **LOOPING:** It is a type of plume which has a wavy character. It occurs in a highly unstable atmosphere because of rapid mixing. The high degree of turbulence helps in dispersing the plume rapidly but high concentrations may occur close to the stack if the plume touches the ground.
- **CONING:** It is a type of plume which is shaped like a CONE. This takes place in a near neutral atmosphere, when the wind velocity is greater than 32 km/hr. However the plume reaches the ground at greater distances than with loping.
- **FANNING:** It is a type of plume emitted under extreme inversion conditions. the plume under these condition will spread horizontally, but little if at all vertically. Therefore the prediction of ground level concentration (SLC) is difficult here.
- **LOFTING:** Lofting occurs when there is a strong lapse rate above a surface inversion. under this condition, diffusion is rapid upwards, but downward diffusion does not penetrate the inversion layer under these conditions, emission will not reach surface.
- **FUMIGATION:** It is a phenomenon in which pollutants that are emitted into the atmosphere are brought rapidly to the ground level when the air destabilizes.
- **TRAPPING:** This refers to conditions where the plume is caught between inversion and can only diffuse within a limited vertical height. The lofting plume is most favorable air to minimizing air pollution. The fumigation and trapping plumes are very critical from the points of ground level pollutant concentrations.



(a) Typical velocity profile, temperature profile, and plume shape in the x-z coordinate system for various atmospheric conditions. (Dry adiabatic lapse rate - - - ; ambient lapse rate—) (a) Looping, strong instability; (b) coning, near neutral stability; (c) fanning, surface inversion; (d) fumigation, aloft inversion; (e) lofting, inversion below stack; (f) trapping, inversion below and above stack height.

AIR POLLUTION MODELS AND STACK EFFLUENT DISPERSION THEORIES

AIR POLLUTION MODEL: Models give answers to many questions conserving pollution and are an important tool for making decisions concerning air pollution. The fundamental of all pollution modeling is to calculate air concentrations of one (or) more pollutants in space and time as related to the independent variables such as emissions into the atmosphere, the meteorological variables and parameters which describe removal and transformation process. This is achieved by a system which quantitatively relates the concentrations of pollutions to other parameters by mathematical or physical methods such as procedure is called the MODEL.

The selection of appropriate model depends upon their use and purpose. An ideal model should be physically realistic and accurate suitable for various Meteorological and topographical conditions, suitable for various emission sources and suitable for various air pollution species. But unfortunately an ideal model does not exist. Also a universal model will not be easy to use efficiently, that is why each model is a comprises between accuracy and practicality, simplicity and sophistication.

VARIOUS TYPES OF MODELS:

Models are developed to address various atmospheric problems. The variety of existing models may be classified according to the different attributes of a model. The models are

1) Eularian grid Model

2) Lagrangian Trajectory Model

3) Guassian Plume Model

GAUSSIAN PLUME MODEL:

There are several models available for predicting the concentrations downwind of a single source, but most of them are Numerical methods. However under a set of simplifying assumptions the analytical solutions can be obtained. The first formulation for the steady state concentration downwind from a continuous point source was presented by SUTTON and further developed by PASQUILL AND GIFFORD. This solution is commonly known a GAUSSIAN PLUME MODEL. The concentration distribution perpendicular to the plume axis is assumed to be Gaussian

Consider a continuous point source located at x-y=o and at a height Z-H. A description of the pollutant concentration (ga) could be facilitated by assuming that all the pollutants are reflected an image source of equal strength at x=y=o and Z= -H. in this method, known as the method of images, the solutions of both the Real and image sources are added together. The resultant equation for pollutant concentration at a selected location (x,y,z) in the three dimensional filed downwind of the elevated point source is given by

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

C = Concentration of the chemical in air. [M/L^3]
Q = Rate of chemical emission. [M/T]
u = Wind speed in x direction. [L/T]
σ_y = Standard deviation in y direction. [L]
σ_z = Standard deviation in z direction. [L]
y = Distance along a horizontal axis perpendicular to the wind. [L]
z = Distance along a vertical axis. [L]
H = Effective stack height. [L]

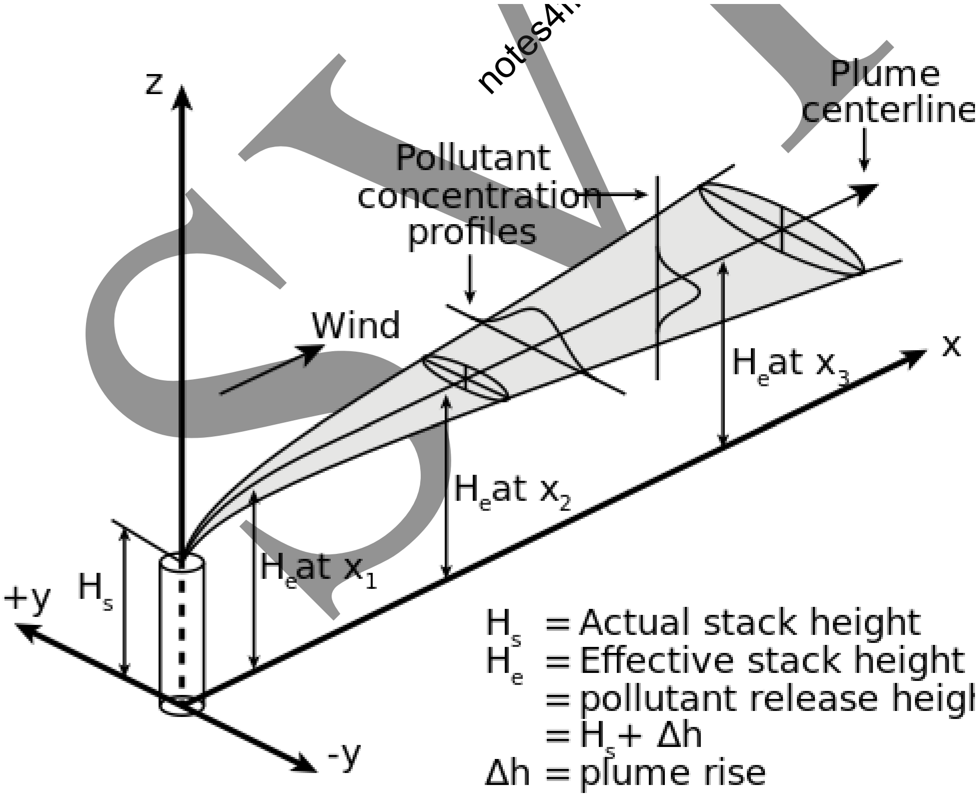


Figure: Schematic figure of a Gaussian plume.

Three common forms obtained from the basic equation are frequently used to analyze specific situations.

EQUATION: Consists of three terms representing

1) The center line concentration as a function of downwind distance

2) The lateral spread relative to the centre line value

3) The vertical spread relative to the centre line value

A. GROUND LEVEL CONCENTRATION: (GLC)

In this case Z = O and cgn.1 reduces to in the above equation, the factor ‘Z’ does not appear in the denominator, it gets cancelled when the two vertical exponential terms are combined.

B. GROUND LEVEL CENTER-LINE CONCENTRATION (GLCC)

In this case Z=0 and Y = 0

Equation 3 is used to estimate the ground level concentrations expected at any distance downwind of an elevated source.

In case the emission source is also at the S.L. i.e H=0, eqn 3 Further simplifies to,

Equation (4) represents the maximum GLC – expected at any distance downwind from an emission source which is at the S.L

Consider a point source somewhere in the air where a pollutant is released at a constant rate Q (kg/s). The wind is blowing continuously in a direction x (measured in metres from the source) with a speed U (m/s). The plume spreads as it moves in the x direction such that the local concentrations C(x,y,z) (kg/m3) at any point in space form distributions which have shapes that are “Gaussian” or “normal” in planes normal to the x direction.

The Gaussian dispersion equation can be written as:

$$C(x,y,z) = \frac{Q}{2\pi\pi_y \sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times$$

$$\left\{ \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right\} \qquad \textbf{……………… (1)}$$

For a receptor at the ground surface, or a source located at the ground (z=0), the previous equation reduces to:

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

…………….. (2)

In analyzing the Gaussian plume model, the following assumptions are usually made:

1) Continuous emission and negligible diffusion in the direction of travel.

2) The material diffused is a stable gas or aerosol, with a negligible deposition rate.

3) Mass is conserved through reflection at surfaces.

4) Background pollution is negligible.

5) Steady-state conditions.

6) Constant wind speed and direction with time and elevation.

7) Negligible wind shear effect on horizontal diffusion.

8) The dispersion parameters are assumed to be functions of x (and hence u alone).

9) The terrain is relatively flat, open country.

The ground-level concentrations directly downwind are of interest, since pollution concentration will be highest along that axis. With y = 0, equation (2) will be simplified to the following downwind ground level form:

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

………… (3)

Using equation (3), the effect of variations in the key parameters (atmospheric stability, wind speed, ambient temperature, stack height, gas exit velocity, and gas exit temperature) on the ground concentrations are calculated and shown as a composite plot

INFINITE LINE SOURCE:

An infinite line source can often be represented by a series of industries located along a river or by a road along which pollution is continuously emitted by heavy traffic. It is thus spatially extended and the direction of the wind with respect to the geometry of the source will influence the downward concentration of the pollutants. When the wind direction is normal to the line of emission, the ELC downwind (x) of a source emitting at a height ‘H’ is given by

Where,

‘Q1’ = source strength/unit distance

If the source is also at the G.L then eqn-6 can be further simplified

i) The plume has a Gaussian distribution in both horizontal and vertical places, with ‘Jy’ and ‘J2’ as the standard deviation of the concentrations of the plume in horizontal cross wind and vertical directions irrespectively

ii) The mean speed affecting the plume is ‘u’ which is the wind speed at the source level i.e. at the point where dispersion starts.

iii) Uniform and continuous emission of ‘Q’ of pollutant takes place.

iv) Diffusion of pollutant in ‘x’ direction is negligible compared to diffusion in cross wind direction. This B +ve if emission is continuous and if wind speed is more than 1m/sec

v) Parameters governing the diffusion of the pollutant do not change in space and time is steady state conditions prevail.

vi) The terrain underlying the plume is flat

Table: Features and assumptions of most Gaussian dispersion models

Represented in most Gaussian models	***Not represented in most Gaussian models***
Advection	Wind shear
Horizontal turbulent diffusion	Change of wind over time
Vertical turbulent diffusion	Change of source parameters over time
Reflection from ground	Wet and dry deposition
Reflection from inversion layer	Gravitational settling
Elevated source	Chemical reactions
Buoyancy (effective stack height)	Radioactive decay
Multiple source points	Complex terrain
	3D diffusion (low-wind case)

Besides turbulence, the elevation of the source, often referred to as stack height is a key parameter of a Gaussian model, because ground concentrations are computed in an analytical way assuming the maximum concentration in the stack height. If buoyant pollutants are present, the horizontal advection starts from considerably higher than the stack's top due to the buoyant rise of the released gas. It led to the definition of the effective stack height that is the stack height added to the buoyant plume rise. Both empirical and theoretical formulas exist to compute the plume rise using the temperature, specific heat capacity, release speed and flux of the material as input data, which can be successfully used even in extremely buoyant cases like pool fires. We note that in situations where buoyant pollutants and a low-level thermal inversion are present, more sophisticated simulations are required to estimate the penetration of the inversion layer by the plume.

The greatest advantage of Gaussian models is that they have an extremely fast, almost immediate response time. Their calculation is based only on solving a single formula (equation 10.11 or similar) for every receptor point, and the model's computational cost mainly consists of meteorological data pre-processing and turbulence parameterization. Depending on the complexity of these sub modules, the model's runtime can be extremely reduced that enables its application in real-time GIS-based decision support software.

Gaussian dispersion models have become a uniquely efficient tool of air quality management for the past decades, especially in the early years when high performance computers had an unreachable price for environmental protection organizations and authorities. They have been successfully used for a wide range of studies of air quality in urban and industrial areas. However, industrial incidents like the ones in Seveso, Bhopal and Chernobyl showed out some critical weaknesses of Gaussian models, and strongly motivated the development of more advanced simulations to satisfy the scientific and public interest in the safety of atmospheric environment.

Although the toxic gas release in Seveso, Italy in 1976 happened during daytime in weakly unstable conditions, Gaussian models couldn't perform well because of the strong horizontal wind shear and fast changing wind direction. As exact deposition maps became available, Cavallaro et al. (1982) managed to give a better computational result with a statistical method that estimated dispersion directions driven by measured wind vectors, which can be regarded as a Lagrangian approach. Eight years later, another serious accident happened in Bhopal, India. The high number of victims warned the world that release of toxic heavy gas in a situation where low-level night time inversion is present can cause catastrophic consequences. Because of the low wind speed, fast settling pollutant and strong temperature inversion connected with local scale terrain effects, it was impossible to obtain reliable results from Gaussian models, however, later simulations with advanced Lagrangian software showed a good agreement with measurements.

Inspired by the serious accidents and the more and more efficient computers, there were large efforts to develop Gaussian models in a way that they could provide more accurate air quality forecasts as well as to take into account some of the unrepresented physical processes). It led to some respectable results like the more sophisticated treatment of vertical mixing in convective boundary layer or the parameterization of complex terrain effects. Due to the developments, today's advanced Gaussian dispersion models like AERMOD, CTDM or ADMS still have a significant role in environmental modeling.

While the incidents in Seveso and Bhopal and other air pollution episodes were concentrated on a local scale, the Chernobyl accident in 1986 had serious consequences in several countries and the radioactive I-131 gas was measured globally (Pudykiewicz, 1988). It was clear that the steady-state assumption of Gaussian models couldn't handle continental scale dispersion processes, however, existing Eulerian and Lagrangian models provided prescious information in the estimation of the impact of the accident (Pudykiewicz, 1988). The fast development of computers and NWP-s allowed researchers to create more and more efficient dispersion simulations using girded meteorological data. Eulerian and Lagrangian models are state-of-the-art tools of recent atmospheric dispersion simulations (Mészáros et al., 2010, Dacre et al., 2011).

LIMITATIONS OF THE MODEL:

i) It does not consider the existence of various stability layers at different heights in the atmosphere.

ii) It does not consider the change in stability characteristics with time.

iii) It does not consider the terrain characteristics such as terrain roughness, existence of mountains and valleys, distribution of land and water masses, etc

iv) It does not consider the existence of free concentration regions and strong wind shears like change of wind directions and change of wind speed with height

v) It can be applied only for shorter distances (up to 10 km) and of shorter travel time (order of 2 hrs). The model is most accurate for downwind distances between approximately 100 and 2000m

MODULE 3

Stack sampling Techniques:

St**ack sampling or source sampling** may be defined as 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.

Stack sampling is used for the assessment of the following:

1. To determine the **quantity and quality of the pollutant** emitted by the source.
2. To measure the **efficiency of the control equipment** by conducting a survey before and after installation
3. To determine the **effect on the emission** due to changes in raw materials and processes.
4. To compare the **efficiency of different control equipments** for a given condition.
5. To **acquire data** from an innocuous individual source so as to determine the cumulative effect of many such sources.
6. **To compare with the emission standards** in order to assess the need for local control , Source sampling is carried out in a process ventilation stack to determine the emission rates/or characteristics of pollutants.

Planning the study:

1. Familiarity of the process and operations to determine the time of cyclic operations, peak loading that might cause variations in the characteristics.
2. Method of sampling
3. Method of analysis of samples
4. Sampling time because certain industries undergo cyclic changes
5. Amount of sample required
6. Sampling frequency

Representative sample:

Sample collected must truly represent the conditions prevailing inside the stack.

The important considerations for accurate representative sample collection include:

1. Accurate measurement of pressure, moisture, humidity and gas composition
2. The selection of suitable locations for sampling
3. Determination of the traverse point required for a velocity and temperature profile across the cross section of the stack and sampling for particulate matter
4. The measurement of the rate of flow of gas or air through the stack
5. Selection of suitable sampling train
6. Accurate isokinetic sampling rate essential for particulate sampling
7. Accurate measurement of weight and volume of samples collected

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 5-10 diameters downstream from any obstructions and 3-5 diameters up stream from similar disturbances.

Size of sampling point:

For collection of samples, an opening has to be made to an extent of accommodating the probes. The size of sampling point may be made in the range of 7-10 cm, in diameter. A flange may be riveted so that the opening may be closed during the nonsampling 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 and temperature (Hence the pollutant concentration) across the cross-section of the stack. Traverse points have to be located to achieve this. These points are to be located at the center of each of a number of equal areas in the selected cross-section of the stack.

The number of traverse point may be selected as per following guideline:

Cross-section area of stack, sq. m	No. Of Points
0.2	4
0.2 to 2.5	12
2.5 and above	20

In **circular stacks**, traverse points are located at the center of equal annular areas across two perpendicular diameters.

In case **of rectangular stacks**, the area may be divided into 12 to 25 equal areas and the center for each area are fixed. The traverse point should be carried out at least on nine hypothetical squares on at least three lines

Sampling System:

Stack sampling is carried out by diverting a part of the gas stream through a sampling “train” of which a general arrangement is shown in fig.

General arrangement of sampling train

The train consists of a nozzle placed in the gas stream, a sampling probe through which the sample is drawn at different traverses, particulate and gas collection devices, a flow measuring device and a prime mover such as a vacuum pump or an ejector.

Nozzle: It is at the end of the probe is sharp edged, pointing inward from the outside edge and the traversing probe is made of stainless steel with glass or Teflon lining. For Sampling hot gases whose temperature are above 400^0 C, these probes are provided with a circulating **coolant system** to prevent combustion of particulate materials inside the probe and to prevent the temperature from exceeding the maximum allowable temperature of filtration materials.

