AIR POLLUTION

UNIT-I

(PART-I)

T. Naga Srinu, Assistant Professor, ACE Engineering College

Contents

Introduction

- Human being contribution towards pollution started with "Discovery of fire"

- There after various contaminants are entering into the atmosphere gradually through Natural and Man-Made processes.

- As the pollution increases the attendant problems of pollution also increases proportionately.

Episodes

12th Century First Anti-Pollution law passed against Coal consumption for domestic heating

(KING EDWARD – I, LONDON)

- Meuse Valley - *Volcanos (1930, Belgium).*
- Severe Air pollution *(1952, London) – High Sulphur Coal for Domestic heating and Thermal Power plants.*
- Bhopal - *Methyl Isocyanate (1984, Union Carbide India Ltd., India).*

AIR POLLUTION

- **Definition**:

  Air Pollution is defined as "Presence of one or more air contaminants in ambient (out door) atmosphere to be (or) threaten to be injurious to human life, animal life, plant life and even damage to property.

Structure of Atmosphere

- The envelope of gases surrounding the Earth is called atmosphere.

- Vertical Space above ground containing Air in 4 distinct zones.
  (1) Troposphere → 0 to 12 km
  (2) Stratosphere → 12 to 52 km
  (3) Mesosphere → 52 to 92 km
  (4) Ionosphere → > 92 km.


The Ozone Layer
by whatarethe7continents.com
The Ozone layer is a ring of protective gases around the Earth that absorbs harmful UV rays before they reach the surface.
The Ozone layer is located inside the stratosphere approximately 6 miles (10km) above Earth's surface.
Ultraviolet Rays (Absorbed by Ozone Layer)
Holes in Ozone Let UV Rays Pass Through
Mesosphere
Stratosphere
6-31 Miles (10-50 km)
Ozone Layer
0-6 Miles (0-10 km)
Troposphere
Ozone Hole

Composition of Air

- The invisible gaseous substance surrounding the Earth is called Air.

- Major gasses in air are

Nitrogen	- 78.09%
Oxygen	- 20.95%
Argon	- 0.92%
Carbon di-oxide	- 0.032%
Remaining gases	- 0.008%

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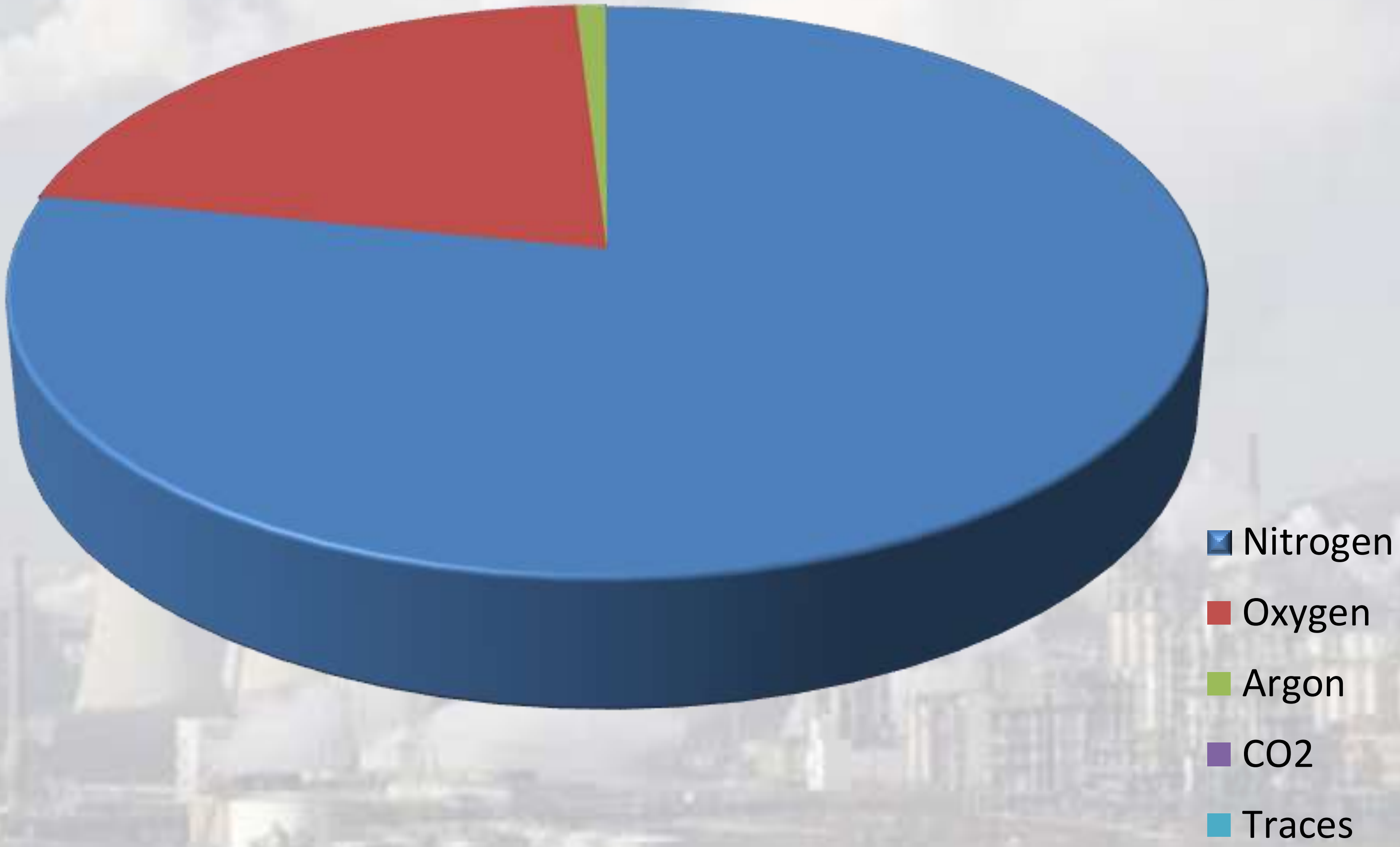
Air Composition