Devices: Collection of particulates: Filtration, wet of dry impingement, impaction, electrostatic and thermal precipitation

Collection of gases: Absorption, adsorption, freeze out

Flow measurement: Use rotameter or orifice meter or dry gas meter if the information on the total volume of the gas sampled is required. Normally placed after the collection devices and upstream of a vacuum pump so that any leak in the vacuum pump will not cause errors in the gas volume measurements

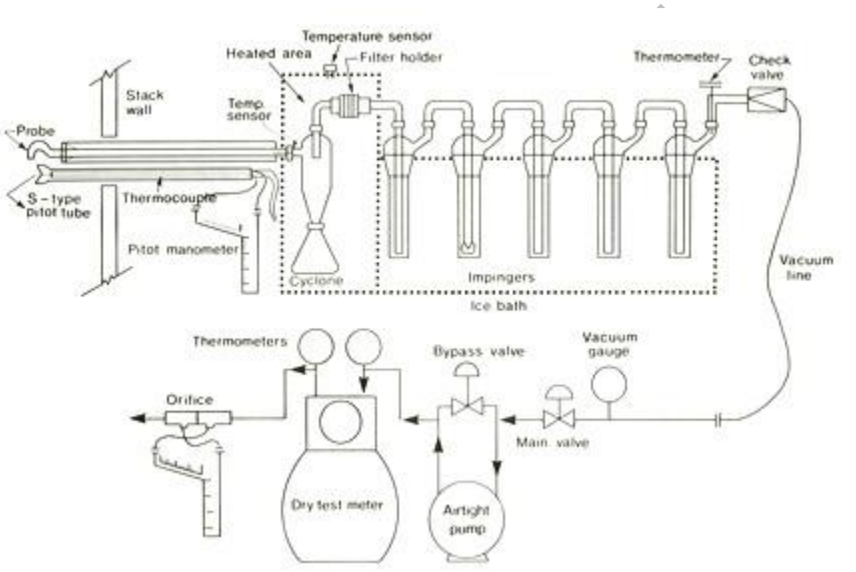
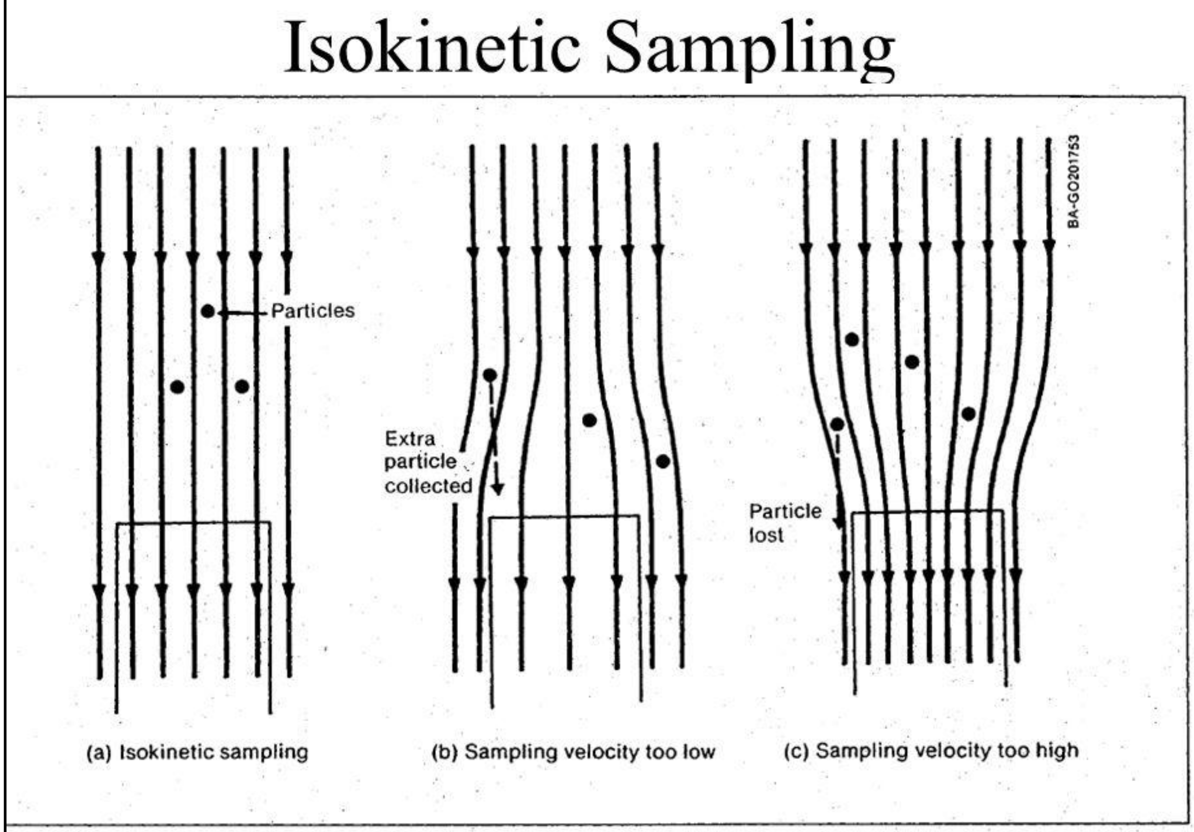


Fig: Sampling Train

STACK SAMPLING: Particulate sampling:

Isokinetic Conditions:
The efficiency of the sampling depends on the condition at which sampling was carried out. The sample collected must be representative like a composite wastewater collection. This can be achieved by **isokinetic sampling**. Isokinetic conditions exist when the velocity in the stack Vs equals the velocity at the top of the probe nozzle Vn at the same point.


Isokinetic Sampling

ig. 7-10. Gas stream lines at the entrance to sampling probes (Source: Adapted from Strauss 1975, Fig. 2.12. © 1975. Used with permission of ergamon Press)

Non – isokinetic and isokinetic sampling

Isokinetic sampling can be achieved by two ways:
(1) By calculating the **point velocity** of the free stream with a pitot tube located as near to the sampling probe as possible without interfering with the free stream and then adjusting the sampling velocity.
(2) By using a **null type** sampling probe

Conversion of Pitot tube readings to orifice pressure differentials Rapid adjustment of sampling rate is required; Pitot tube readings and stack temperatures are converted to equivalent orifice pressure differentials to maintain isokinetic sampling velocities.
Orifice diameter: 3/6 inch
P = absolute static pressure in duct, inches of Hg
T= absolute temperature in duct, ^{0}R
Pa = absolute static pressure at orifice outlet, inches of Hg
T_2 = absolute temperature at orifice outlet ^{0}R
G= specific gravity (air = 1), dimensionless

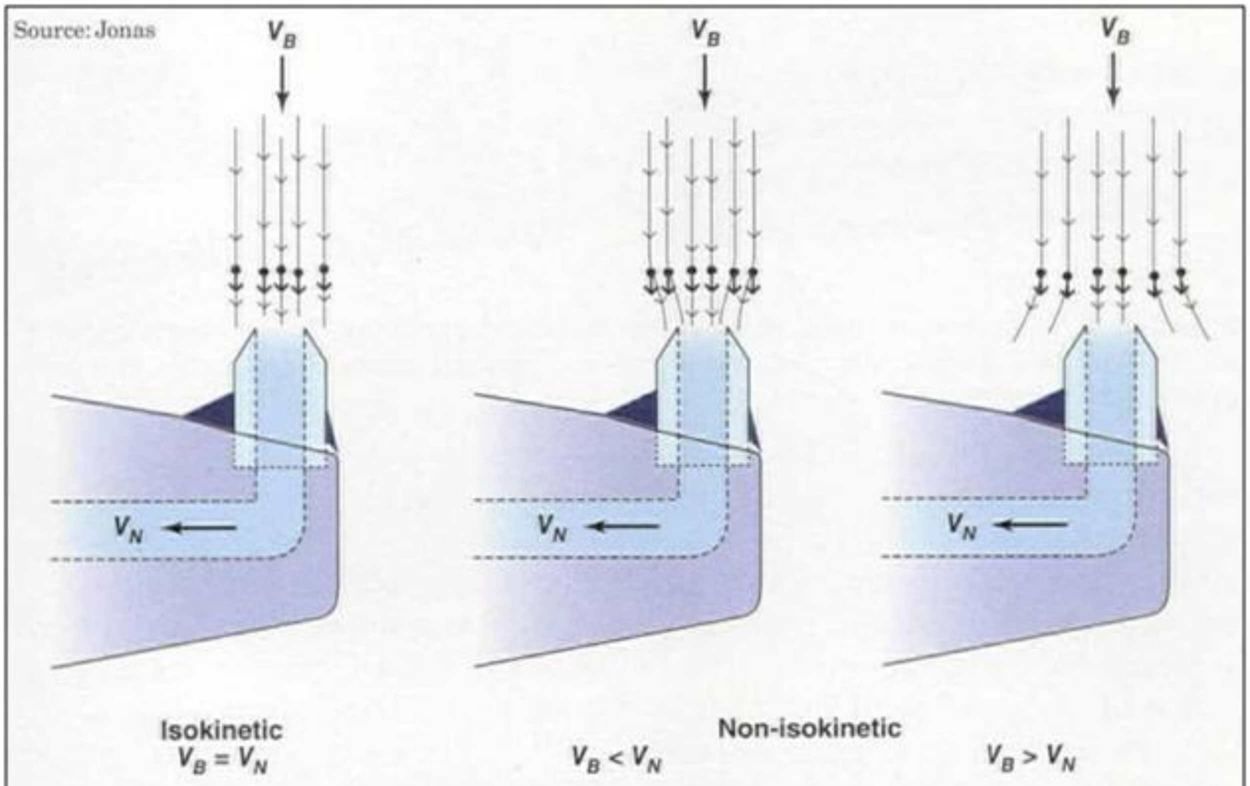


FIGURE Shown here is the ideal flow path of particulate matter and droplets into isokinetic and non-isokinetic sampling nozzles. In isokinetic sampling, the extracted fluid is representative of the composition in the process pipe, including particles and droplets. When the sampling is non-isokinetic, the concentration of particles and droplets can be higher or lower than that found in the process fluid. V_B = velocity of process fluid; V_N = velocity in the sampling nozzle

Differential null type stack sampler probe

In this the static pressure measured between the inner and outer probe walls is balanced. This assumes that the velocity within the probe is equal to the free stream velocity. Conduct calibration over the test range.

Determination of gas composition:

Gas composition can be determined by **Orsat apparatus**.

The gas is collected in the Orsat apparatus and analyzed for the composition of CO_2, O_2 and CO in the same order and the remaining is assumed to be nitrogen.

Molecular weight of gas = $\sum Mx\ Bx$

Where,

Mx = Molecular weight of CO_2, O_2 and CO and N_2 (44, 32, 28 and 28 respectively) and

Bx represent % of gases

Determination of moisture Content:

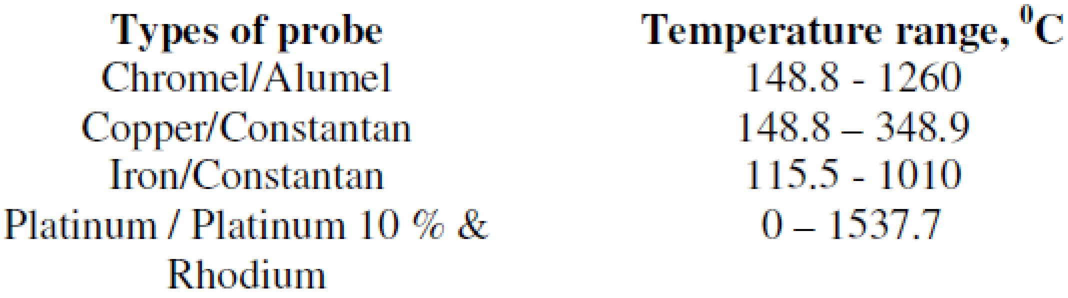
The moisture content in the stack may be determined by any one of the following methods:

1. **Wet bulb and dry bulb temperature technique** (Moisture content is less than 18 % and dew point is less than 51 0C and cannot be used for acid stream)
2. Condenser technique
3. Silica gel tube

Determination of Temperature:

The temperature has to be measured across the cross-section of the stack at predetermined traverse point.

The temperature probe is inserted into the stack and the readings are taken with the help of a pyrometer.



Types of probe	Temperature range, ^{0}C
Chromel/Alumel	148.8 - 1260
Copper/Constantan	148.8 – 348.9
Iron/Constantan	115.5 - 1010
Platinum / Platinum 10 % & Rhodium	0 – 1537.7

Determination of velocity

The standard Pitot tube in combination with a differential manometer is widely used to measure velocity.

Type – S pitot tube manometer assembly

The Pitot tube is connected to the inclined manometer.

It is kept at the traverse point.

The velocity head is calculated from the deflection in the manometer

Procedure for particulate matter sampling

1. Determine the gas composition and correct to moisture content.
2. Determine the temperature and velocity at each traverse point.
3. Determine the empty weight of the thimble (W_1).
4. Mark out the traverse points on the probe. The marks are normally fixed by tying with asbestos thread.
5. Check all points for leakages.
6. Determine the flow rate to be sampled under isokinetic condition.
7. Insert the probe at the traverse point 1, very close to the stack. Start the pump and adjust the flow so that the rotameter reads the predetermined value.
8. Switch ff the pump at the end of sampling time.
9. Read the vacuum at the dry gas meter (DGM) and also the temperature
10. Move the probe to subsequent traverse points by repeating the steps five to eight.
11. After completion of collection of samples, remove the probe and allow it to cool.

12. Remove the thimble carefully. Some of the dust would have adhered to the nozzle. This should be removed by trapping and transferred to the thimble.
13. Weight the thimble with the sample. The difference in weight gives the dust collected.
14. The volume of sample collected in either given by the dry gas meter (m^3) or by sampling rate given by rotameter multiplied by the sampling time.
15. Hence from (13) and (14), the emission rate can be calculated. This will be at DGM conditions. This is to be corrected for temperature and pressure so as to obtain values for standard conditions.

Sample recovery:
After cooling, the outside of probe assembly is cleaned with cotton waste.
Disconnect the nozzle.
Remove the thimble and keep it in a clean glass beaker.
The particulate matter adhered to the inside walls of the nozzle, should be transferred carefully to the thimble.
Weigh the thimble with sample (W_2).
The difference in weight (W_2 - W_1) will give the particulate collected.

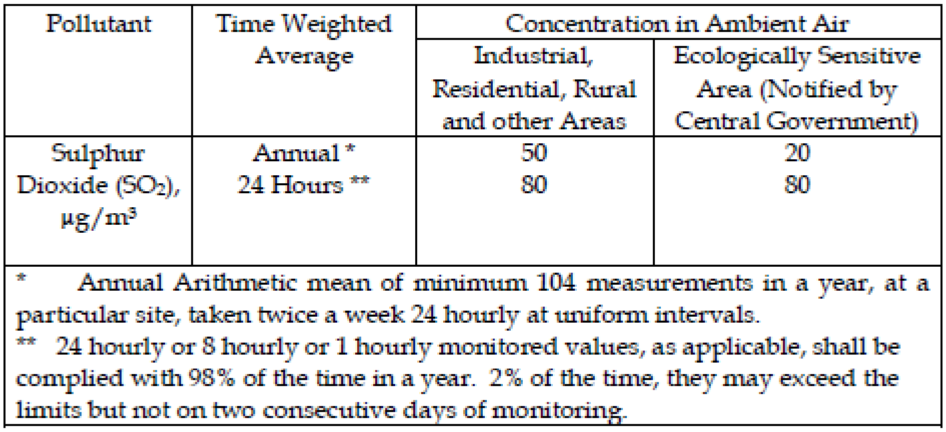
Guidelines for sampling and analysis of sulphur dioxide in ambient air (Improved West and Gaeke method)

1. Purpose

The purpose of this protocol is to provide guidelines for monitoring and analysis of sulphur dioxide in ambient air.

2. Standard

The national ambient air quality standards for sulphur dioxide is presented in the table



Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
Sulphur Dioxide (SO_2), µg/m³	Annual * 24 Hours **	50 80	20 80

* Annual Arithmetic mean of minimum 104 measurements in a year, at a particular site, taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

* Annual Arithmetic mean of minimum 104 measurements in a year, at a particular site, taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

3. Principle of the method

Modified West & Gaeke Method (IS 5182 Part 2 Method of Measurement of Air Pollution: Sulphur dioxide). Sulphur dioxide from air is absorbed in a solution of potassium tetrachloromercurate (TCM). A dichlorosulphitomercurate complex, which resists oxidation by the oxygen in the air, is formed. Once formed, this complex is stable to strong oxidants such as ozone and oxides of nitrogen and therefore, the absorber solution may be stored for some time prior to analysis. The complex is made to react with para-rosaniline and formaldehyde to form the intensely coloured pararosaniline methylsulphonic acid. The absorbance of the solution is measured by means of a suitable spectrophotometer

4. Instrument/Equipment

The following items are necessary to perform the monitoring and analysis of nitrogen dioxide in ambient air:

· Analytical balance:

· Vacuum pump : Capable of maintaining an air pressure differential greater than 0.7 atmosphere at the desired flow rate

· Calibrated flow-measuring device to control the airflow from 0.2 to 1 l/min.

· Absorber: all glass midget impinger

· Spectrophotometer: Capable of measuring absorbance at 560 nm equipped with 1 cm path length cells.

· Glass wares: low actinic glassware must be used for analysis

5. Reagents / Chemicals

All the chemicals should meet specifications of Analytical Reagent grade

· Distilled water

· Mercuric chloride

· Potassium chloride / Sodium chloride

· EDTA di sodium salt

· Absorbing Reagent, 0.04 M Potassium Tetrachloro mercurate (TCM) - Dissolve 10.86 g, mercuric chloride, 0.066 g EDTA, and 6.0 g potassium chloride or sodium chloride 4.68 gm in water and bring to the mark in a 1 litre volumetric flask. C*aution : highly poisonous if spilled on skin, flush off with water immediately*. The pH of this reagent should be approximately 4.0 but, it has been shown that there is no appreciable difference in collection efficiency over the range of pH 5 to pH 3. The absorbing reagent is normally stable for six months. If, a precipitate forms, discard the reagent after recovering the mercury.

· Sulphamic Acid (0.6%) - Dissolve 0.6 g sulphamic acid in 100 ml distilled water. Prepare fresh daily.

· Formaldehyde (0.2%) - Dilute 5 ml formaldehyde solution (36-38%) to 1 litre with distilled water. Prepare fresh daily.

· Purified Pararosaniline Stock Solution (0.2% Nominal) Dissolve 0.500 gm of specially purified pararosaniline (PRA) in 100 ml of distilled water and keep for 2 days (48 hours).

· Pararosaniline Working Solution - 10 ml of stock PRA is taken in a 250 ml volumetric flask. Add 15 ml conc. HCL and make up to volume with distilled water.

· Stock Iodine Solution (0.1 N) - Place 12.7 g iodine in a 250 ml beaker, add 40 g potassium iodide and 25 ml water. Stir until all is dissolved, then dilute to 1 litre with distilled water.

· Iodine Solution (0.01 N) - Prepare approximately 0.01 N iodine solution by diluting 50 ml of stock solution to 500 ml with distilled water.

· Starch Indicator Solution - Triturate 0.4 gm soluble starch and 0.002 g mercuric iodide preservative with a little water and add the paste slowly to 200 ml boiling water. Continue boiling until the solution is clear, cool, and transfer to a glass-stoppered bottle.

· Potassium iodate

Stock Sodium Thiosulfate Solution (0.1 N) - Prepare a stock solution by placing 25 g sodium thiosulfate pentahydrate in a beaker, add 0.1 g sodium carbonate and dissolve using boiled, cooled distilled water making the solution up to a final volume of 1 litre. Allow the solution to stand one day before standardizing.

To standardize, accurately weigh to the nearest 0.1 mg, 1.5 g primary standard potassium iodate dried at 180**o**C, dissolve, and dilute to volume in a 500 ml volumetric flask. Into a 500 ml Iodine flask, transfer 50 ml of iodate solution by pipette. Add 2 g potassium iodide and 10 ml of N hydrochloric acid and stopper the flask. After 5 min, titrate with stock thiosulfate solution to a pale yellow. Add 5 ml starch indicator solution and continue the titration until the blue colour disappears. Calculate the normality of the stock solution.

· Sodium Thiosulphate Titrant (0.01 N) - Dilute 100 ml of the stock thiosulfate solution to 1 litre with freshly boiled and cooled distilled water.

· Standardized Sulphite Solution for Preparation of Working Sulphite- TCM Solution - Dissolve 0.30 g sodium metabisulphite ($Na_2S_2O_5$) or 0.40g sodium sulphite (Na_2SO_3) in 500 ml of recently boiled, cooled, distilled water. Sulphite solution is unstable; it is, therefore, important to use water of the highest purity to minimize this instability. This solution contains the equivalent of 320-400 µg/ml of SO_2.

· Working Sulphite-TCM Solution - Measure 2 ml of the standard solution into a 100 ml volumetric flask by pipette and bring to mark with 0.04 M TCM. Calculate the concentration of sulphur dioxide in the working solution in micrograms of sulphur dioxide per millilitre. This solution is stable for 30 days if kept in the refrigerator at 5oC. If not kept at 5^oC, prepare fresh daily.

5. Sampling

Place 30 ml of absorbing solution in an impinger and sample for four hours at the flow rate of 1 L/min. After sampling measure the volume of sample and transfer to a sample storage bottle.

7. Analysis

Replace any water lost by evaporation during sampling by adding distilled water up to the calibration mark on the absorber. Mix thoroughly, pipette out 10 ml of the collected sample into a 25 ml volumetric flask. Add 1 ml 0.6% sulphamic acid and allow reacting for 10 minutes to destroy the nitrite resulting pararosaniline solution and make up to 25 ml with distilled water. Prepare a blank in the same manner using 10 ml of unexposed absorbing reagent. After a 30 min colour development interval and before 60 minutes, measure and record the absorbance of samples and reagent blank at 560 nm. Use distilled water; not the reagent blank, as the optical reference.

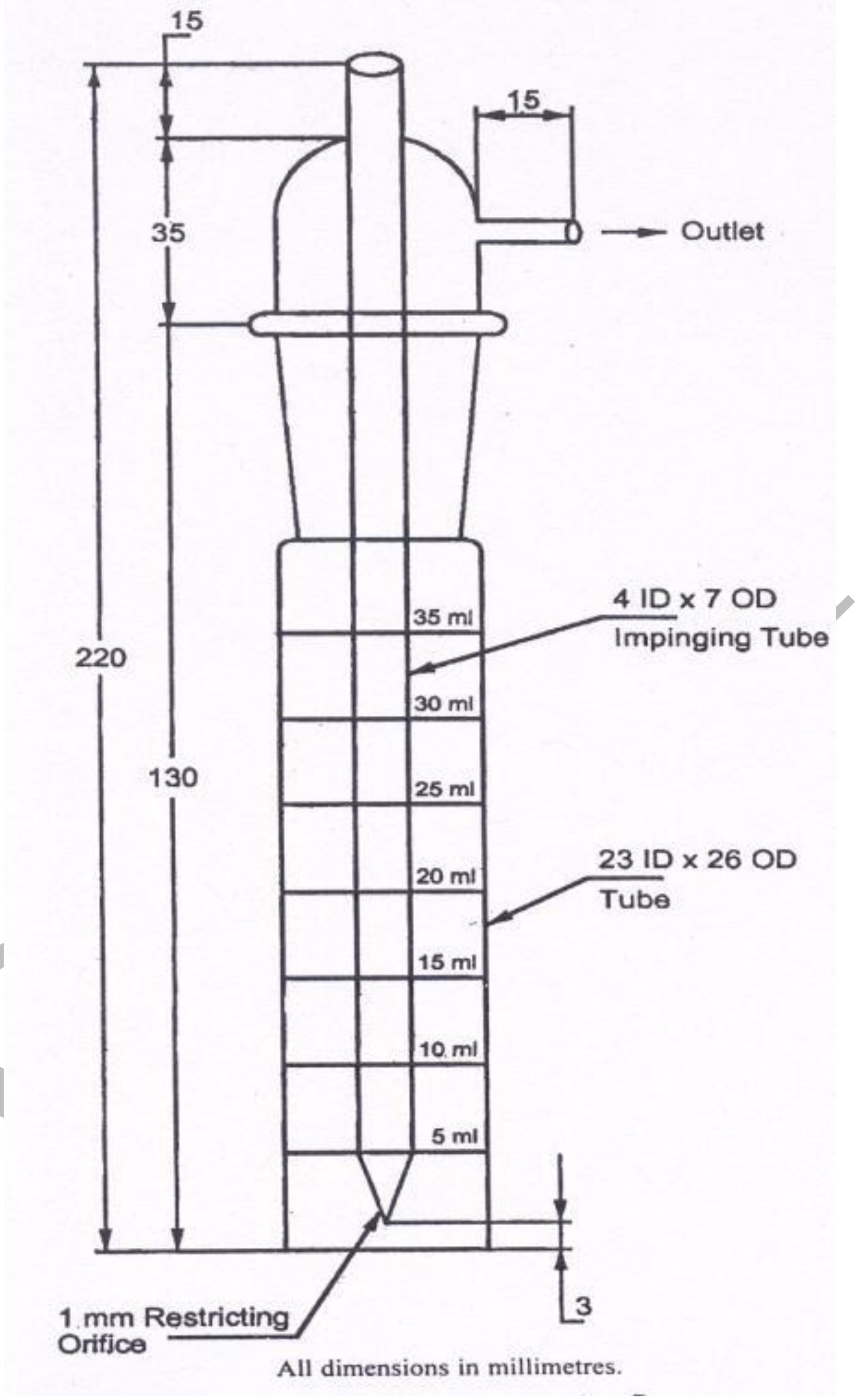


Fig: Standard Impinger

8. Calibration

The actual concentration of the sulphite solution is determined by adding excess iodine and back titrating with standard sodium thiosulfate solution. To back-titrate, measure, by pipette, 50 ml of the 0.01 N iodine solution into each of two 500 ml iodine flasks A and B. To flask A (blank) add 25 ml distilled water and into flask B (sample) measure 25 ml sulphite solution by pipette. Stopper the flasks and allow to react for 5 minutes. Prepare the working sulphite-TCM solution at the same time iodine solution is added to the flasks. By means of a burette containing standardized 0.01 N thiosulfate, titrate each flask in turn to a pale yellow. Then add 5 ml starch solution and continue the titration until the blue colour disappears.

8.1. Preparation of Standards

Measure 0.5 ml, 1.0 ml, 1.5 ml, 2.0 ml, 2.5 ml, 3.0 ml, 3.5 ml and 4.0 ml of working sulphite TCM solution in 25 ml volumetric flask. Add sufficient TCM solution to each flask to bring the volume to approximately 10 ml. Then add the remaining reagents as described in the procedure for analysis. A reagent blank with 10 ml absorbing solution is also prepared. Read the absorbance of each standard and reagent blank

8.2. Standard Curve

Plot a curve absorbance (Y axis) versus concentration (X axis). Draw a line of best fit and determine the slope. The reciprocal of slope gives the calibration factor (CF).

9. Calculation

Concentration of sulphite solution:

$$C = \frac{(V1-V2) \times N \times K}{V}$$

Where,

C = SO_2 concentration in mg/ml

V1 = Volume of thiosulfate for blank, ml

V2 = Volume of thiosulfate for sample, ml

N = Normality of thiosulfate

K = 32000 (Milliequivalent weight $SO_2/\mu g$)

V = Volume of standard sulphite solution, ml

C (SO_2 $\mu g/m^3$)= (As – Ab) x CF x Vs/ Va x Vt

Where,

C SO_2 = Concentration of Nitrogen dioxide, $\mu g/m^3$

As = Absorbance of sample

Ab = Absorbance of reagent blank

CF = Calibration factor

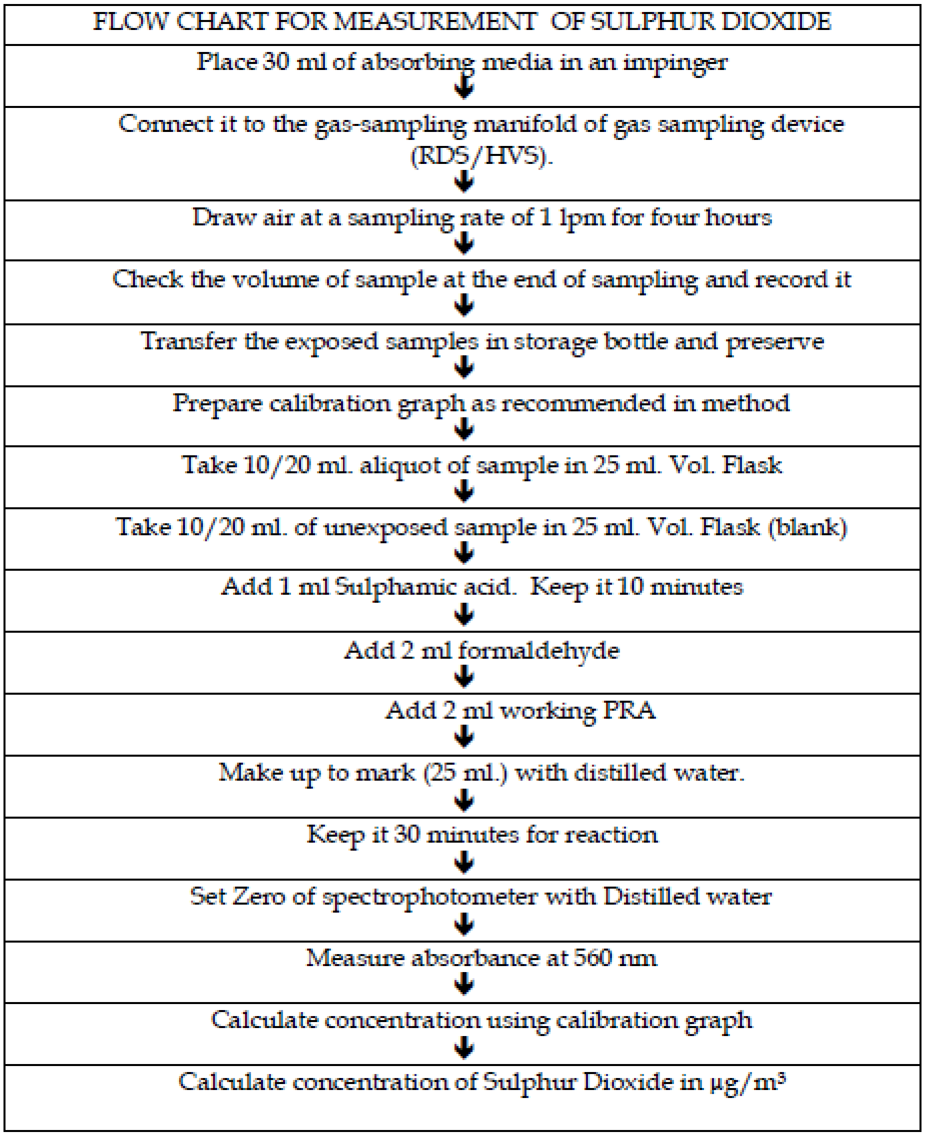
Va = Volume of air sampled, m^3

Vs = Volume of sample, ml

Vt = Volume of aliquot taken for analysis, ml

10. Quality Control

Quality Control (QC) is the techniques that are used to fulfill requirements for quality. The QC procedures for the air sampling and monitoring sections of this protocol include preventative maintenance of equipment, calibration of equipment, analysis of field blanks and lab blanks.



FLOW CHART FOR MEASUREMENT OF SULPHUR DIOXIDE

Place 30 ml of absorbing media in an impinger
↓
Connect it to the gas-sampling manifold of gas sampling device (RDS/HVS).
↓
Draw air at a sampling rate of 1 lpm for four hours
↓
Check the volume of sample at the end of sampling and record it
↓
Transfer the exposed samples in storage bottle and preserve
↓
Prepare calibration graph as recommended in method
↓
Take 10/20 ml. aliquot of sample in 25 ml. Vol. Flask
↓
Take 10/20 ml. of unexposed sample in 25 ml. Vol. Flask (blank)
↓
Add 1 ml Sulphamic acid. Keep it 10 minutes
↓
Add 2 ml formaldehyde
↓
Add 2 ml working PRA
↓
Make up to mark (25 ml.) with distilled water.
↓
Keep it 30 minutes for reaction
↓
Set Zero of spectrophotometer with Distilled water
↓
Measure absorbance at 560 nm
↓
Calculate concentration using calibration graph
↓
Calculate concentration of Sulphur Dioxide in µg/m³

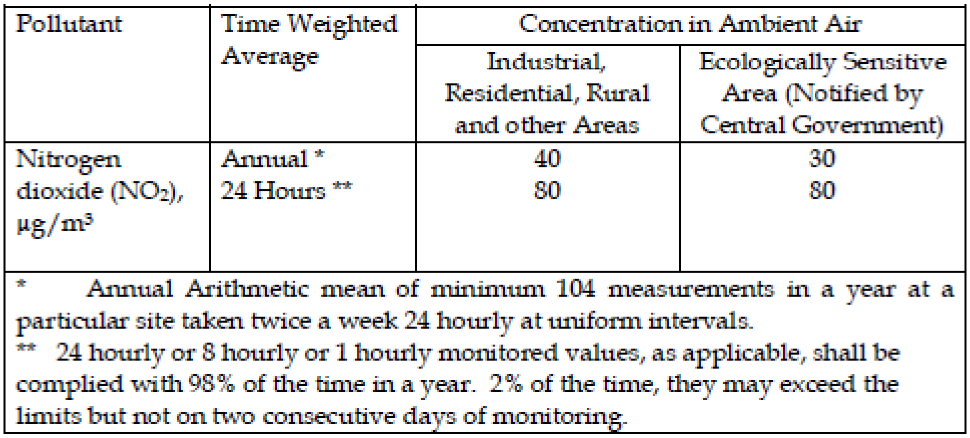
Guidelines for sampling and analysis of Nitrogen dioxide in ambient air (Modified Jacob and Hochheiser Method)

1. Purpose

The purpose of this protocol is to provide guidelines for monitoring of nitrogen dioxide in ambient.

2. Standard

The national ambient air quality standard for nitrogen dioxide is presented in the table:



Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
Nitrogen dioxide (NO_2), µg/m³	Annual * 24 Hours **	40 80	30 80

* Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

3. Principle of the method

Modified Jacobs & Hochheiser Method (IS 5182 Part 6 Methods for Measurement of Air Pollution: Oxides of nitrogen). Ambient nitrogen dioxide (NO_2) is collected by bubbling air through a solution of sodium hydroxide and sodium arsenite. The concentration of nitrite ion (NO_2) produced during sampling is determined colorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide, and N-(1-naphthyl)- ethylenediamine di-hydrochloride (NEDA) and measuring the absorbance of the highly coloured azo-dye at 540 n m.

4. Instrument/Equipment

The following items are necessary to perform the monitoring and analysis of nitrogen dioxide in ambient air:

· Analytical balance:

· Vacuum pump: Capable of maintaining a vacuum of at least 0.6 atmospheres across the flow control device. Flow control device capable of maintaining a constant flow of 200-1000 ml per minute through the sampling solution

· Calibrated flow measuring device: To control the airflow from 0.2 to
1 l/min.

· Absorber: a midget impinger

· Spectrophotometer: Capable of measuring absorbance at 540 nm equipped with 1 cm path length cells.

· Glass wares: low actinic glassware must be used for analysis

5. Reagents / Chemicals

All the chemicals should meet specifications of ACS Analytical Reagent grade

· Distilled water

· Sodium hydroxide

· Sodium Arsenite

· Absorbing solution (Dissolve 4.0 g of sodium hydroxide in distilled water, add 1.0 g of sodium Arsenite, and dilute to 1,000 ml with distilled water)

· Sulphanilamide - Melting point 165 to 167°C

· N-(1-Naphthyl)-ethylenediamine Di-hydrochloride (NEDA) - A 1% aqueous solution should have only one absorption peak at 320 nm over the range of 260-400 nm. NEDA showing more than one absorption peak over this range is impure and should not be used

· Hydrogen Peroxide - 30%

· Phosphoric Acid - 85%

· Sulphanilamide Solution - Dissolve 20 g of sulphanilamide in 700 ml of distilled water. Add, with mixing, 50 ml of 85% phosphoric acid and dilute to 1,000 ml. This solution is stable for one month, if refrigerated
· NEDA Solution - Dissolve 0.5 g of NEDA in 500 ml of distilled water. This solution is stable for one month, if refrigerated and protected from light
· Hydrogen Peroxide Solution - Dilute 0.2 ml of 30% hydrogen peroxide to 250 ml with distilled water. This solution may be used for one month, if, refrigerated and protected from light
· Sodium nitrite - Assay of 97% $NaNO_2$ or greater
· Sodium Nitrite stock solution (1000 µg NO**2**/ml)
· Sodium Nitrite solution (10 µg NO_2/ml.)
· Sodium Nitrite working solution (1 µg NO_2/ml)
(Dilute with absorbing reagent, prepare fresh daily)

6. Sampling

Place 30 ml of absorbing solution in an impinger and sample for four hour at the flow rate of 0.2 to 1 L/min. After sampling measure the volume of sample and transfer to a sample storage bottle.

7. Analysis

Replace any water lost by evaporation during sampling by adding distilled water up to the calibration mark on the absorber, mix thoroughly. Pipette out 10 ml of the collected sample into a 50 ml volumetric flask. Pipette in 1 ml of hydrogen peroxide solution, 10 ml of sulphanilamide solution, and 1.4 ml of NEDA solution, with thorough mixing after the addition of each reagent and make up to 50 ml with distilled water. Prepare a blank in the same manner using 10 ml of unexposed absorbing reagent. After a 10 min colour development interval, measure and record the absorbance of samples and reagent blank at 540 nm. Use distilled water; not the reagent blank, as the optical reference Samples with an absorbance greater than 1.0 must be re-analyzed after diluting an aliquot of the collected samples with an equal quantity of unexposed absorbing reagent. A randomly selected 5-10% of the samples should be re-analyzed as apart of an internal quality assurance program.

8. Calibration

8.1. Preparation of Standards

Pipette 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15 and 20 ml of working standard solution in to 50 ml volumetric flask. Fill to 20 ml mark with absorbing solution. A reagent blank with 10 ml absorbing solution is also prepared. Add reagents to each volumetric flask as in the procedure for analysis. Read the absorbance of each standard and reagent blank against distilled water reference.

8.2. Standard Curve:

Plot a curve absorbance (Y axis) versus concentration (X axis). Draw a line of best fit and determine the slope. The reciprocal of slope gives the calibration factor (CF).

9. Calculation

$$C\ (NO_2\ \mu g/m^3) = (A_s - A_b) \times CF \times V_s / V_a \times V_t \times 0.82$$

Where,
C NO_2 = Concentration of Nitrogen dioxide, µg/m^3
As = Absorbance of sample
Ab = Absorbance of reagent blank
CF = Calibration factor
Va = Volume of air sampled, m^3
Vs = Volume of sample, ml

Vt = Volume of aliquot taken for analysis, ml
0.82 = Sampling efficiency

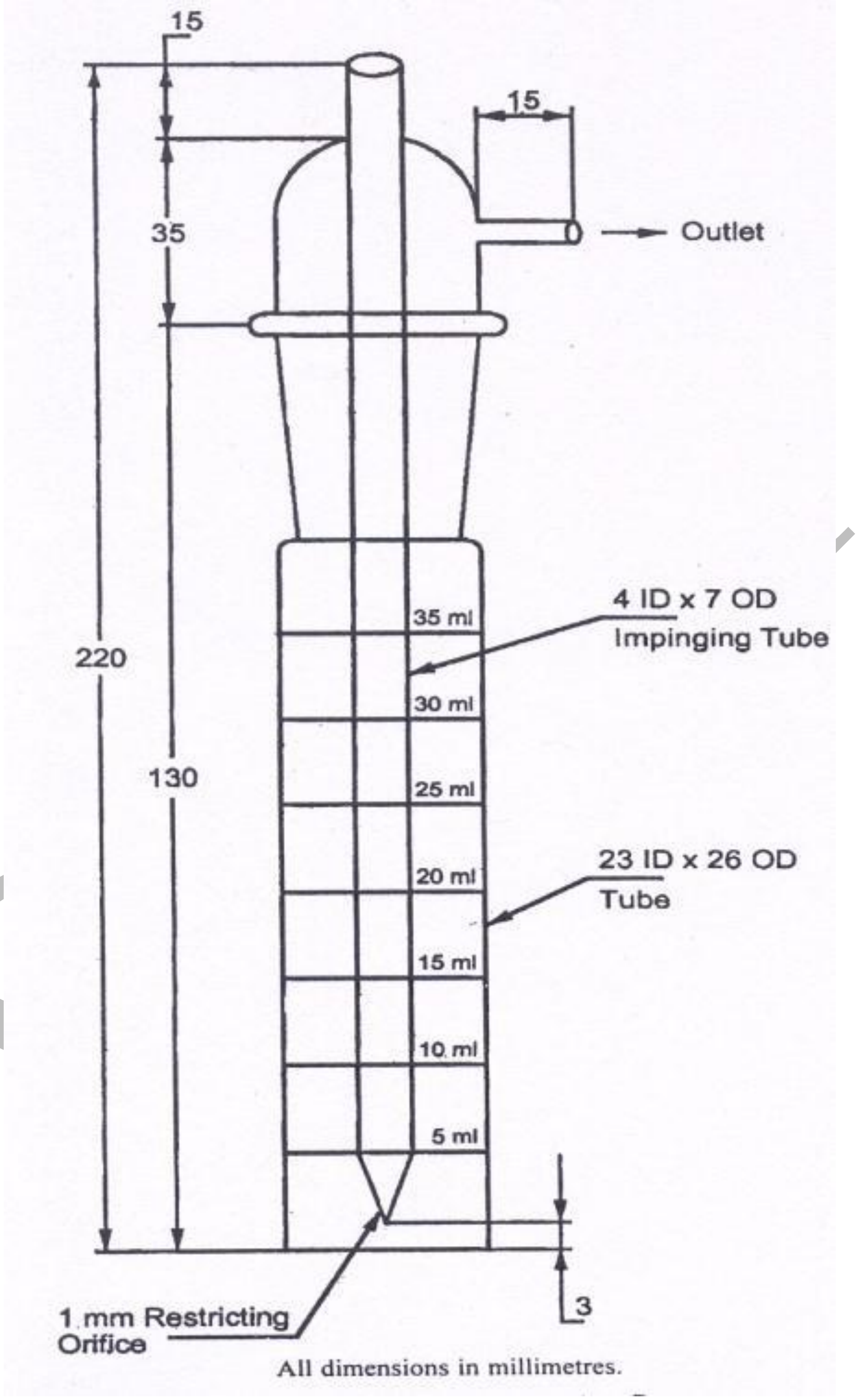
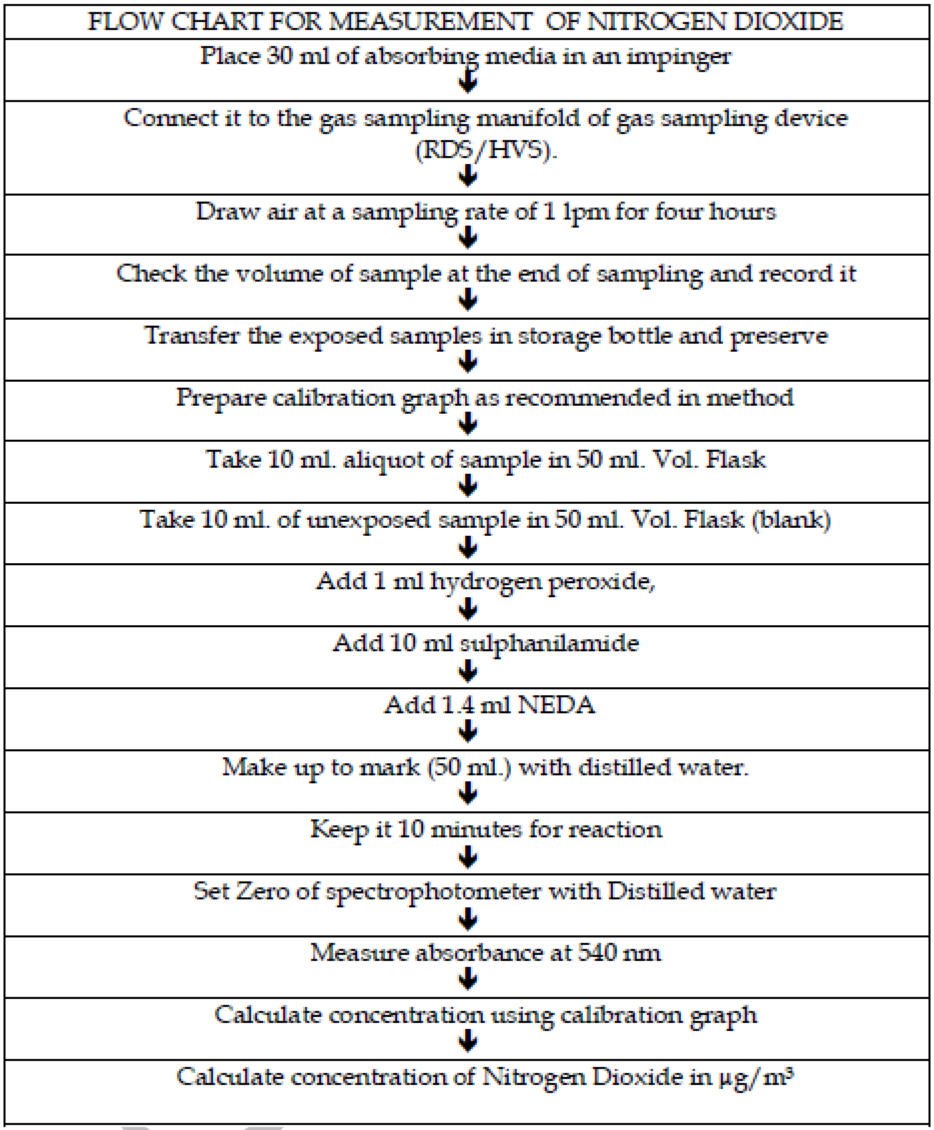