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Classification of Air Pollutants

Based on

1. Origin
   (i) Primary pollutants
   (ii) Secondary pollutants
2. Nature
   (i) Organic air pollutants Ex: HC
   (ii) In-Organic air pollutants Ex: CO,SOx
3. State of Matter
   (i) Particulates (Solid & Liquid)
   Ex: Dust & Mist
   (ii)Gases (Ex: CO, NOx, SOx)

Sources of Air Pollution

Based on:-

1. Origin of source

(i) Natural Sources — Ex: Forest Fires & Volcanos

(ii) Man-Made Sources — Ex: Industries, Auto-Mobiles

2. Spatial distribution of source

(i) Point Source — Ex: An Industry @ Place

(ii) Non-Point Source — Ex: Group of Industries

3. Position of source w.r.t Time & Space

(i) Stationary Source — Ex: An Industry

(ii) Mobile Source — Ex: A Truck on Highway

Natural Sources of Air Pollution

1) Products from atmospheric reactions.
2) Aerosols (Particulates) Ex: Dust, Smoke, Fog
3) Micro-Organisms (from infects plants and animals)
4) Radio actives minerals
5) Pollens (from anthers of flowers)
6) Volcanic ash and gases

Man-Made Sources of Air Pollution

1. Combustion of fuels
2. Industries
3. Thermal power plants
4. Automobiles
5. Agricultural activities
6. Nuclear power plants

SMOG (Smoke+Fog)

- Smog is a synchronym of two words – i.e., Smoke and Fog.
- Smog is caused by the interaction of some hydrocarbons and oxidants under the influence of sunlight giving rise to dangerous Peroxy Acetyl Nitrate (PAN).
- Smog reduces visibility, causes eye irritation and damage to vegetation.

UNIT – I

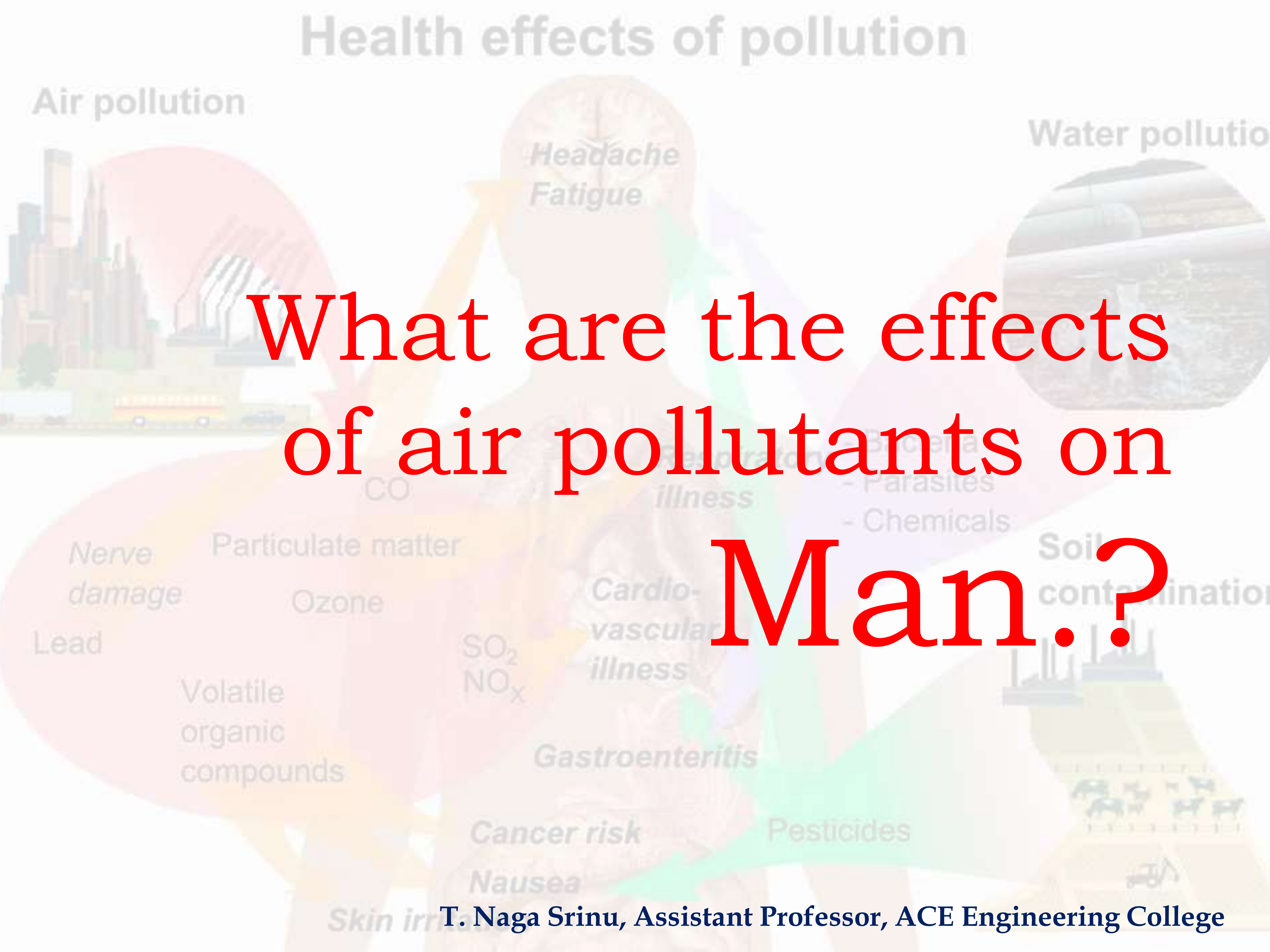
(PART – II)

T. Naga Srinu, Assistant Professor, ACE Engineering College

Contents

- Effects of pollutants on
  - Man
  - Animals
  - Vegetation (plants)
  - Structures (Materials)

- Effects on physical features of atmosphere
  - Green house effect
  - Ozone layer depletion
  - Acid rain
  - Global warming



What are the effects of air pollutants on Man.?