Fig: Standard Impinger

10. Quality Control

Quality Control (QC) is the techniques that are used to fulfil requirements for quality. The QC procedures for the air sampling and monitoring sections of this protocol include preventative maintenance of equipment, calibration of equipment, analysis of field blanks and lab blanks.



FLOW CHART FOR MEASUREMENT OF NITROGEN DIOXIDE

Place 30 ml of absorbing media in an impinger ↓

Connect it to the gas sampling manifold of gas sampling device (RDS/HVS). ↓

Draw air at a sampling rate of 1 lpm for four hours ↓

Check the volume of sample at the end of sampling and record it ↓

Transfer the exposed samples in storage bottle and preserve ↓

Prepare calibration graph as recommended in method ↓

Take 10 ml. aliquot of sample in 50 ml. Vol. Flask ↓

Take 10 ml. of unexposed sample in 50 ml. Vol. Flask (blank) ↓

Add 1 ml hydrogen peroxide, ↓

Add 10 ml sulphanilamide ↓

Add 1.4 ml NEDA ↓

Make up to mark (50 ml.) with distilled water. ↓

Keep it 10 minutes for reaction ↓

Set Zero of spectrophotometer with Distilled water ↓

Measure absorbance at 540 nm ↓

Calculate concentration using calibration graph ↓

Calculate concentration of Nitrogen Dioxide in µg/m³

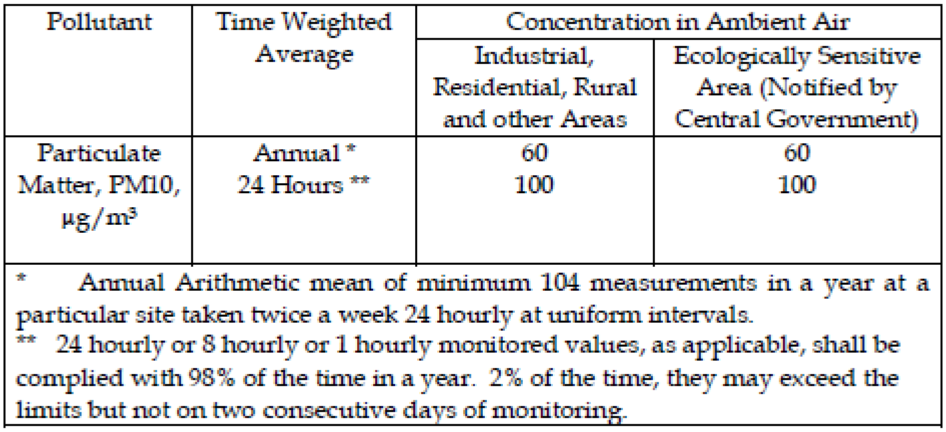
Guidelines for sampling and analysis of Particulate Matter (PM10) in ambient air (Gravimetric Method)

1. Purpose

The purpose of this protocol is to provide guidelines for monitoring and analysis of Particulate Matter PM10 in ambient air.

2. Standard

The national ambient air quality standards for Particulate Matter PM10 is presented in the table



Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
Particulate Matter, PM10, $\mu g/m^3$	Annual * 24 Hours **	60 100	60 100

* Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

3. Principle of the method

Air is drawn through a size-selective inlet and through a 20.3 X 25.4 cm (8 X 10 in) filter at a flow rate, which is typically 1132 L/min. Particles with aerodynamic diameter less than the cut-point of the inlet are collected, by the filter. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of PM10 in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

4. Instrument/Equipment

The following items are necessary to perform the monitoring and analysis of Particulate Matter PM10 in ambient air:

· Analytical balance:

· Sampler : High Volume Sampler with size selective inlet for PM10 and automatic volumetric flow control

· Calibrated flow-measuring device to control the airflow at 1132 l/min.

· Top loading orifice kit

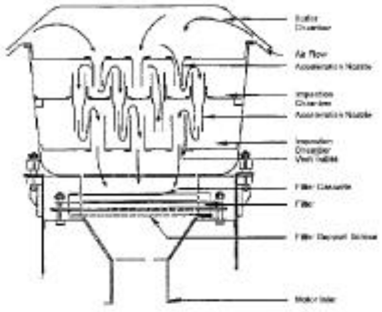
5. Reagents / Chemicals

Filter Media – A Glass fibre filter of 20.3 X 25.4 cm (8 X 10 in) size

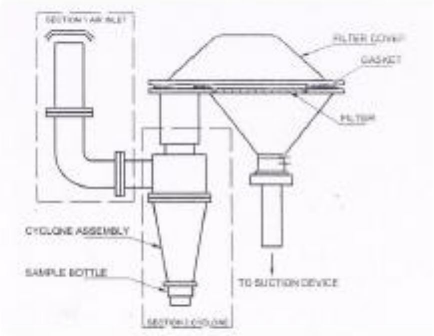
6. Sampling

Field Sampling - Tilt back the inlet and secure it according to manufacturer's instructions. Loosen the faceplate wing nuts and remove the faceplate.

Remove the filter from its jacket and centre it on the support screen with the rough side of the filter facing upwards. Replace the faceplate and tighten the wing nuts to secure the rubber gasket against the filter edge. Gently lower the inlet. For automatically flow-controlled units, record the designated flow rate on the data sheet. Record the reading of the elapsed time meter. The specified length of sampling is commonly 8 hours or 24 hours. During this period, several reading (hourly) of flow rate should be taken. After the required time of sampling, record the flow meter reading, take out the filter media from the sampler, and put in a container or envelope.



PM$_{10}$ Sampler (Impaction Inlet)



PM$_{10}$ Sampler (Cyclonic Inlet)

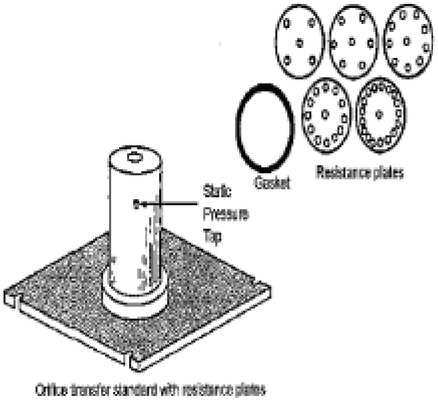
7. Analysis

Filter inspection: Inspect the filter for pin holes using a light table. Loose particles should be removed with a soft brush. Apply the filter identification number or a code to the filter if it is not a numbered. Condition the filter in conditioning room maintained within 20-30° C and 40-50% relative humidity or in an airtight desiccator for 24 hours. Take initial weight of the filter paper (W_i) before sampling. Condition the filter after sampling in conditioning room maintained within 20-30° C and 40-50% relative humidity or in an airtight desiccator for 24 hours. Take final weight of the filter paper (W_f)

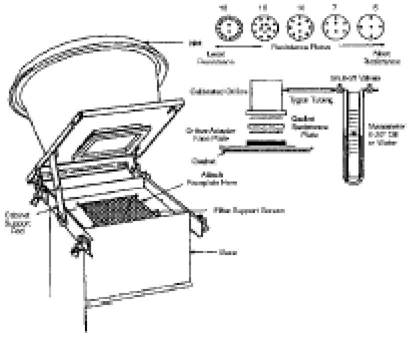
8. Calibration

Periodical calibration of the sampler is being done by Orifice Transfer Standard

- The PM10 sampler calibration orifice consists of a 3.175 cm (1.25 in) diameter hole in the end cap of 7.62 cm (3 in) diameter by 20.3 cm (8 in) long hollow metal cylinder. This orifice is mounted tightly to the filter support in place of the inlet during calibration. A small tap on the side of the cylinder is provided to measure the pressure drop across the orifice. A flow rate of 1132 L/min through the orifice typically results in a pressure difference of several inches of water. The relationship between pressure difference and flow rate is established via a calibration curve derived from measurements against a primary standard such as a Roots meter at standard temperature and pressure. Flow resistances that simulate filter resistances are introduced at the end of the calibrator opposite the orifice by a set of perforated circular disks.



Top loading Orifice kit



Calibration set up

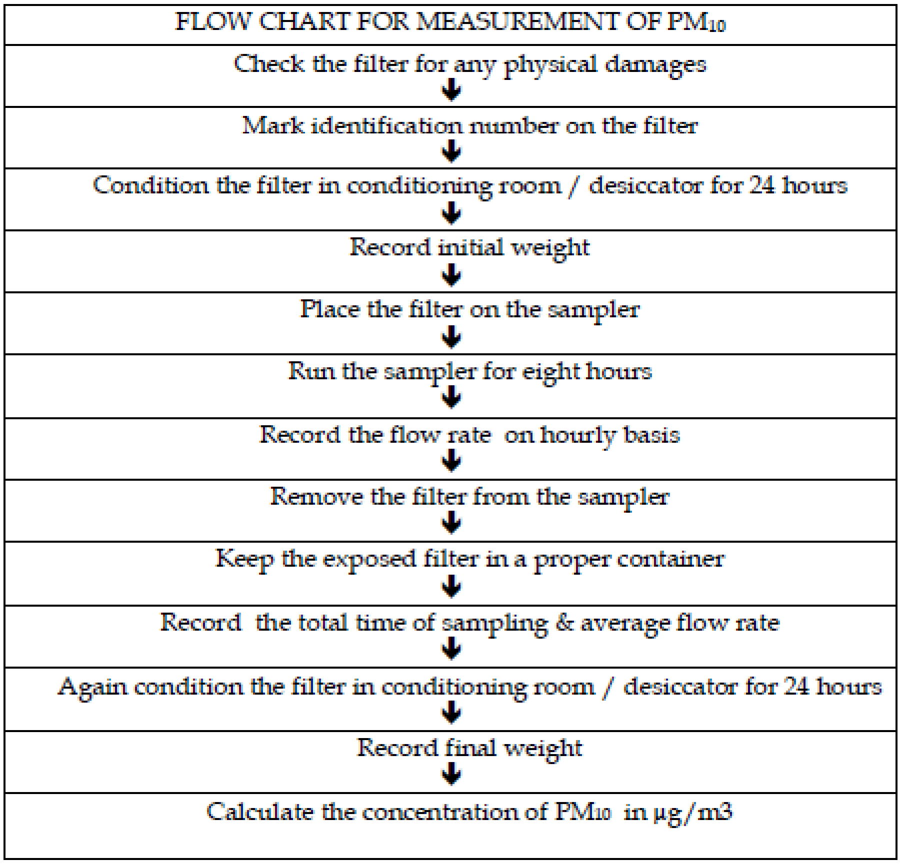
9. Calculation

$$C\ PM10\ \mu g/m3 = (Wf - Wi) \times 106\ /\ V$$

Where,
C PM10 = Concentration of Nitrogen dioxide, $\mu g/m^3$
W_f = Initial weight of filter in g
W_i = Initial weight of filter in g
106 = Conversion of g to µg
V = Volume of air sampled, m^3

10. Quality Control

Quality Control (QC) is the techniques that are used to fulfill requirements for quality. The QC procedures for the air sampling and monitoring sections of this protocol include preventative maintenance of equipment, calibration of equipment, analysis of field blanks and lab blanks.



FLOW CHART FOR MEASUREMENT OF PM_{10}

Check the filter for any physical damages
↓
Mark identification number on the filter
↓
Condition the filter in conditioning room / desiccator for 24 hours
↓
Record initial weight
↓
Place the filter on the sampler
↓
Run the sampler for eight hours
↓
Record the flow rate on hourly basis
↓
Remove the filter from the sampler
↓
Keep the exposed filter in a proper container
↓
Record the total time of sampling & average flow rate
↓
Again condition the filter in conditioning room / desiccator for 24 hours
↓
Record final weight
↓
Calculate the concentration of PM_{10} in µg/m3

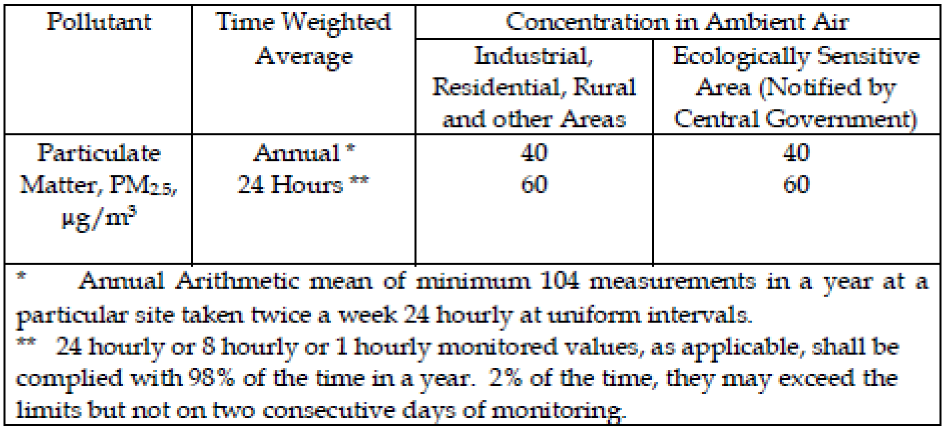
Guidelines for determination of PM2.5 in ambient air (Gravimetric Method)

1. Purpose

The purpose of this protocol is to provide guidelines for monitoring and analysis of Particulate Matter PM2.5 in ambient air.

2.0 Definition

PM2.5 refers to fine particles that are 2.5 micrometers (µm) or smaller in diameter. Ambient air is defined as any unconfined part of the Earth's atmosphere, that the surrounding outdoor air in which humans and other organisms live and breathe.
FRM – Federal Reference Method
FEM – Federal Equivalent Method



Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
Particulate Matter, $PM_{2.5}$, $\mu g/m^3$	Annual * 24 Hours **	40 60	40 60

* Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

4.0 Principle

An electrically powered air sampler draws ambient air at a constant volumetric flow rate (16.7 lpm) maintained by a mass flow / volumetric flow controller coupled to a microprocessor into specially designed inertial particle-size separator (i.e. cyclones or impactors) where the suspended particulate matter in the PM2.5 size ranges is separated for collection on a 47 mm polytetrafluoroethylene (PTFE) filter over a specified sampling period. Each filter is weighed before and after sample collection to determine the net gain due to the particulate matter. The mass concentration in the ambient air is computed as the total mass of collected particles in the PM2.5 size ranges divided by the actual volume of air sampled, and is expressed in µg/m3. The microprocessor reads averages and stores five-minute averages of ambient temperature, ambient pressure, filter temperature and volumetric flow rate. In addition, the microprocessor calculates the average temperatures and pressure, total volumetric flow for the entire sample run time and the coefficient of variation of the flow rate.

5.0 Interferences and Artefacts

The potential effect of body moisture or oils contacting the filters is minimized by using non-serrated forceps to handle the filters at all times. This measure also moderates interference due to static electricity. Teflon filters accumulate a surface electrical charge, which may affect filter weight. Static electricity is controlled by treating filters with a "Static Master" static charge neutralizer prior to weighing. Placement of filters on a "Static Master" unit is required for a minimum of 30 seconds before any filter can be weighed. Moisture content can affect filter weight. Filters must be equilibrated for a minimum of 24 hours in a controlled environment prior to pre- and postweighing. The balance room's relative humidity must be maintained at a mean value range of 45 ± 5 % and its air temperature must be maintained at a mean value range of 25.0 ± ºC. Airborne particulate can adversely affect accurate mass measurement of the filter. Filters undergoing conditioning should not be placed within an airflow path created by air conditioning ductwork, computer printers, or frequently opened doorways. Cleaning laboratory bench-tops and weighing areas daily, installing “sticky” floor mats at doorway entrances to the balance room and wearing clean lab coats over regular clothing can further minimize dust contamination.

5.1 Precision and Accuracy

The performance segment of the PM2.5 FRM specifies strict guidelines for controls that must be observed, as well as the range of precision and accuracy of those controls. The flow rate through the instrument is specified as 16.67 lpm (1 m^3/hr). This flow must be volumetrically controlled to a precision of 5% and an accuracy of 2%. The flow control must be upgraded at least every 30 seconds and recorded (logged) every five minutes. Barometric pressure, ambient temperature and filter temperature should be measured on the same schedule. Filter temperature, it must not exceed the ambient temperature by more than 5° C for more than 30 minutes. A fan blowing filtered ambient air through the enclosure provides the necessary cooling effect. It is necessary for the entire apparatus to provide accurate performance over a temperature range of –20 to 50° C. The supporting run-time (interval) data, which are stored in detailed 5- minute intervals in the sampler’s microprocessor, as well as 24-hour integrated performance (filter) data, must be capable of being extracted at the completion of a 24-hour run. The FRM mandates the provision of an RS232 port for this purpose. Data may be extracted to a portable computer.

Mass of the filter deposit, flow rate through the filter, and sampling time have typical precision of ± 0.2 mg, ± 5%, and ± 30 seconds, respectively. These uncertainties combine to yield a propagated precision of approximately ± 5 % at 10 $\mu g/m^3$ and approximately ± 2% at 100 $\mu g/m^3$.