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Introduction

- Get complicated by factors such as overcrowding, occupation, habits and presence of more than one pollutant at a time in the air.
- Some groups (very young, very old and people with respiratory diseases) may be more sensitive to air pollution.
- Some quantity of air pollution may enter into the body through the contaminated food.

Effects of air pollutants on Man

The effects of air pollution on human health have been concentrated mainly on the following:

- The respiratory system
- The eye
- Chronic bronchitis
- Lung cancer
- Other respiratory diseases

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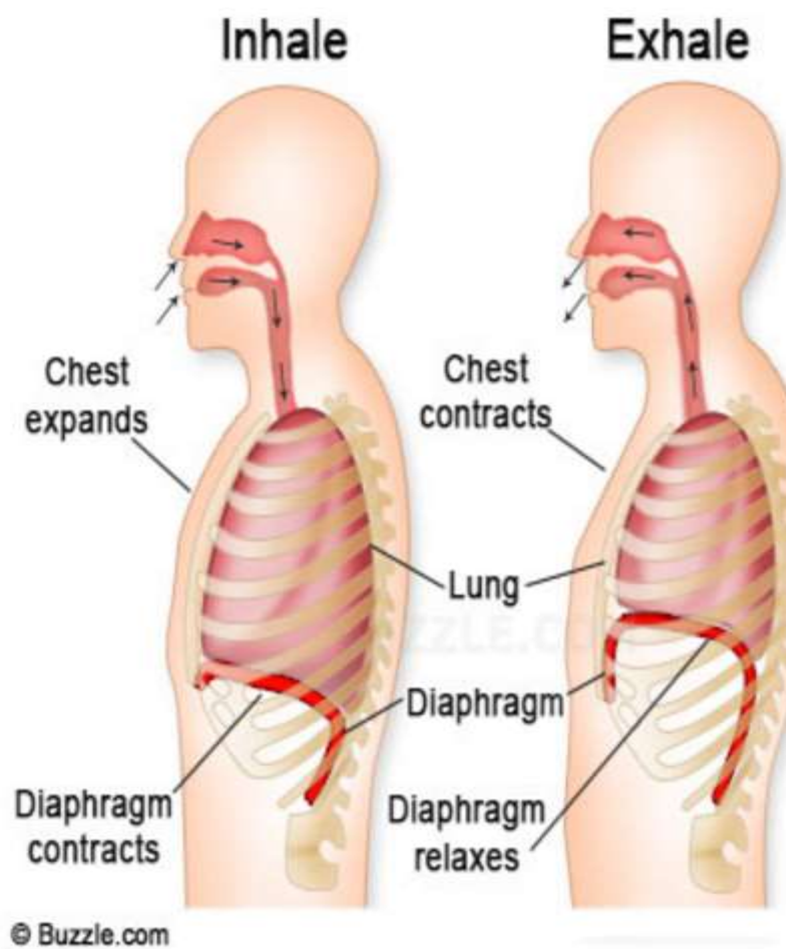
The Respiratory System

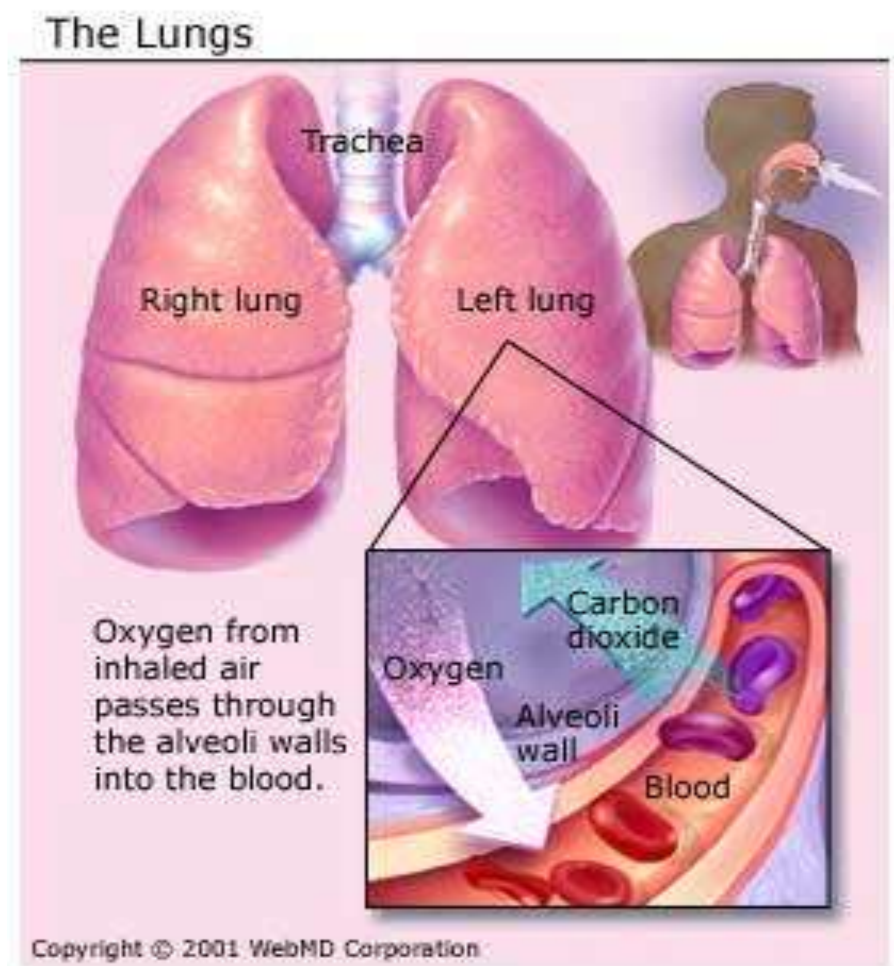
What is Respiration.?

And

What is the function of respiratory system.?

Particles less than 10 MICRONS may frequently enter into the ALVEOLI WALL





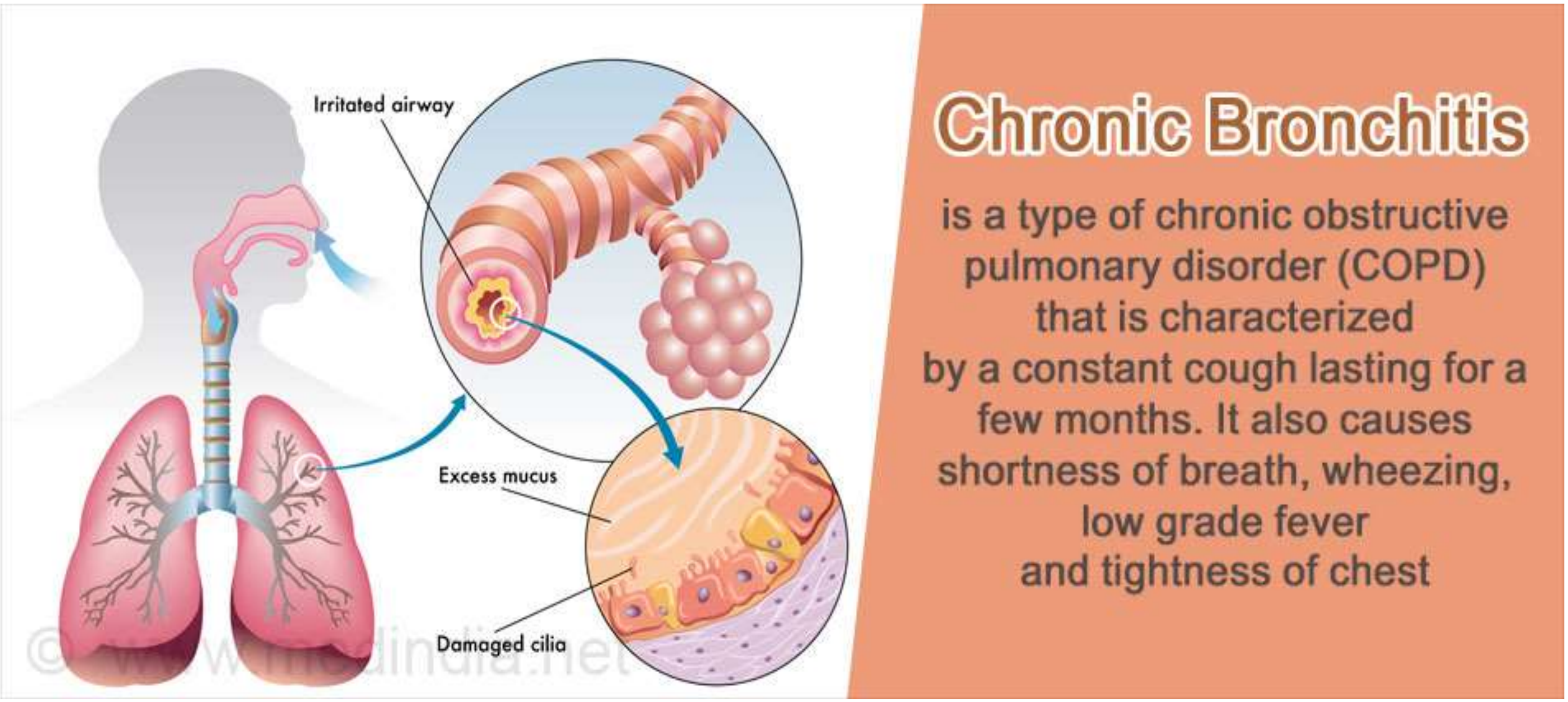
Increase in the concentration of these pollutants effects the respiratory system.

The Eye

Pollutants contact with the external layers of the eye and internal mucous lining of eyelid

causes irritation of eye and some times it may leads to damage of eyes due to excessive rubbing of eye.

Chronic Bronchitis



Lung Cancer

- When CARCINOMA of lung breaks after enlargement, it spreads throughout the body moving rapidly through blood stream to spread cancer to other parts of the body.

- A number of carcinogenic compounds including Benzo(a)pyrene present in the air as a pollutant may be responsible for lung cancer.

Other Respiratory Diseases

- Bronchial asthma is the narrowing of respiratory passage causing difficulty in breathing.

- Pulmonary fibrosis is toughening of the lung tissues.

- Pulmonary edema is a condition where excess fluid is accumulated in lungs.

What are the effects of air pollutants on Animals.?

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- Besides inhalation, a large quantity of air pollutants reach the animals by consumption of contaminated food.