6.0 Sitting Requirements

Samplers should be sited to meet the goals of the specific monitoring project. For routine sampling to determine compliance with the National Ambient Air Quality Standards (NAAQS), sampler sitting is described in CPCB guidelines shall apply

The monitoring should be done at outside the zone of influence of sources located within the designated zone of representation for the monitoring site. Height of the inlet must be 3 – 10 m above the ground level. And at a suitable distance from any direct pollution source including traffic. Large nearby buildings and trees extending above the height of the monitor may present barriers or deposition surfaces for PM. Distance of the sampler to any air flow obstacle i.e. buildings, must be more than two times the height of the obstacle above the sampler. There should be unrestricted airflow in three of four quadrants. Certain trees may also be sources of PM in the form of detritus, pollen, or insect parts. These can be avoided by locating samplers by placing them > 20 m from nearby trees. If collected sampling has to be performed the minimum distance between two Samplers should be 2 m.

7.0 Apparatus and Materials

· Sampling equipment designated as FRM (Federal Reference Method) or FEM (Federal Equivalent Method)

· Certified Flow Transfer Standard for Flow Calibration Following established EPA methods and procedures, all calibration transfer standards (i.e. temperature, pressure and flow) must be certified against traceable standards at least once per year. Calibration of these transfer standards will be conducted by the transfer standard manufacturer.

· Certified Standards for Pressure and Temperature (Optional)

· Electronic microbalance with a minimum resolution of 0.001 mg and a precision of ± 0.001 mg, supplied with a balance pan. The microbalance must be positioned on a vibration-damping balance support table.

· Calibration weights, utilized as Mass Reference Standards, should be non-corroding, range in weight from 100 mg to 200 mg, and be certified as traceable to NIST mass standards. The weights should be ASTM Class 1 category with a tolerance of 0.025 mg.
· Non-serrated forceps for handling filters.

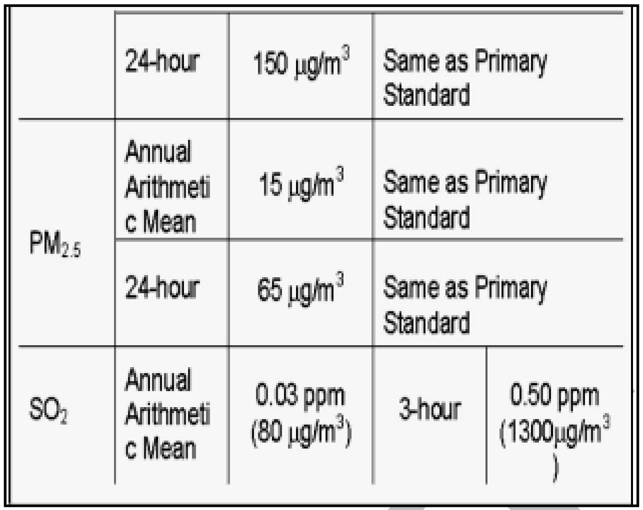
AIR QUALITY MONITORING

The primary goal of any air pollution control program is to protect people and their environment from excessive exposure to atmospheric pollutants. Evaluating the success or failure of pollution control programs largely depends on the availability of accurate data about ambient (outside) concentrations of air pollutants or air quality. Consequently, an entire body of research has emerged that attempts to better estimate the quantity and types of pollutants in the ambient air, and to better characterize and quantify the specific sources of those pollutants. Air Quality is a dynamic and complex environmental phenomenon exhibiting large temporal and spatial variation.

The temporal and spatial variations in atmospheric levels of pollution, which is the essence of air quality, are caused by
(a) Changes in the pollutant source(s) emission rates
(b) Changes in meteorology and topography, which provide the mechanisms for chemical reactions of pollutants in the atmosphere and for the control and removal of atmospheric pollutants.

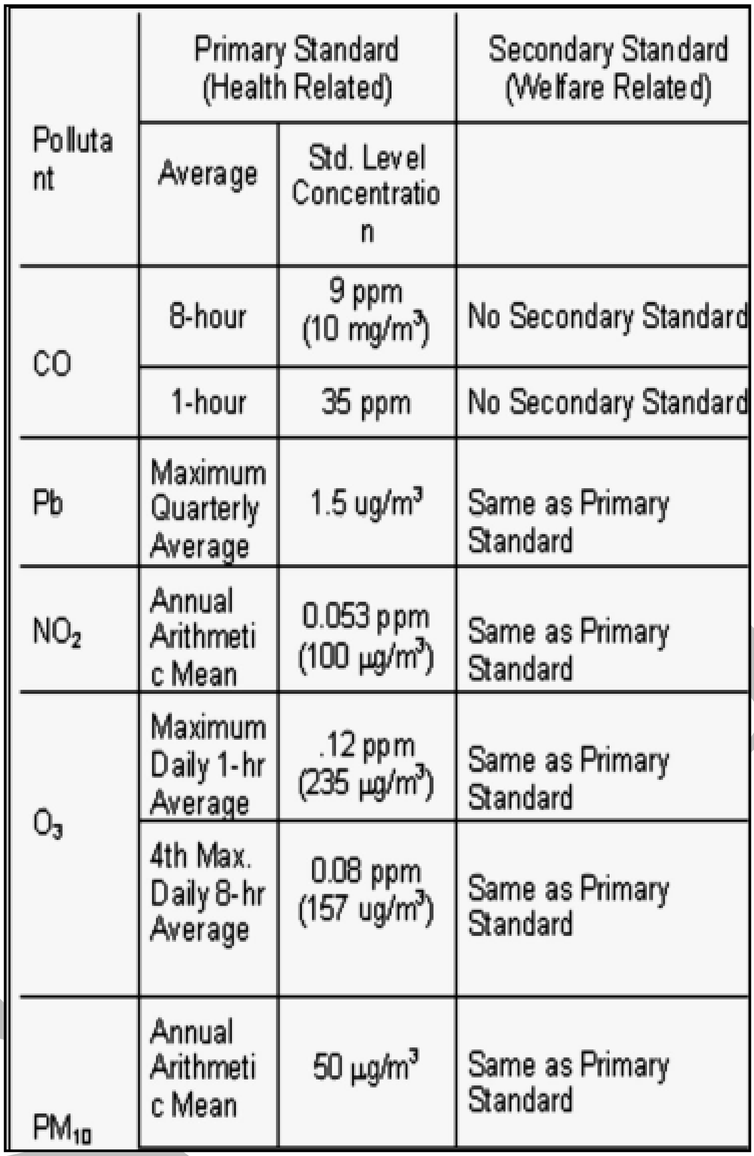
Monitoring of the air quality can be very complex, since it requires the collection of data that allows for a resolution of the dynamic nature of air quality in terms of its spatial and temporal variation. Ambient air quality monitoring can be defined as a systematic, long-term assessment of air pollutant levels in our communities. This monitoring is usually undertaken to characterize air quality in urban areas, near large point sources of air pollution or where there are sensitive environmental receptors. In general, ambient air monitoring networks are typically used to:

- characterize local, regional, and national air quality conditions
- assess health impacts
- assess effectiveness of control programs
- help form the basis for new control programs
- assess source impacts
- provide information to the public



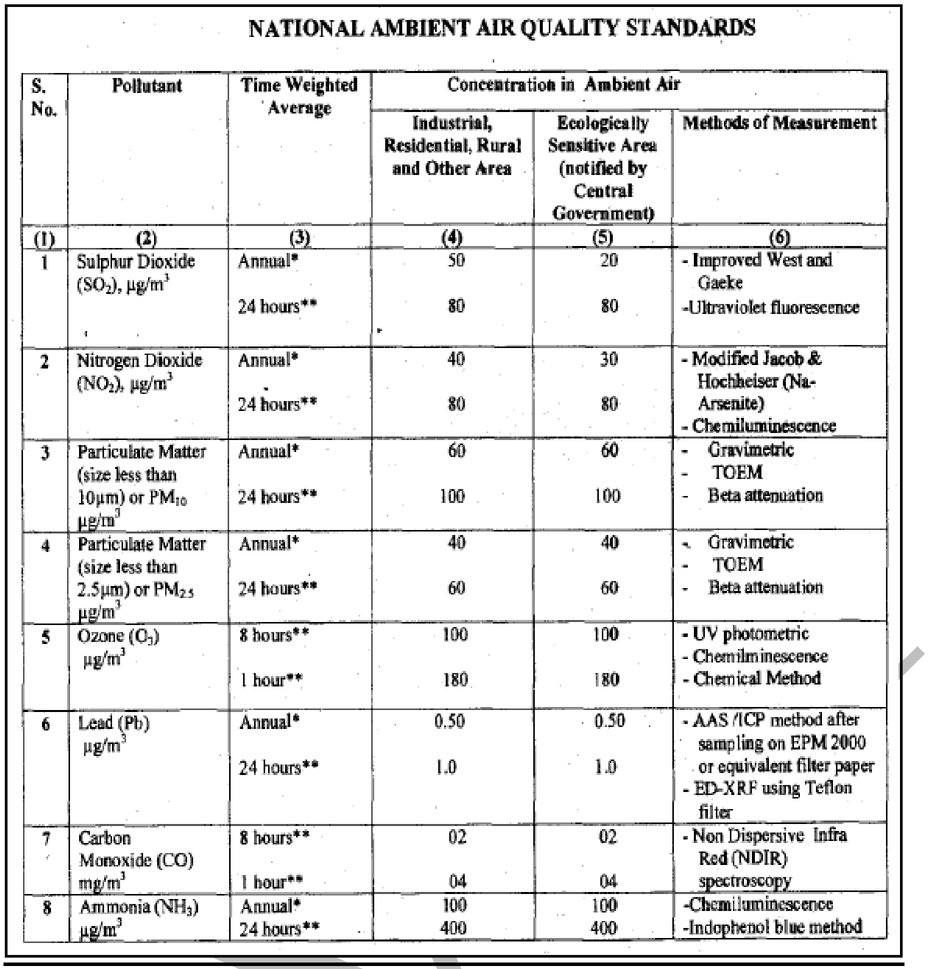
	24-hour	150 $\mu g/m^3$	Same as Primary Standard	
$PM_{2.5}$	Annual Arithmetic Mean	15 $\mu g/m^3$	Same as Primary Standard	
	24-hour	65 $\mu g/m^3$	Same as Primary Standard	
SO_2	Annual Arithmetic Mean	0.03 ppm (80 $\mu g/m^3$)	3-hour	0.50 ppm (1300$\mu g/m^3$)

Fig: Ambient Air Quality Standards



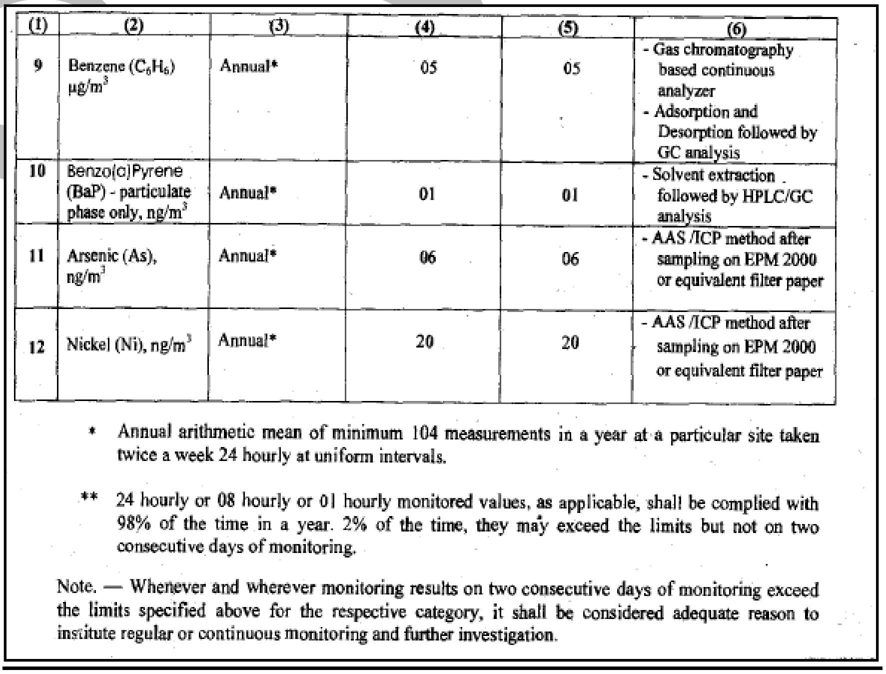
Pollutant	Primary Standard (Health Related)		Secondary Standard (Welfare Related)
	Average	Std. Level Concentration	
CO	8-hour	9 ppm (10 mg/m^3)	No Secondary Standard
	1-hour	35 ppm	No Secondary Standard
Pb	Maximum Quarterly Average	1.5 ug/m^3	Same as Primary Standard
NO_2	Annual Arithmetic Mean	0.053 ppm (100 μg/m^3)	Same as Primary Standard
O_3	Maximum Daily 1-hr Average	.12 ppm (235 μg/m^3)	Same as Primary Standard
	4th Max. Daily 8-hr Average	0.08 ppm (157 ug/m^3)	Same as Primary Standard
PM_{10}	Annual Arithmetic Mean	50 μg/m^3	Same as Primary Standard

Fig: Ambient Air Quality Standards



NATIONAL AMBIENT AIR QUALITY STANDARDS

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
(1)	(2)	(3)	(4)	(5)	(6)
1	Sulphur Dioxide (SO_2), µg/m^3	Annual* 24 hours**	50 80	20 80	- Improved West and Gaeke -Ultraviolet fluorescence
2	Nitrogen Dioxide (NO_2), µg/m^3	Annual* 24 hours**	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenite) - Chemiluminescence
3	Particulate Matter (size less than 10µm) or PM_{10} µg/m^3	Annual* 24 hours**	60 100	60 100	- Gravimetric - TOEM - Beta attenuation
4	Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m^3	Annual* 24 hours**	40 60	40 60	- Gravimetric - TOEM - Beta attenuation
5	Ozone (O_3) µg/m^3	8 hours** 1 hour**	100 180	100 180	- UV photometric - Chemilminescence - Chemical Method
6	Lead (Pb) µg/m^3	Annual* 24 hours**	0.50 1.0	0.50 1.0	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter
7	Carbon Monoxide (CO) mg/m^3	8 hours** 1 hour**	02 04	02 04	- Non Dispersive Infra Red (NDIR) spectroscopy
8	Ammonia (NH_3) µg/m^3	Annual* 24 hours**	100 400	100 400	-Chemiluminescence -Indophenol blue method



(1)	(2)	(3)	(4)	(5)	(6)
9	Benzene (C_6H_6) µg/m^3	Annual*	05	05	- Gas chromatography based continuous analyzer - Adsorption and Desorption followed by GC analysis
10	Benzo(a)Pyrene (BaP) - particulate phase only, ng/m^3	Annual*	01	01	- Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As), ng/m^3	Annual*	06	06	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel (Ni), ng/m^3	Annual*	20	20	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note. — Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigation.

POLLUTION PREVENTION

For decades, research and government regulation have been conducted to focus the attention of the environmental community on the measurement and control of pollutants in the ambient air. However, slowly emerging within the pages of air pollution control is a new approach to waste management: a strategy known as Pollution Prevention. For decades, air pollution professionals have been so consumed with how to control and eliminate air pollution that little thought was given to preventing its creation. Recognizing this deficiency, Congress passed the Clean Air Act Amendment of 1990 and installed the framework and structure for an effective pollution prevention program. Pollution prevention emphasizes the reduction or elimination of waste production before it is emitted into the environment. Scientists, engineers, and technicians joining this new effort of air pollution management focus their attention on how industries can reduce or altogether eliminate the production of waste at the source. At industrial or commercial facilities, pollution prevention may require the substitution of process chemicals in the refining process that will be less hazardous to human health or the environment. Pollution prevention may also include creative alterations of the process, equipment, or plant operating practices in order to reduce or eliminate air pollution.

LEGISLATIVE HISTORY

Since much of the air pollution problem in the United is plant, process, or vehicle related, Congress and the U.S. EPA drafted a new management strategy directed toward controlling these pollutants. The Pollution Prevention Act (1990) shifted the focus from the measurement and control of industrial emissions to preventing the generation of pollution altogether. While only a fine distinction may appear to exist between the two approaches, the Act clearly defines Pollution Prevention. According to the legislation, Pollution Prevention is any reduction of generated waste or recycling activity undertaken at the pollutant source that results in either (1) a reduction in the total volume or quantity of waste or (2) a reduction in the toxicity of the waste in order to eliminate the threat to human health and the environment.

Resource Conservation and Recovery Act (1984):

The concept of pollution prevention first emerged in an amendment to the Resource Conservation and Recovery Act (RCRA) in 1984. Congress made “waste minimization” – as pollution prevention was first defined – a national policy objective and declared that the generation of hazardous waste was to be reduced or eliminated wherever possible. On the heels of the RCRA, Congress issued an important 1986 report (EPA/530-SW-033) that more narrowly defined and articulated the concept of “waste minimization” or pollution prevention (Theodore and Young, 1992). This legislation regulates over 400 various chemicals and compounds that require treatment or disposal.

Superfund Amendments and Reauthorization Act (1986):

The Superfund Amendments and Reauthorization Act (SARA) of 1986 created the Emergency Planning and Community Right- To-Know Act (EPCRA), also known as SARA Title III. This statute was designed to improve community access to information about local chemical hazards and to facilitate development of chemical emergency response plans by State and local agencies. EPCRA requires that companies in specific categories that manufacture, process, or use chemicals in specified quantities must file written reports, provide notification of spills or releases and maintain an inventory of toxic chemicals.

Certain companies are required to submit annual reports listing any releases of “toxic chemicals” in relation to EPCRA Section 313, and commonly known as the Toxic Chemical Release Inventory.

Pollution Prevention Act (1990)

This landmark legislation was passed in 1990 that established pollution prevention as a national objective. The Pollution Prevention Act (PPA) raised pollution prevention from “a desirable goal” to the status of national policy and created the U.S. EPA’s Office of Pollution Prevention. The law directs every facility to report information about the management of each toxic chemical they release or treat and requires manufacturing facilities to describe what efforts have been made to eliminate or reduce the quantities of those chemicals.

AIR QUALITY INDEX

An air quality index is defined as an overall scheme that transforms the weighed values of individual air pollution related parameters (for example, pollutant concentrations) into a single number or set of numbers. The result is a set of rules (i.e. most set of equations) that translates parameter values into a more simple form by means of numerical manipulation.

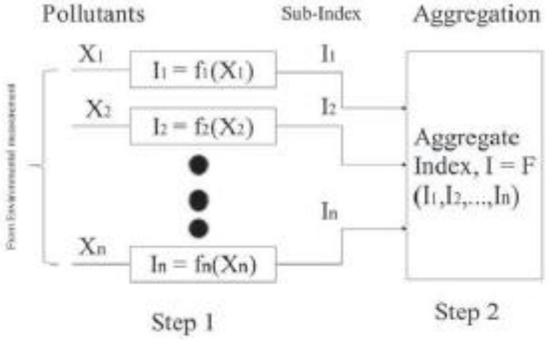


Fig: Formation of an Aggregated Air Quality Index

If actual concentrations are reported in µg/m^3 or ppm (parts per million) along with standards, then it cannot be considered as an index. At the very last step, an index in any system is to group specific concentration ranges into air quality descriptor categories.

Structure of an Index

Primarily two steps are involved in formulating an AQI: (i) formation of sub-indices (for each pollutant) and (ii) aggregation of sub-indices to get an overall AQI.

Formation of sub-indices (I_1, I_2,...., In) for n pollutant variables (X_1, X_2...., Xn) is carried out using sub-index functions that are based on air quality standards and health effects. Mathematically;

$$I_i = f\,(X_i),\ i=1, 2,...,n \ldots\ldots\ldots [1]$$

Each sub-index represents a relationship between pollutant concentrations and health effect. The functional relationship between sub-index value (I_i) and pollutant concentrations (X_i) is explained later in the text.

Aggregation of sub-indices, Ii is carried out with some mathematical function (described below) to obtain the overall index (I), referred to as AQI.

$$I = F\,(I_1, I_2, ..., I_n) \ldots\ldots\ldots\ldots [2]$$

The aggregation function usually is a summation or multiplication operation or simply a maximum operator.

Sub-indices (Step 1)

Sub-index function represents the relationship between pollutant concentration X_i and corresponding sub index I_i. It is an attempt to reflect environmental consequences as the concentration of specific pollutant changes. It may take a variety of forms such as linear, non-linear and segmented linear. Typically, the I-X relationship is represented as follows:

$$I = \alpha X + \beta \ldots\ldots\ldots\ldots [3]$$

Where, α =slope of the line, β = intercept at X=0.