- The effects of pollutants on animals are dose related. Ex: Young animals often more susceptible to air pollution than the adults.

- Several experimental studies concluded that where almost similar effects of pollutants are expected on both humans and animals.

What are the effects of air pollutants on Plants.?

- The effects (injury) to the plants can be regarded to the Acute or Chronic exposures of air pollutants.

- Acute Exposures: Relate to the short term exposures to the high concentrations.

- Chronic Exposures: Long term (prolonged) exposures to low concentrations (general condition)

- The responses of the plants to air pollution appears to be in the following forms:

    (a) Invisible injury (b) Visible injury

- <u>Invisible injury:</u>

The most severe effects can occur on photosynthesis, respiration, photorespiration, metabolism, pigment synthesis and enzyme structures.

Reduction in growth, yield, reproduction is a measure of disturbances by a pollutants in the plants.

Visible injury:

- Necrosis: Death and collapse of the cells causes lose water leaving a discolored dead area in the green tissue.
- Chlorosis: Fading of the green colour that makes the leaf appears yellowish or pale green.
- Abscission: Dropping of leaves.
- Epinasty: Downward curvature of the leaf due to higher rate of growth on the upper surface.

What are the effects of air pollutants on Structures.?

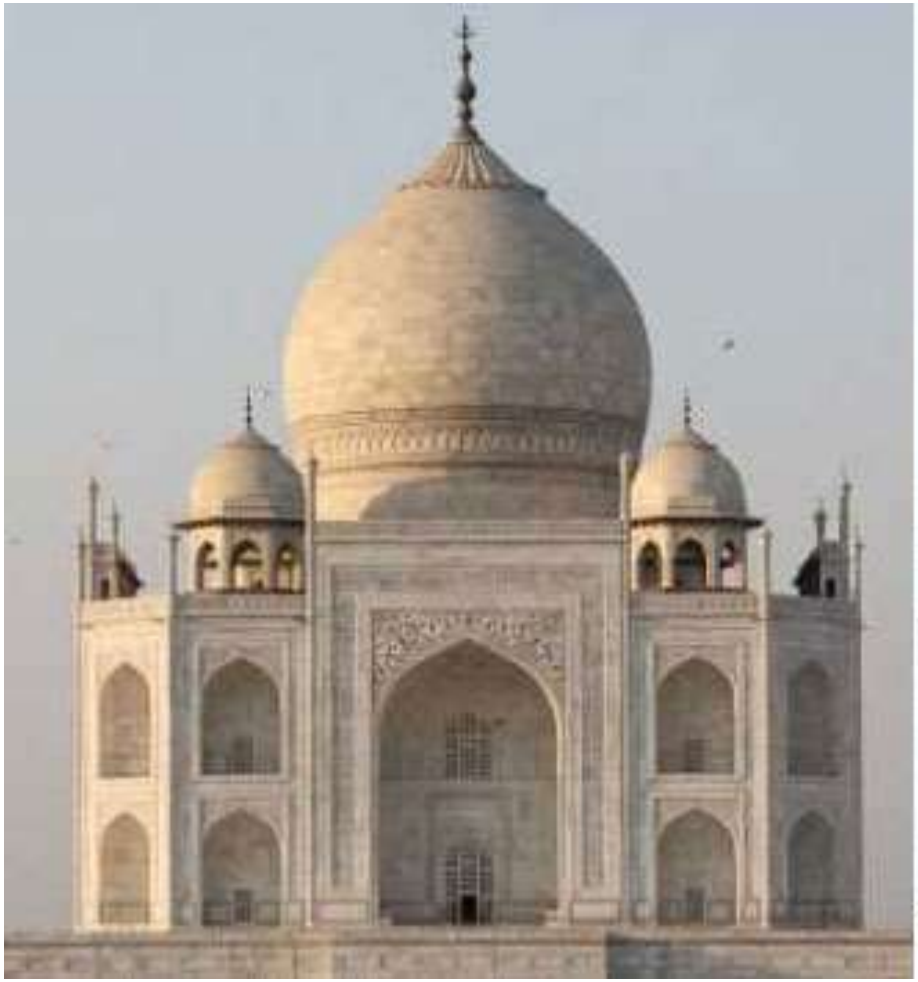
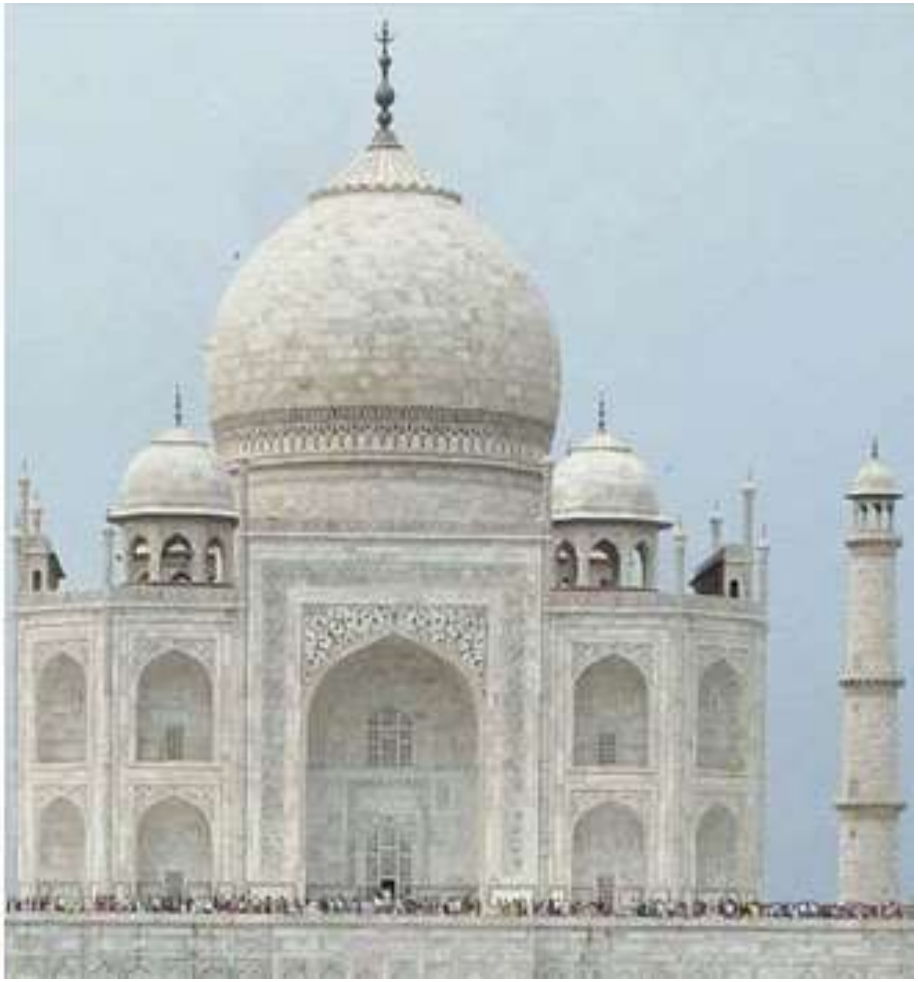
Effects of air pollution on physical structures:

- Corrosion of metallic surfaces
- Soiling and erosion of buildings
- Damage to surface coatings, paints, fabrics, textiles, plastics and other materials.

The common air pollutants responsible:

- Acid mists
- Sulphur dioxide
- Hydrogen-sulphide
- Oxidants like ozone

The best example is case study of Taj Mahal

UNIT – I

(PART – III)

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What are the effects of air pollutants on Physical Features of Atmosphere.?

Physical Features of Atmosphere

Effects on physical features of atmosphere are nothing but Global effects of air pollution.

They are as follows:

1) Effect on Visibility
2) Effect on atmospheric constituents (Air)
3) Green-House effect
4) Ozone layer depletion
5) Acid Rain
6) Global warming

Effects on Visibility

Fog and photo chemical SMOG reduce Visibility.

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Effects on Atmospheric Constituents (Air)

- The main effect of pollutants on air is "Rise in Ambient Temperature".

- Carbon-di-oxide (CO_2) is responsible for that rise in outdoor temperature.

Green House Effect

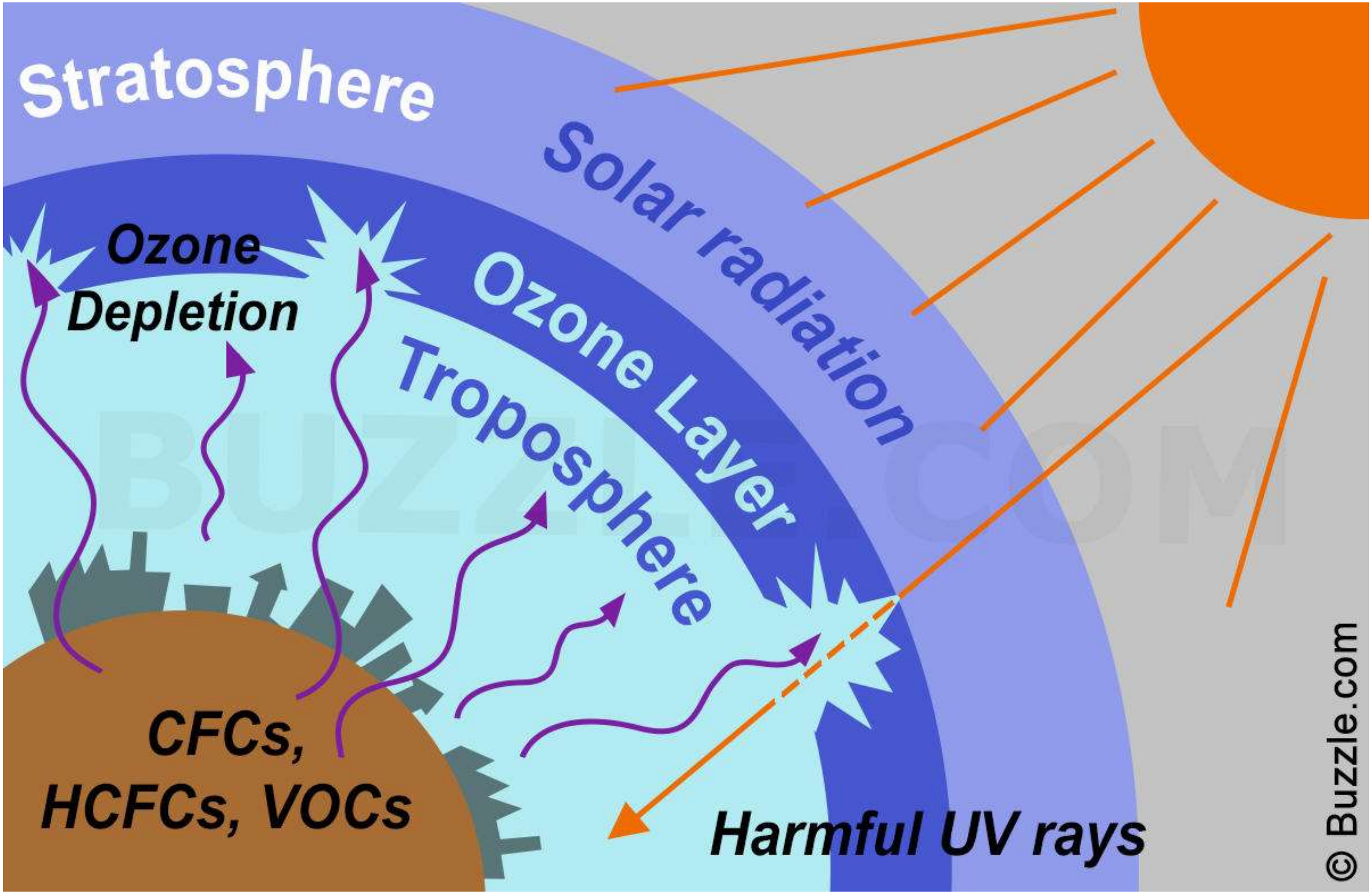
The green house effect is a process by which Radiations from a planet's atmosphere warms up the planet's surface to a temperature above what it would be without it's atmosphere.