The general equation for the sub-index (I_i) for a given pollutant concentration (C_p); as based on 'linear segmented principle' is calculated as:

$$I_i = [\{(I_{HI} - I_{LO})/(B_{HI} - B_{LO})\} * (C_p - B_{LO})] + I_{LO} \ldots\ldots\ldots [4]$$

where,

B_{HI}= Breakpoint concentration greater or equal to given concentration.

B_{LO}= Breakpoint concentration smaller or equal to given concentration.

I_{HI} =AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

I_p = Pollutant concentration

For example, we take PM_{10} with concentration of 85 μ g/m^3, B_{HI}, B_{LO}, I_{HI}, I_{LO} values from Greater Vancouver

Air Quality Index and using equation [4],

$$\text{Sub Index } (I_p) = \{(100 - 50)/(100 - 50)\} * (85 - 50) + 50 = 85$$

Similarly, Sub Index can be calculated for other pollutants as well.

Aggregation of Sub-indices (Step 2)

Once the sub-indices are formed, they are combined or aggregated in a simple additive form or weighted additive form:

Weighted Additive Form

$$I = \text{Aggregated Index} = \Sigma\, w_i I_i \text{ (For i= 1, ⋯..,n)} \ldots\ldots.. [5]$$

where, $\Sigma\, w_i = 1$

I_i= sub-index for pollutant i
n = number of pollutant variables
w_i = weightage of the pollutant

Root-Sum-Power Form (non-linear aggregation form)

$$I = \text{Aggregated Index} = [\,\Sigma\, I_i^{p}](1/p)\ldots\ldots\ldots\ [6]$$

where, p is the positive real number >1.

Root-Mean-Square Form

$$I = \text{Aggregated Index} = \{1/k\ (I_1{}^{2} + I_2{}^{2} + \cdots\cdots + I_k{}^{2}\}^{0.5}$$

Min or Max Operator (Ott 1978)

$$I = \text{Min or Max}\ (I_1, I_2, I_3, ..., In)\ldots\ldots\ldots\ldots\ldots\ [8]$$

Indices in the Literature

1) **Green Index (GI)**

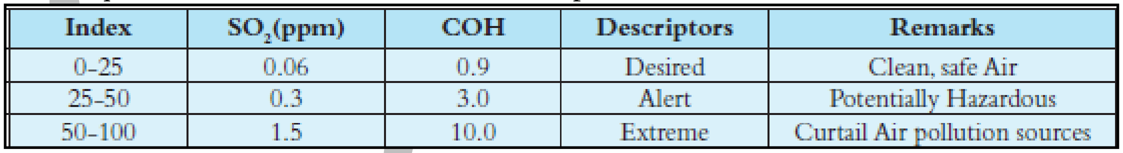
One of the earliest air pollution indices to appear in literature was proposed by Green (1966). It included just two-pollutant variables - SO2 and COH (Coefficient of Haze). The equations to calculate the subindices were:

$I_{SO2} = 84 *X^{0.431}$
$I_{COH} = 26.6 *X^{0.576}$
Where,
I_{SO2} = Sulphur dioxide sub-index
I_{COH}= Coefficient of Haze Sub-index
X = Observed pollutant concentration

The Green Index is computed as the arithmetic mean of the two sub-indices:

$$\mathbf{GI = 0.5 * (I_{SO2} + I_{COH})}$$

The above equations are obtained from the break point concentration shown in Table below.



Index	SO_2(ppm)	COH	Descriptors	Remarks
0-25	0.06	0.9	Desired	Clean, safe Air
25-50	0.3	3.0	Alert	Potentially Hazardous
50-100	1.5	10.0	Extreme	Curtail Air pollution sources

Table : Break Point Concentration of Green Index

As the index did not include any other pollutants besides SO_2 and SPM, it had limited applications. It is applicable in colder seasons only. It is also subjected to eclipsing and ambiguity phenomena (arithmetic mean weighted as linear sum). This index was intended more as a system for triggering control actions during air pollution episodes than a means for reporting air quality data to the public.

2) **Fenstock Air Quality Index (AQI):**

Fenstock (1969) proposed an index to assess the relative severity of air pollution and applied it to assess AQI of 29 U.S cities. This was the first index to estimate air pollutant concentrations from the data on source emissions and meteorological conditions in each city:

$$\mathbf{AQI = W_i\ I_i}$$

where, W_i = weightages for CO, TSP and SO_2

I_i= estimated sub-indices for CO, TSP and SO_2

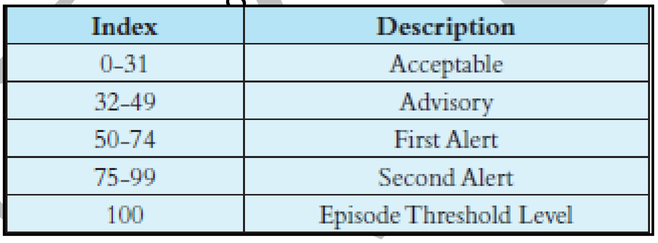
This index is applicable to square urban area with wind always parallel to one side for uniform meteorological conditions under neutral stability with continuous source distributed uniformly. This AQI is not used for daily air quality reports but for estimating overall air pollution potential for a metropolitan area.

3) Ontario API

Shenfeld (1970) developed Ontario Air Pollution Index in Canada. This index was intended to provide the public with daily information about air quality levels and to trigger control actions during air pollution episodes. It includes two pollutants variables:

$$\mathbf{API = 0.2\ (30.5\ COH + 126\ SO_2)\ 1.35}$$

Both COH and SO_2 (in ppm) are 24 hour running averages; Descriptor scale is given in Table.



Index	Description
0-31	Acceptable
32-49	Advisory
50-74	First Alert
75-99	Second Alert
100	Episode Threshold Level

Table : Descriptor categories for Ontario API

4) Oak Ridge Air Quality Index (ORAQI)

Oak Ridge National Laboratory published the ORAQI in 1971. It was based on the 24-hour average concentrations of the following five pollutants:

1. SO_2
2. NO_2
3. PM
4. CO
5. Photochemical Oxidants

The sub-index is calculated as the ratio of the observed pollutant concentration to its respective standard. As reported by Babcock and Nagda (1972), the ORAQI aggregation function was a non-linear function:

$$\mathbf{ORAQI = \{5.7\ \Sigma\ I_i\}^{1.37}}$$

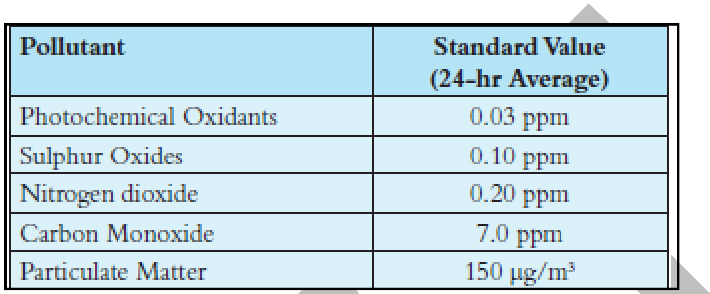
where, $I_i = (X/Xs)_i$

X = Observed pollutant concentration

X_s = Pollutant Standard

I = Pollutant

The standards for the pollutants used in developing ORAQI are given in Table.

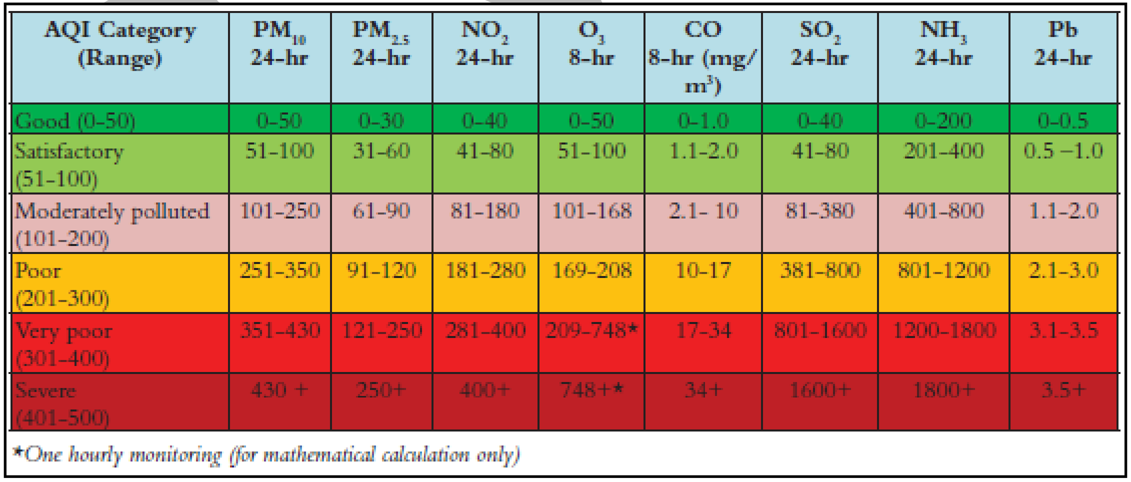


Pollutant	Standard Value (24-hr Average)
Photochemical Oxidants	0.03 ppm
Sulphur Oxides	0.10 ppm
Nitrogen dioxide	0.20 ppm
Carbon Monoxide	7.0 ppm
Particulate Matter	150 μg/m^3

<u>Table :</u> Break Point Concentrations of ORAQI

The constants (e.g. 5.7 and 1.37 in equation) are so selected that the ORAQI = 10 when all concentrations are at their naturally occurring or backgrounds levels and ORAQI = 100 when all concentrations are at their standards.

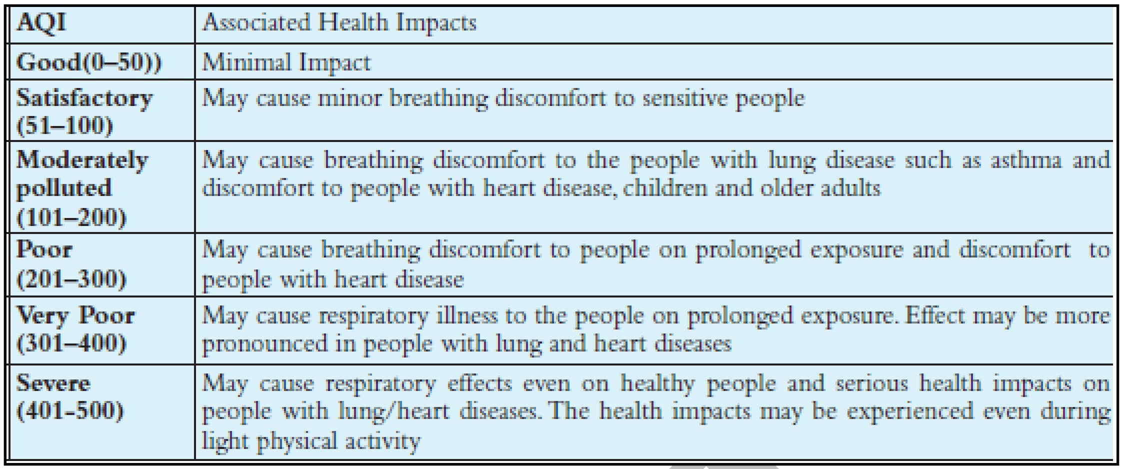
Although well-defined descriptors are given, its developers imply no correlation with health effects. It is subjected to eclipsing and ambiguity. It is also difficult to explain to public and involves complex calculations.



AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5 –1.0
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

**One hourly monitoring (for mathematical calculation only)*

Table: Proposed Breakpoints for AQI Scale 0-500 (units: μg/m^3 unless mentioned otherwise)



AQI	Associated Health Impacts
Good(0–50))	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people
Moderately polluted (101–200)	May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease
Very Poor (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe (401-500)	May cause respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases. The health impacts may be experienced even during light physical activity

Table : Health Statements for AQI Categories

KYOTO PROTOCOL

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which **commits** its Parties by setting internationally binding emission reduction targets.

Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."

The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords." Its first commitment period started in 2008 and ended in 2012.

In Doha, Qatar, on 8 December 2012, the "Doha Amendment to the Kyoto Protocol" was adopted. The amendment includes:

- New commitments for Annex I Parties to the Kyoto Protocol who agreed to take on commitments in a second commitment period from 1 January 2013 to 31 December 2020;
- A revised list of greenhouse gases (GHG) to be reported on by Parties in the second commitment period; and
- Amendments to several articles of the Kyoto Protocol which specifically referenced issues pertaining to the first commitment period and which needed to be updated for the second commitment period.

On 21 December 2012, the amendment was circulated by the Secretary-General of the United Nations, acting in his capacity as Depositary, to all Parties to the Kyoto Protocol in accordance with Articles 20 and 21 of the Protocol.

During the first commitment period, 37 industrialized countries and the European Community committed to reduce GHG emissions to an average of five percent against 1990 levels. During the second commitment period, Parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020; however, the composition of Parties in the second commitment period is different from the first.

Under the Protocol, countries must meet their targets primarily through national measures. However, the Protocol also offers them an additional means to meet their targets by way of three market-basedmechanisms.

The Kyoto mechanisms are:

- International Emissions Trading
- Clean Development Mechanism (CDM)
- Joint implementation (JI)

The mechanisms help to stimulate green investment and help Parties meet their emission targets in a cost-effective way.

Monitoring emission targets

Under the Protocol, countries' actual emissions have to be monitored and precise records have to be kept of the trades carried out.

Registry systems track and record transactions by Parties under the mechanisms. The UN Climate Change Secretariat, based in Bonn, Germany, keeps an international transaction log to verify that transactions are consistent with the rules of the Protocol.

Reporting is done by Parties by submitting annual emission inventories and national reports under the Protocol at regular intervals.

A compliance system ensures that Parties are meeting their commitments and helps them to meet their commitments if they have problems doing so.

Adaptation

The Kyoto Protocol, like the Convention, is also designed to assist countries in adapting to the adverse effects of climate change. It facilitates the development and deployment of technologies that can help increase resilience to the impacts of climate change.

The Adaptation Fund was established to finance adaptation projects and programmes in developing countries that are Parties to the Kyoto Protocol. In the first commitment period, the Fund was financed mainly with a share of proceeds from CDM project activities. In Doha, in 2012, it was decided that for the second commitment period, international emissions trading and joint implementation would also provide the Adaptation Fund with a 2 percent share of proceeds.

The road ahead

The Kyoto Protocol is seen as an important first step towards a truly global emission reduction regime that will stabilize GHG emissions, and can provide the architecture for the future international agreement on climate change.

In Durban, the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) was established to develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention, applicable to all Parties. The ADP is to complete its work as early as possible, but no later than 2015, in order to adopt this protocol, legal instrument or agreed outcome with legal force at the twenty-first session of the Conference of the Parties and for it to come into effect and be implemented from 2020.

MODULE 4

CONTROL TECHNIQUES

PARTICULATE EMISSION CONTROL:

Particulate matter emitted in gaseous streams consists of discrete and minute suspended particles. Particle glazes range generally from 100□m down to 1.0□m and even less. The choice of collection devices depends upon a number of footers the physical and chemical characteristics of particulates, the particle size and concentration in the gas, volume of particulates to be handled, and the temperature and humidity of gaseous medium. In particular factors like toxicity and inflammability must be taken into consideration when evaluating operating efficiency.

PARTICULAR CONTROL EQUIPMENT

Control devices re diverted into five major groups

1) Gravitational setting chambers
2) Cyclones
3) Fabric filters
4) Electrostatic precipitators
5) Scrubbers or wet collectors
6) Inertial separators

SETTLING CHAMBERS

It is one of the simplest types of collection equipment for aerosols. The principle it works on is that it consists of a chamber in which the carrier gas velocity is reduced so as to allow the particulates to settle out of the moving stream under the action of gravity. It is constructed from brick and concrete. It is of the form of long box like structure with an inlet and an outlet set horizontally on the ground. The carrier gas is made and passes at low velocities through the inlet. The solid particulates having higher density than the surrounding gas settle at the bottom of the chamber under the influence of gravity which is removed using happens. Usually the gas velocity must be kept low say less than 3m/sec to prevent re-entertainment of the settled particles, less than 0.5m/sec for good results and hence to reduce turbulence and uniform velocity curtains, rods and mesh screens may be suspended in the chamber.

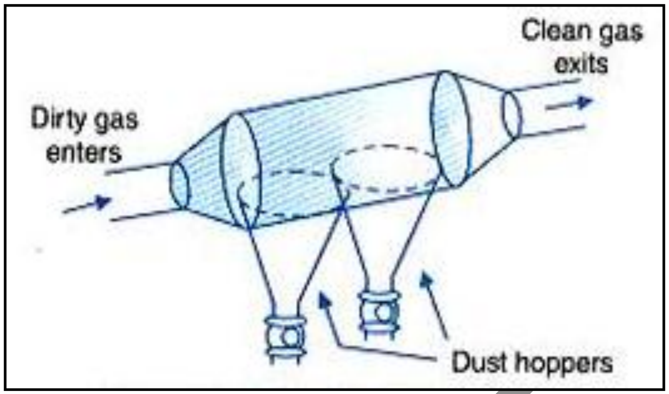


Fig: Gravity settling chamber

ADVANTAGES:

1) Low initial cost
2) Simple construction
3) Low maintenance cost
4) Low pressure drop
5) Dry and continuous disposal of solid particulates
6) It can be constructed out of any material
7) Temperature and pressure limitations imposed only to be materials of construction used.

DISADVANTAGES:

1) Large space requirements
2) Only large particles can be collected (above 40µ)

APPLICATIONS:

Setting chambers are used generally to remove particulates above 40□ in diameter, such as carbon black and various metallurgical fumes from agglomerates.

They are used widely for the removal of large solid particles from natural draft furnace, Kilns etc. and sometimes used in the process industries such as good and metallurgical industries as a first step in dust control.

INERTIAL (OR) IMPACT SEPARATORS

There are 3 different types of inertial separators

1) Baffle type separator
2) Louvre type separator
3) Dust traps

BAFFLE TYPE SEPARATOR: It is one of the simplest forms of inertial separator which is simple to operate. It has no moving parts and construction expenses are more because of As interior work of fabricating at installing the baffles. Here the gas stream is made to follow a tortuous flow path which is obtained by the insertion of staggered path into the path of the gas stream. As a result, the gas is subjected to service of solid surfaces. This device is suitable for removing particles larger than 20□ in diameter. These devices are widely used for particulate removal in power plants and rotary kilns.

LOUVRE TYPE SEPARATOR

Louvre type separator is one of the inertial separators. The separator usually is set at an angle to the carrier gas stream so as to cause a rapid reversal of the gas flow the direction which causes particulates to impinge on the louvers which are bound back into the moving gas stream in the inlet diameter which are removed by secondary air circuit. This device is suitable for removing particles larger than 30µ in diameter. The efficiency depends on Louvre spacing, closer spacing producing higher efficiency and the operating velocities are of order 12-15m/s at the inlet.

DUST TRAP

It is another common type of impact separator. Here dust Laden gas is introduced into a control pipe and is made to undergo a change in direction by 180^0, due to inertia the dust settles in the control chamber. It is not important of reverse flow of gas. The dust trap B used as a pre cleaner and to reduce the load of the larger diameter particles so as to pass through more efficient mechanisms, for removing smaller particles. The gas velocity of the inlet is about 10M/S and in chamber it is about 1 M/S. The collection efficiency for particles greater than 30µ is about 70%.

CYCLONE SEPARATORS

Cyclone separators diffused centrifugal force generated by the spinning gas stream to separate the particulate matter from the carrier gas. The centrifugal force on particles in a spinning gas stream is much greater than gravity therefore cyclones are effective in the removal of much smaller particles than gravitational setting chambers and negative much less space to handle the same gas volume.