Green House Effect… (Cont)

- Causes: Carbon-di-oxide (Chief Gas), Nitrogen oxide, Ozone and chemicals like Chlorofluorocarbons (CFCs) are responsible for Green House effect.

- Remedy: Reducing the consumption of fossil fuels like petrol, diesel and coal.

Ozone Layer Depletion



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Ozone Layer Depletion

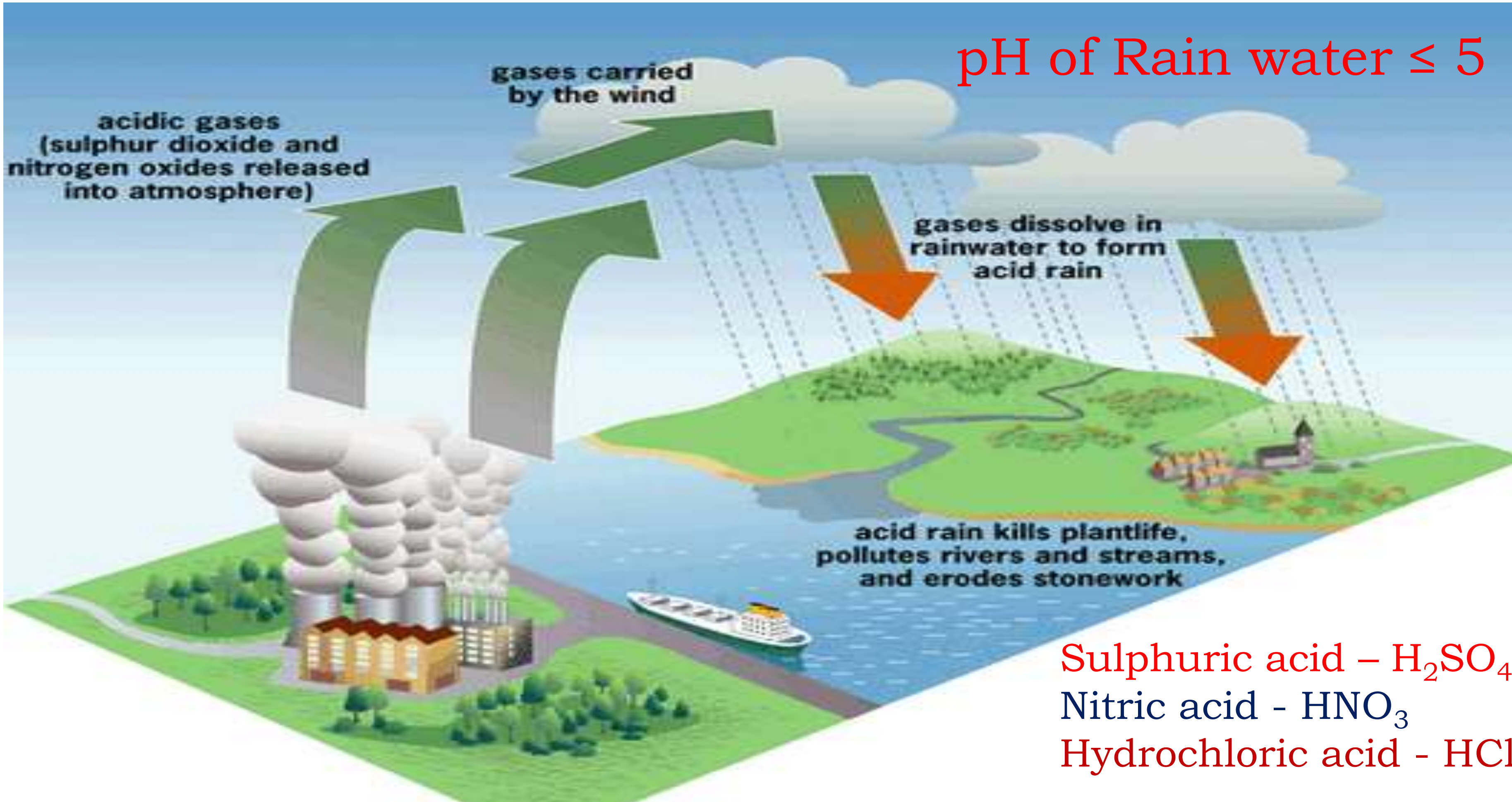
- Ozone layer acts as an umbrella for ultraviolet radiations which are coming from the sun.
- CFCs emitted from the refrigeration and other industrial operations, Nitrous oxide decreases the ozone layer concentration.
- As a result more Ultraviolet radiation reaches the earth.