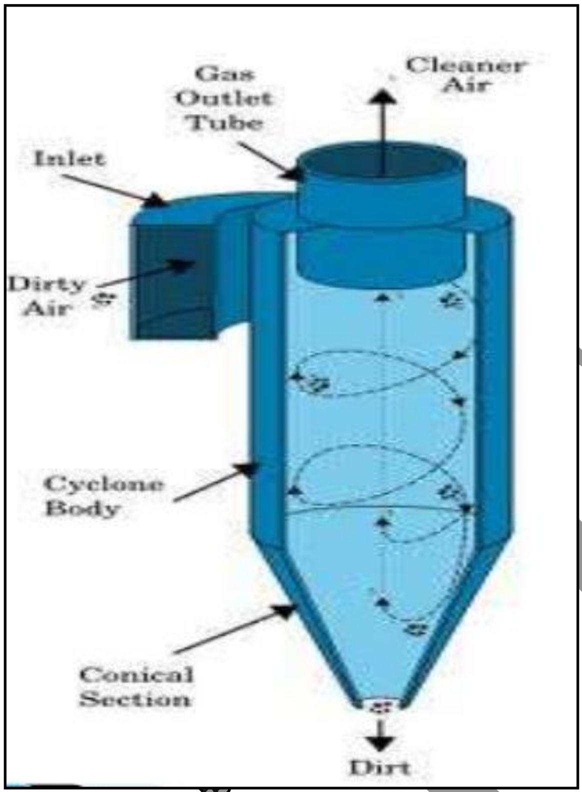


Fig: CYCLONE SEPARATORS

REVERSE FLOW CYCLONE SEPARATOR

A simple reverse flow cyclone separator consists of a vertical cylinder having a conical bottom and is fitted with a tangential inlet located near the top, and an out-let at the bottom of the cone for discharging separated particles. The gas outlet pipe is extended into the cylinder to prevent short circulating of gas from inlet to outlet. In operation, the particle-laden gas open entering the cyclone cylinder receives a rotating motion. The velocity so formed develops a centrifugal force, which acts to throw the particles radically towards the wall. The gas spirals downward to the bottom of the cone and at the bottom the gas flow reverses to form an inner vertex which leaving through the outlet pipe.

ADVANTAGES:

1) Low initial cost
2) Simple construction and operation
3) Low pressure drop and low maintenance requirements.
4) It has no moving points
5) Continuous disposal of solid, particles

DISADVANTAGES:

1) Low collection efficiency for particles below 5-10□ in diameter.

2) Equipment is subjected severe abrasive deterioration.

APPLICATIONS:

1) Cyclones are widely used in cement manufacturers, feed and grain processing and wood working industries for the control of gas borne particulates.

2) They are used in rock crushing, ore handling, sand conditioning in industries to separate dust in disintegration operation.

3) Also used as catalyst dusts in the petroleum industry and in the reduction fly ash emissions.

FABRIC FILTERES [BAG HOUSE FILTER]

As the name indicates, it is in the form of a Fabric bag arrangement or cloth envelops. That is numerous vertical bags 120-400mm diameter and 2-10m long are housed together which are suspended with open ends attached to a manifold, and a hopper is attached at the bottom for then collection of dust.

The gas entering through the inlet pipes strikes a baffle plate, which causes the larger particles to fall into a hopper due to gravity. The carrier gas then flows upwards into tubes and then outward through the Fabric leaving the surface of the bags, which requires a periodical cleaning by rapping, shaking or vibration or by reverse air flow.

Some of the operating problems of filters are,

1) Cleaning
2) Rapture of cloth
3) Temperature
4) Bleeding
5) Humidity
6) Chemical attack

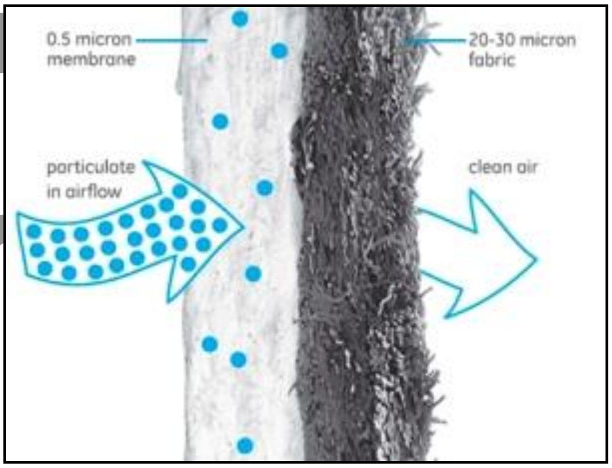


Fig: Removal mechanism in fabric filters

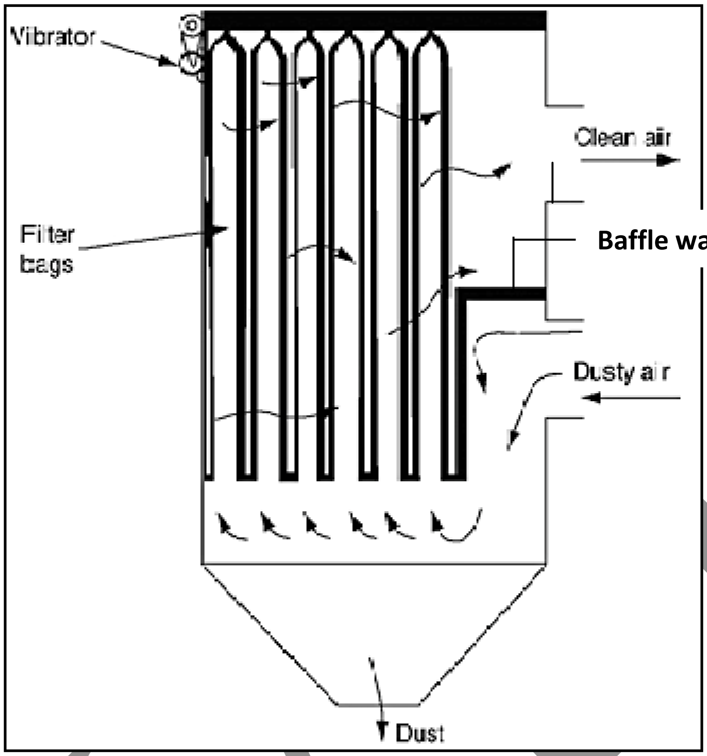


Fig: Fabric filter

Efficiency during pre-coat formation is low but as the pre coat (cake) is formed efficiency is 99%.

Factors Affecting Efficiency:

1) Excessive filter ratios i.e., the ratio of the carrier gas volume to grass filter area, per minute flow of the gas.

2) Improper selection of filter media

ADVANTAGES:

1) High collection efficiency for all particle sizes especially for particles smaller than 10 mirror diameter.

2) Simple construction and operation

3) Normal power consumption

4) Dry disposal of collected material

DISADVANTAGES:

1) Operating units are imposed by high carrier gas temperature, high humidity, etc.

2) High maintenance and fabric replacement costs (replacement of lacking bags)

3) Larger size of equipment.
4) Problems in handling dust which may abrade corrode or blind the dust.

APPLICATIONS

Fabric filters are extensively used in the follows industries and operations.

1) Metallurgical industry
2) Foundries
3) Cement lime plants
4) Chalk and lime plants
5) Brick works
6) Ceramic industry
7) Floor Mills etc.

ELECTROSTATIC PRECIPITATORS [ESP]

The electrostatic precipitator is one of the most widely used devices for controlling particulate emissions from industrial installations ranging from house hold appliances to power plants, cement and proper mills and oil refineries. It is a physical process by which particles suspended in gas stream are charged electrically and under the influence of the electrical field, separated from the gas stream.

ELECTROSTATIC PRECIPITATOR: Consists of six major components,

i) A source of high voltage
ii) Discharge electrodes and collecting electrodes
iii) Inlet and outlet for the gas
iv) An electric cleaning system
v) ‘Hopper’ for collection and disposal of particulates
vi) An outer casing [called shell] to form an enclosure around the electrodes.

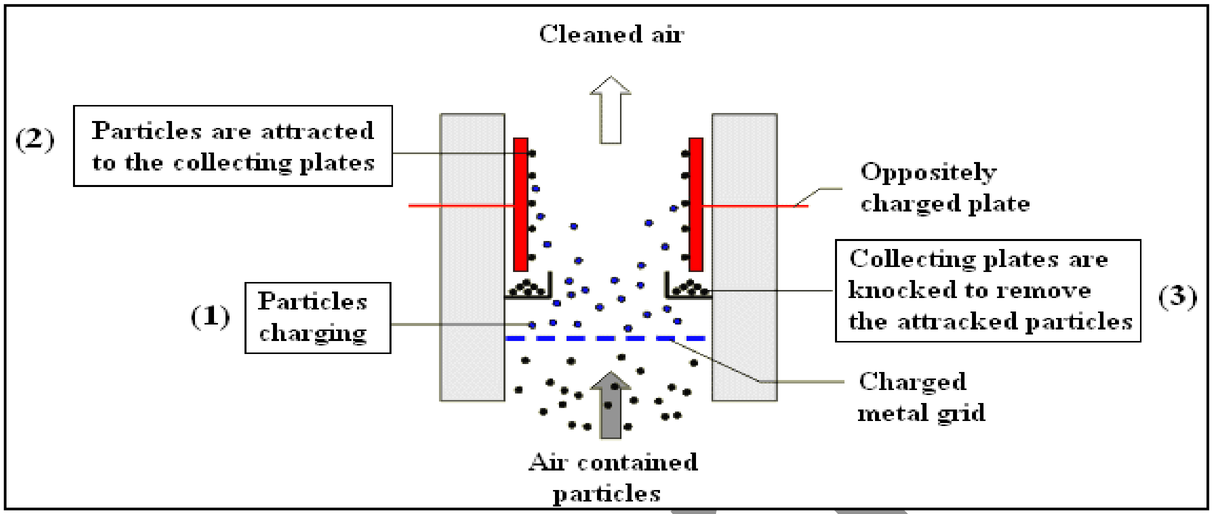


Fig: ESP Mechanism

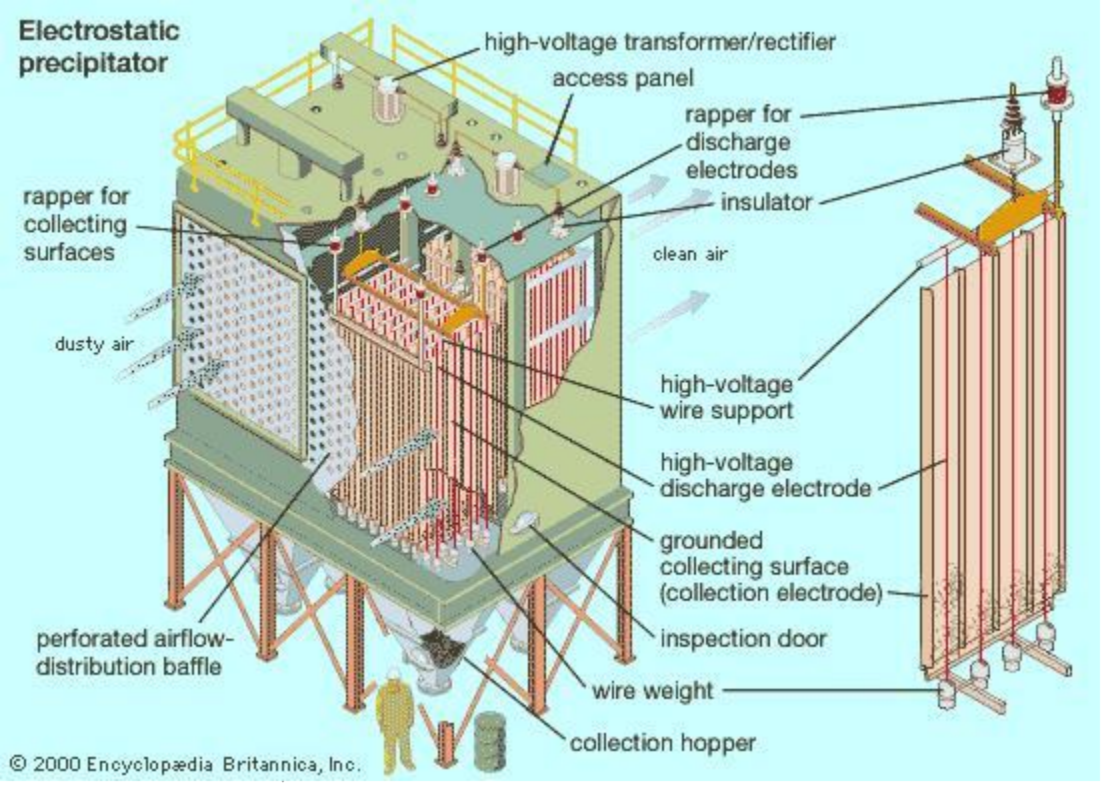


Fig: Electrostatic precipitator

TYPES OF PRECIPITATORS

Based on the electrode arrangements they may be classified into

i) Pipe type precipitator

ii) Plate type precipitator

PIPE TYPE PRECIPITATOR

In this type, the nest of parallel pipes acts as the collecting electrode. The pipes may be of round, square or octagonal cross-section. Generally the pipe is about 30cm or less in diameter. The discharge electrode is a wire [2.8mm dia] with a small radius of curvature suspended along the axis of each pipe. The wires are suspended from an insoluble hanger at the top and kept under tension by weights attached to their lower ends and strong enough to with stand rapping or vibrating for cleaning purposes. The gas flow path is down around the outside of the tubes and then up through the inside of the tubes. The pipe electrodes are 2 to 5m is height / Length.

As the gas flows upwards, electrostatic forces causes the dust particles to migrate to the collector electrode where they stick. The cleaned gas then emerges at the top. The collected dust (aerosols) is removed periodically from the collector electrodes by rapping it; this dust then falls to the dust hopper and is accumulated there for periodic removal. Generally the pipe type precipitators are used for the removal of liquid particles in which case no cleaning mechanism is required.

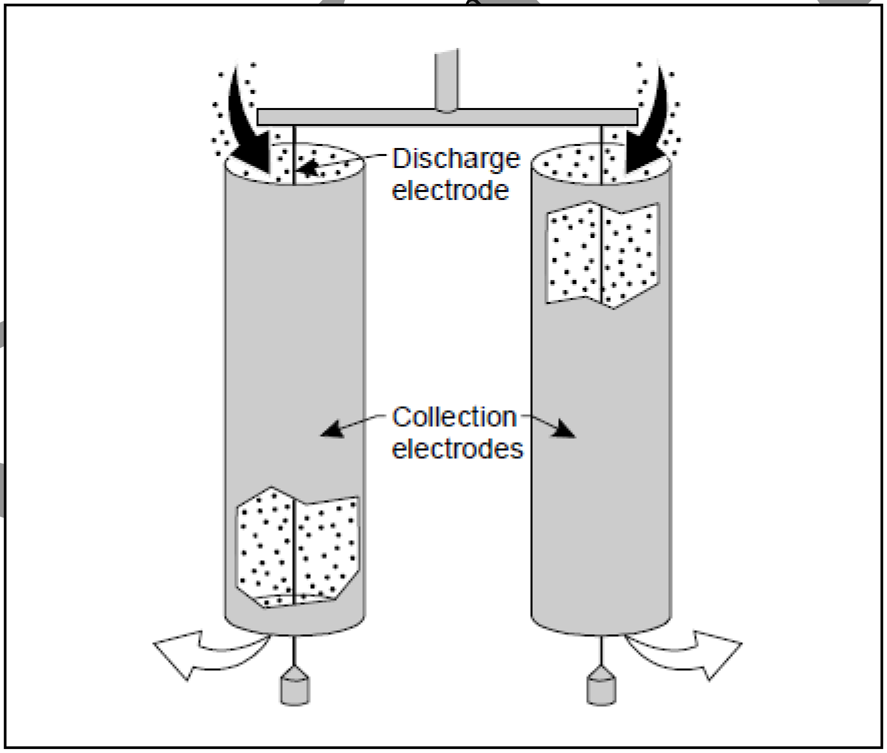


Fig: Pipe type ESP

PLATE-TYPE PRECIPITATORS

In the plate-type precipitators, the collecting electrodes consists of parallel plates of size 1-2m wide and 3-cm high. These parallel plates are special at 20-30cm. The number of plates in the precipitators depends upon the inlet flow; so that the inlet gas velocities are 1-2m/set in each channel. The discharge electrodes are similar to those used in pipe type precipitators. Sometimes electrodes of square rods (4 to 5mm) and twisted square rods (3.2 to 6.4mm) are used. These discharge electrodes (i.e. wires), made from non-corrosive materials like tungsten, alloys of steel and copped are suspended from the top and hang free with a weight attached at the bottom to keep them straight. The collection of the aerosols takes place on the inner sides of the parallel plates. The dust material can be removed by rapping and vibrating periodically. The plate type precipitators are generally employed for the collection of solid particulates.

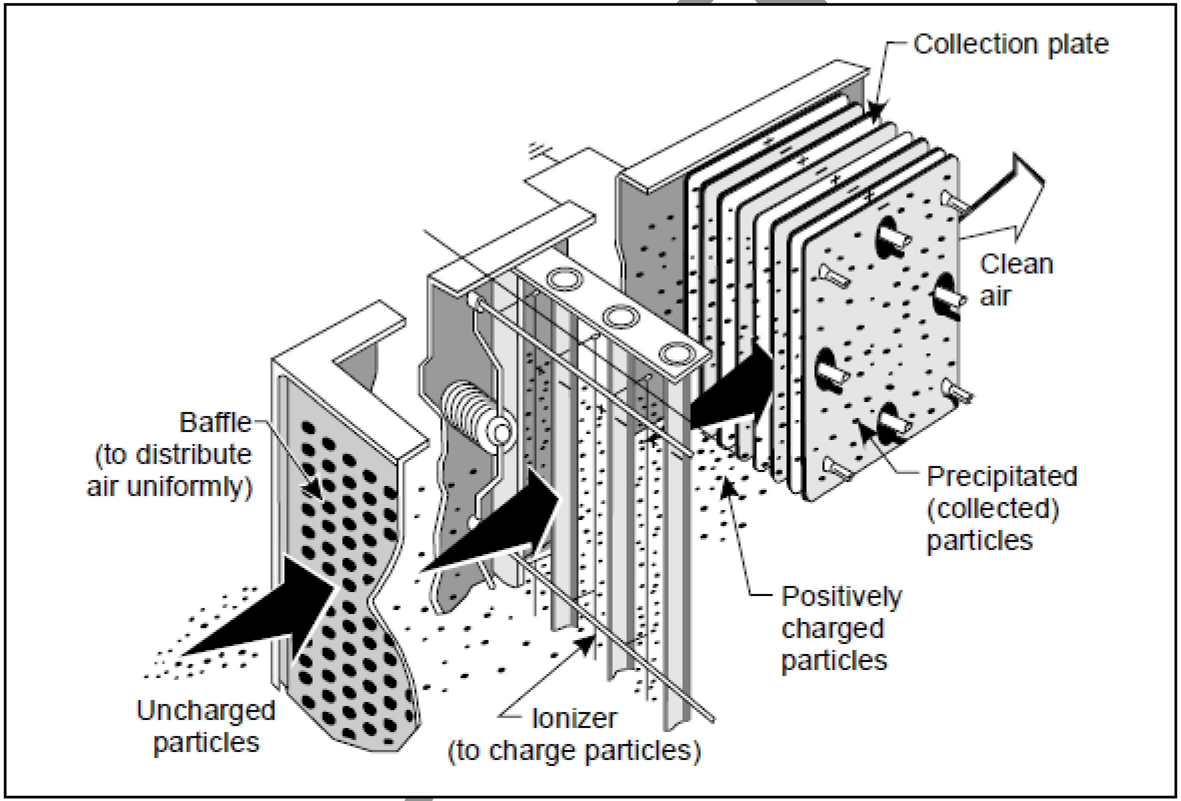


Fig: Plate type ESP

COLLECTION EFFICIENCY OF ESP

The ESP is a high efficiency collector with 98-99%

ADVANTAGES:

1) High collection efficiency.
2) Particles as small as 0.1 micron can be removed.

3) Low maintenance and operative cost.
4) Low pressure drop (0.25 to 1.25 of water)
5) Satisfactory handling of large quantities of high temperature gas.
6) Treatment time is negligible (0.1 to 10 seconds)
7) Cleaning is easy by removing units of the precipitator from operation.
8) There is no limit to solid, liquid or corrosive chemical usage.

DISADVANTAGES

1) High initial cost
2) Space requirements is more because of the large size of the equipment
3) Possible explosion hazards during collection of combustible gases or particulates well trained personnel are necessary to operate.
4) The poisonous gas, ozone is produced by the negatively charged discharge electrodes during gas ionization.
5) Precautions are necessary to maintain safety during operation.
6) Gases cannot be removed by ESP's

APPLICATIONS

1) Cement factories: Cleaning of flue gas from cement kilns, recovery of cement dust from kilns.
2) Pulp and paper: Soda-Fume recovery in Kraft pulp mills.
3) Steel plants: Cleaning blast furnace gas, removing tars from coke over gases, cleaning open hearth and electric furnace gases.
4) Chemical Industries – collection of Sox. Phosphoric Acid mist, cleaning various types of gases i.e., hydrogen, CO_2, SO_2, Removing dost from elemental phosphorus in the vapor state.
5) Petroleum industry:- Recovery of catalyst.
6) Carbon black industry: - Agglomeration and collection of carbon black.
7) Thermal Power plants:- collecting Fly ash from coal fired boilers.

WET SCRUBBERS OR WET COLLECTORS

These devices utilize a liquid called scrubbing liquid such as water to assist in the removal of particulates from the carrier gas stream. The Operational range for particulate removal by scrubbers includes material less than 0.2μ in diameter. To large particles which can be suspended in the gas phase.

COLLECTION MECHANISMS

Particulates are removed from the gas stream by the following merchandisers.

1. **IMPINGEMENT:** - Here gas containing dust is swept through as area counseling liquid droplets from where dust particles will impinge upon the droplets, once they adhere they will be collected by them.

2. **INTERCEPTION:** - some time particles moving may not impinge on the droplets but can be captured because they brush against the droplet and adhere there, this is called interception.
3. **DIFFUSION:** - diffusion of the dispersed solids onto the liquid medium helps in removal of the particulate matter.
4. **CONDENSATION:** - condensation of liquid medium vapors on the particulate, increases the size and weight of particles which can be easily removed.

TYPES OF SCRUBBERS

The common and important types of scrubbers are as follows.

1. Spray towers
2. Venturi Scrubbers.
3. Cyclone Scrubbers.
4. Packed scrubbers.
5. Mechanical Scrubbers.

SPRAY TOWER

A spray tower is the simplest type of wet scrubber into which water is introduce by means of spray nozzles. It can be ether round or rectangular in which gas is passes. Counter current to falling drops of liquid (usually water) from spray nozzles the particle collection can be done by the mechanism of inertial impaction and interception on the droplets spray towers cause. Very little pressure loss and can handle large volume of gasser the towers are very effective in removing particles in excess o0f 10 um. The efficiency of a spray tower depends upon the droplet size, flow velocity of the gas validity of liquid etc., it is 94% for sill particles to 99% for 25 um particles.

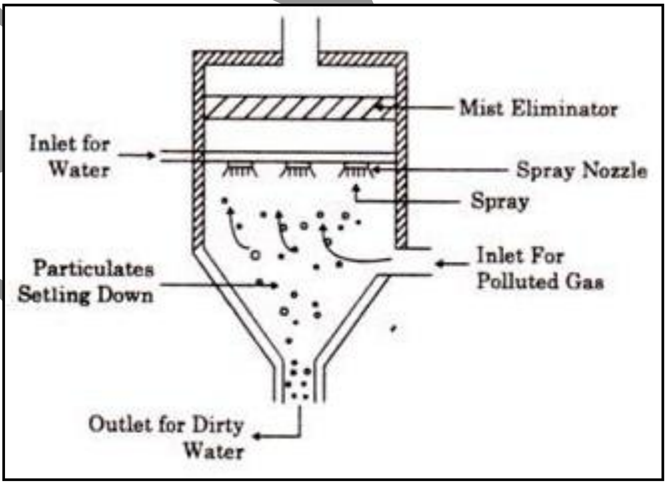


Fig: Spray Tower

VENTURI SCRUBBERS

They are high energy wet scrubbers with high performance collection of fine particles, usually smaller than 0.5 5 µm diameter. The high performance of the various scrubber is achieved by accelerating the gas strew to very high velocities. The droplets accelerate – throat section and due to the velocity difference between the particles and the droplets the particles are impacted agonist the slow moving droplets. The celebration continues to some extent into the leveraging section of the venture. The gas liquid mixture is then directed to a separation device such as cyclone separator where particulate matter is separated from the gas stream. The application of various scrubber is more often in Kraft mill furnaces metallurgical furnaces Sulphuric Acid concentrators etc., for removing mists and dusts from gases.

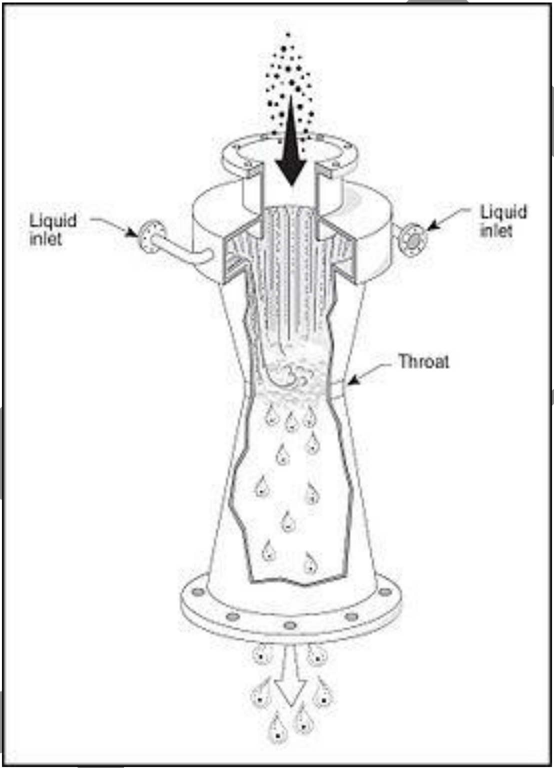


Fig: Venturi Scrubber

CYCLONE SCRUBBERS:

It is the modification of the dry cyclone by the addition of liquid phase. In cyclone scrubbers the gas is tangentially swirled around, same as in dry cyclone. Water sprays from the top of cyclone and outside the wall. These sprays assist in the collection of the dispersed and prevent re entertainment. In cyclone scrubbers inertial impaction and separation are the main collection mechanisms. For droplets of 100um efficiency approaches 100% and 90 to 98% removal is achieved for droplets between 5 and 50µm.

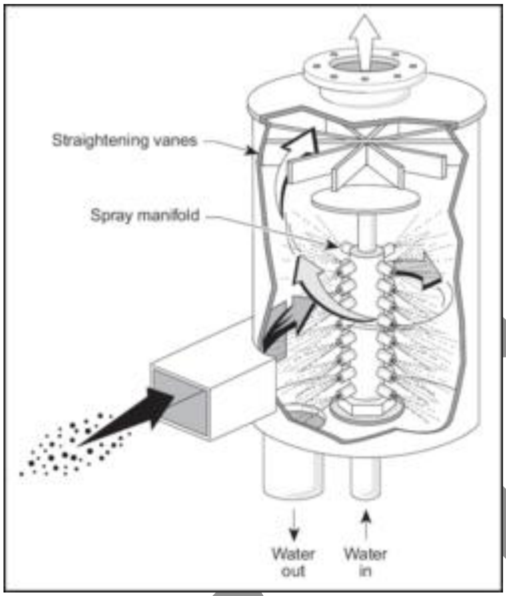


Fig: Cyclonic spray scrubber

PACKED SCRUBBER (PACKED TOWER)

In packed scrubber fiber glass (fine glass filaments) or other packing (coke or broken stone) accused as the collection material. The polluted gas stream moves upward in a counter current flow packed scrubber and comes in contact with the scrubbing liquid stream which is moving downward over the packing in a film. The gas stream pass through the packing pore spaces and captures the particles by inertial impaction. Because of the good mass transfer characteristics of the packing, efficient collection of the fine particles by diffusion is also possible. Similar packing increases the efficiency of collection but its shape does not appear to affect the collection efficiency. Sometimes packing towards encounter plugging problems, which can be reduced by employing sprays to wash the packing or by using low density spheres etc.,

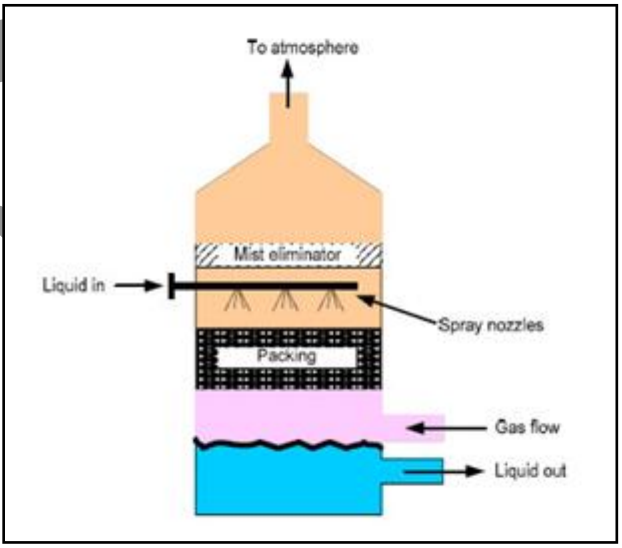


Fig: Packed Tower

MECHANICAL SCRUBBER:

It is the high energy scrubber and ha mechanical means of breaking up the scrubbing liquid into small droplet and simultaneously creating turbulence. It has internal rotating mechanical part, where the liquid dispersed contact is achieved by the simultaneously introduction of the liquid medium and the gas stream. The scrubbing liquid dribbles down on the rotating part and is struck violently and disintegrated by the centrifugal force and are removed quite easily. These scrubbers have a high initial cost; high operating cost and requires considerable maintenance.

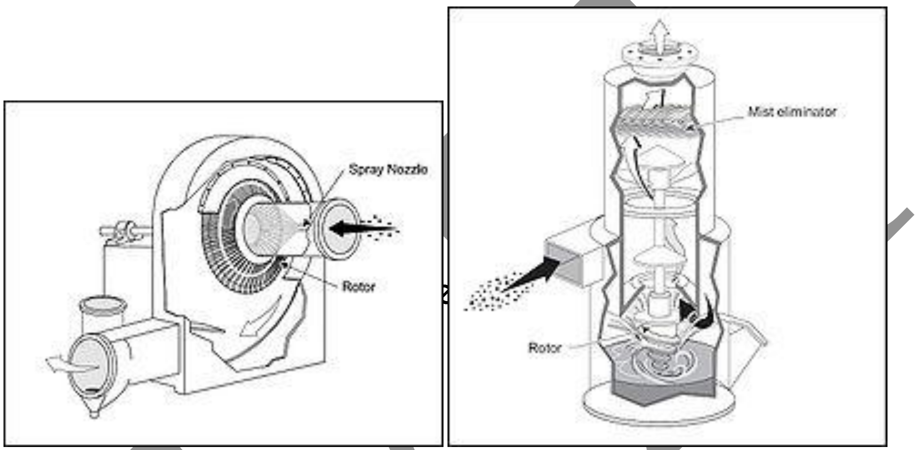


Fig: Centrifugal fan scrubber and Induced spray scrubber

ADVANTAGES OF SCRUBBERS (WET COLLECTORS)

1. Simultaneous removal of gases and particulates
2. Effective performance ever a wide loading range
3. Equipment occupies only a moderate amount of space compared to dry collectors such as bag houses.
4. Hazards of explosive dust air mixtures air reduced.
5. Indifference to the temperature and moisture content of gas.
6. Corrosive gases may be neutralized by proper choice of scrubbing liquid.

DISADVANTAGES:

1. Relatively high energy costs
2. Problem of wet sludge disposal
3. Corrosion problems
4. Visible wet plume, reduction to buoyancy.
5. Very small particles (sub-micron particles) may not be captured.

MODULE 5

The automobile emissions play a major role in the air pollution menace. Various causes of the genesis and exodus of those pollutants have been identified.

CLASSIFICATION OF AUTOMOBILES IN INDIA:

The three main types of automotive vehicles being used in our country are
a) Passenger cars powered by four stroke gasoline engines
b) Motor cycles, scooters and auto rickshaws powered mostly by small two stroke gasoline engines
c) Large buses and trucks powered mostly by four stroke diesel engines

EMISSIONS FROM GASOLINE POWERED VEHICLES are generally classified as
a) Exhaust emissions
b) Crank case emissions and
c) Evaporative emissions

EXHAUST EMISSIONS: The important exhaust emissions from a gasoline engine care carbon dioxide, unburnt hydro carbons, nitrogen oxides and particulates containing lead compounds. These emissions vary with the air fuel ration spark timings and the engine operating conditions.

CRANK CASE EMISSIONS: It consist of engine blow by which leaks past the piston mainly during the compression stroke, and of all vapors generated into the crank case. The quality of blow by depends on engine design and operating conditions. Worn out piston rings and cylinder liner may greatly increase blow by. Those gases mainly contain hydro carbons and account nearly for 25% of the total hydro carbon emissions from a passenger car.

EVAPORATIVE EMISSIONS: Through a short term experimental determination it has been estimated that an average Indian passenger car would emit about 20 kg of hydro carbons through evaporation annually. For controlling evaporation of fuel from the carburetor and fuel system Systems are being developed that store fuel vapors in the crank case or on a charcoal canister that absorbs hydro carbons for recycling the engine.

Evaporative emissions essentially constitute the fuel evaporation from the fuel tank and carburetors and consists of hydro carbons alone The amount of pollutants, that an automobile emits depends on a number of factors, including the design and operation (idle, acceleration etc) of the hydro carbons emitted by a car with no controls, the exhaust gases account for roughly 65%, evaporation from the fuel tank and carburetors for roughly 15% and blow by crank emission gases that escape around the piston rings for about 20%.

DIESEL POWERED ENGINES: Diesel powered vehicles create relatively minor pollution problems compared to gasoline powered ones. The diesel engine exhausts only about a tenth of the amount of carbon monoxide exhausted by a gasoline engine, although its hydro carbon emissions. They approach those of the gasoline engine. Blow by is negligible in the diesel, since the cylinders contain only air on the compression stroke. Evaporative emissions are also low because the diesel engine uses a closed injection fuel system and because the fuel is less volatile than gasoline. The major problems of diesel engines are smoke and odour.

ADVERSE EFFECTS OF VEHICLE EXHAUSTS:

i) Contacts with pollutants – Irritation of the skin, eyes and respiratory system

ii) Excess amount of carbon dioxide and Methane – Asphyxiates

iii) Lack of Oxygen – destroys brain cells and affects central nervous system

The adverse effects experiment by the individual depends on

i) Age

ii) General state of health and nutrition

iii) Concurrent exposure

iv) Pre existing disease

v) Temperature and humidity of the time of exposure, duration of exposure

vi) Nature and concentration of pollutants

ADVERSE EFFECTS OF SOME POLLUTANTS ARE

1) Particular matter – smoke from diesel engines and load from gas line engines produces skin cancer and tumors of the lungs.

Lead – long term effects, high blood levels, and anemia affects liver and kidney functions.

2) Carbon monoxide – it reduces oxygen carrying capacity of blood, irreversible damage to the central nervous system.

3) Hydrocarbons – it causes smog which in turn damage plant, eye and imitation in respiratory tract.

4) NO_X – death and chronic respiratory diseases.

CONTROL OF EXHAUST EMISSIONS IN VEHICLES:

Two main approaches to minimize exhaust emissions are

1. Modifications in the engine design and operating variables.
2. Treatment of exhaust gases after emission from the engine.

1. The following modifications may help in cleaner exhaust.

a. Use of cleaner idle mixtures.

b. Use of cleanest possible mixture and maximum spark retard compatible with good power output and drivability
c. Use of minimum valve over tap necessary.
d. Pre treatment of the mixture to improve vaporization and mixing of fuel with air.
e. Low quench combustion chambers
f. Piston and ring variables
2. Exhaust treatment devices

The basic techniques are to promote oxidation of HC and CO after emission from the engine. Exhaust oxidation devices fall into two categories
a. Promotion of after burning of the pollutants by exhaust heat conservation, introduction of additional air and by providing sufficient volume to ensure adequate reaction time
b. Use of catalytic converters. In after burners air from an engine driven blower is injected into the exhaust stream just after the exhaust valve. Sometimes an additional source of ignition is provided in the exhaust passage to initiate the after burning under certain engine conditions.
Other methods
1) Petrol injection
2) Stratified charge engine

CONTROL OF EVAPORATIVE EMISSIONS:

Insulation of the fuel tank to reduce temperature, sealed and pressurized fuel systems, and vapor collection systems have all been explored to reduce tank emissions.

CONTROL OF CRANK CASE EMISSIONS:

Designers are shifting crank-case exhaust vents from simple open ending to a feed back.
New engines equipped with the positive crank-base ventilation (PVC) system return crank-case vapors through a vacuum valve, back to downstream side of the carburetor recycling burns hydrocarbon in the cylinders, dropping overall pollution by 25%

NOISE POLLUTION - CAUSES, TYPES, EFFECTS AND CONTROL OF NOISE POLLUTION

Noise is defined as, "the unwanted, unpleasant or disagreeable sound that causes discomfort to all living beings". Sound intensity is measured in decibels (dB), that is the tenth part of the longest unit Bel. One dB is the faintest sound that a human ear can hear.

TYPES OF NOISE: Environmental noise has been doubling every ten years. Noise is classified as:

1. Industrial Noise
2. Transport Noise and

3. Neighborhood noise

Industrial Noise: It is sound with a high intensity sound caused by industry machines. Sources of such noise pollution are caused by machines from machines in various factories, industries and mills. Noise from mechanical saws and pneumatic drills is unbearable and a nuisance to the public.
The Indian Institute of Oto-Rino Laryngology, Chennai reported that increasing industrial pollution damages the hearing ability by atleast 20%.
Workers in steel industry, who work close to heavy industrial blowers are exposed to 112dB for eight hours suffer from occupational pollution.

Transport Noise: Transport noise mainly consists of traffic noise from road, rail and aircraft. The number of automobiles on roads like motors, scooters, cars, motor cycles, buses, trucks and diesel engine vehicles have increased enormously in the recent past further aggravating the problem of transport noise.
Noise levels in most residential areas in metropolitan cities is hovering around the border line due to increased vehicular noise pollution. This high level of noise pollution leads to deafening in the elderly.

Neighbourhood noise: This type of noise includes disturbance from household gadgets and community. Common sources being musical instruments, TV, VCR, Radios, Transistors, Telephones, and loudspeakers etc. Statistically, ever since the industrial revolution, noise in the environment has been doubling every ten years.

Effects of Noise pollution

1. Noise pollution affects both human and animal health. It leads to:
    1. contraction of blood vessels
    2. making skin pale
    3. excessive adrenalin in the blood stream which is responsible for high blood pressure.
    4. Blaring sounds are known to cause mental distress
    5. Heart attacks, neurological problems, birth defects and abortion
2. Muscle contraction leading to nervous breakdown, tension, etc
3. The adverse reactions are coupled with a change in hormone content of blood, which in-turn increases heart beat, constriction of blood vessels, digestive spams and dilation of the pupil of the eye.
4. Adverse affects health, work efficiency and behavior. Noise pollution may cause damage to the heart, brain, kidneys, liver and may produce emotional disturbance.

5. The most immediate and acute effect of noise is impairment of hearing that diminishes some part of the auditory system. Prolonged exposure to noise of certain frequency pattern leads to chronic damage to the inner ear.
6. Impulsive noise may cause psychological and pathological disorders
7. Ultrasonic sound can affect the digestive, respiratory, cardiovascular system and semicircular canals of the internal ear.
8. The brain is adversely affected by loud and sudden noise by jets and airplanes. People are subjected to psychiatric illness.
9. Recent reports suggest that blood is thickened by excessive noise.
10. The optical system of human beings is also affected by noise pollution. Severe noise pollution causes:
    1. Pupullary dilation
    2. Impairment of night vision and
    3. Decrease in rate of colour perception

Control measures:

1. SOURCE CONTROL: This includes source modification such as acoustic treatment to machine surface, design changes, limiting operational timings, etc
2. TRANSMISSION PATH INTERVENTION: This includes containing the source inside a sound insulating enclosure, constructing a noise barrier or provision of sound absorbing materials along the path.
3. RECEPTOR CONTROL: This includes protection of the receiver by altering the work schedule or provision of personal protection devices such as ear plugs for operating noisy machinery. The measure may include dissipation and deflection methods.
4. OILING: Proper oiling will reduce noise from the machine.

Preventive measures:

1. Prescribing noise limits for vehicular traffic
2. Ban on honking (usage of horns) in certain areas
3. Creation of silence zones near schools and hospitals
4. Redesigning buildings to make them noise proof
5. Reduction of traffic density in residential areas
6. Giving preference to mass public transport system