Ozone Layer Depletion… (Cont)

- Effects:
  1) Damage of immune system
  2) Disturbance in ecosystem
  3) Effect on crop yield
  4) Increase of skin cancer
  4) Shorter life of paints and plastics

- Remedy: Reducing the emission of CFCs and VOCs.

Acid Rain



pH of Rain water ≤ 5

Sulphuric acid – H_2SO_4
Nitric acid - HNO_3
Hydrochloric acid - HCl

<u>NOTE:</u> Effects Soil micro nutrients, aquatic ecosystem and Historical monuments.

Global Warming

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Global warming is the overall increase in the temperature of atmosphere due to the green house effect.

Global warming may lead to burning of crops and may also cause forest fires.

Remedy: Usage of renewable energy sources and plantation of trees…etc.

Types of pollutant sampling and measurement

Air quality monitoring:
Sampling and measurement of air pollutants generally known, as air quality monitoring.

It is an integral component of any air pollution control programme.

Monitoring is important:

1. Air quality can be evaluated
2. Information is helpful in implementing control measures for reducing pollutant concentration to acceptable levels.
3. Assessing the effect of air pollution control strategies.

Classification of sampling methods

- Sampling of **impurities of every nature** (Ranging from particulate matter to gases)
- Sampling under various **environmental conditions** (ranging from samples taken from chimneys to samples taken in the open air)
- Sampling methods varying according to the **time factor** (Ranging from intermittent to continuous sampling).

Air Quality measurement is undertaken in two situations

1. Ambient air quality measurement
2. Stack monitoring

Ambient air quality measurement: Where the pollutant levels in the ambient atmosphere are measured.

Stack sampling: It deals with the pollutants emitted from a source such as smoke stack and is known as stack sampling.

It provides information on the nature and quantities of various pollutants that are emitted into the atmosphere.

Difficulties encountered in sampling:

1. Collecting samples of true representative character.

2. Errors arising from methods used for the collection and separation of the various components of pollution.

3. Difficulty in preventing any change in the concentration of particulate matter in suspension, as a result of sampling operation.

Basic consideration of air sampling

1. The sample collected must be representative in terms of time and location.

2. The sample volume should be large enough to permit accurate analysis.

3. The sampling rate must be such as to provide maximum efficiency of collection.

4. The duration of sampling and frequency of sampling should reflect accurately the occurrence of fluctuations in pollution level.

5. The contaminants must not be modified or altered in the process of collection.

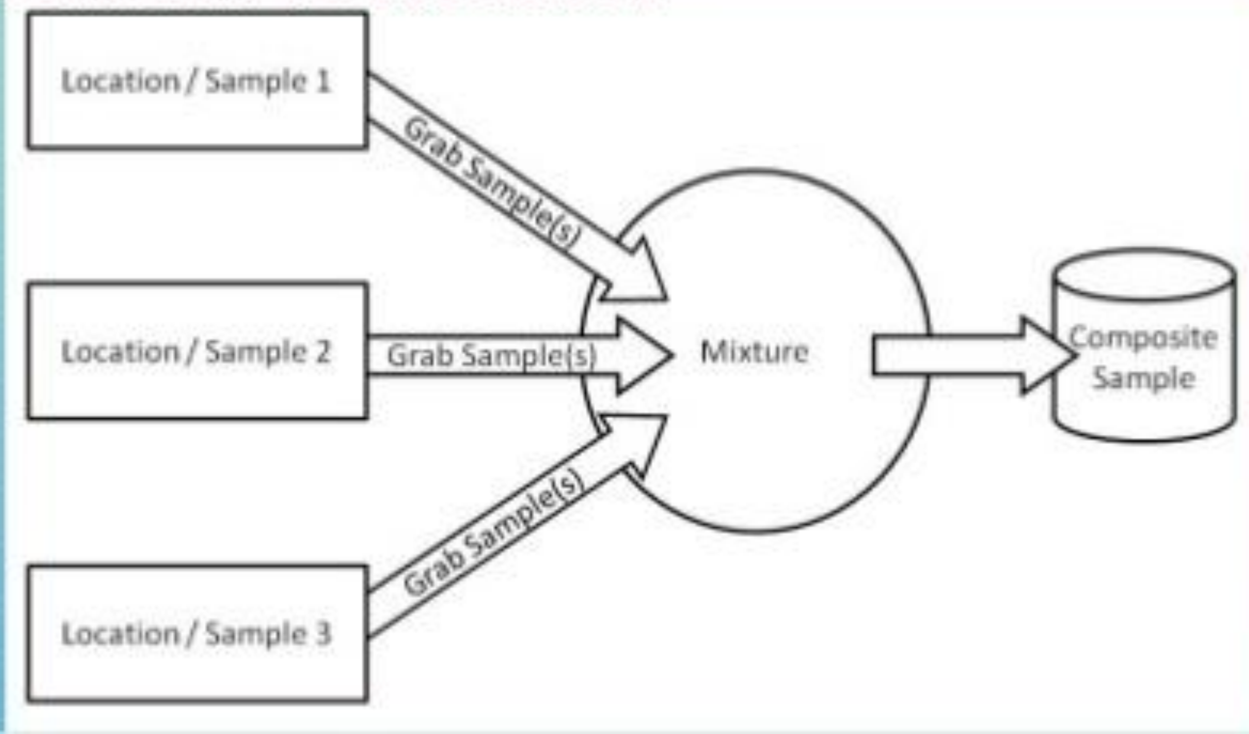
Ambient Air Sampling Methods

There are many methods available for collection of Air pollutants from atmospheric air in process of Environmental Monitoring.

- Grab Sampling,
- Absorption in liquids,
- Adsorption on solids materials
- Freeze-out sampling

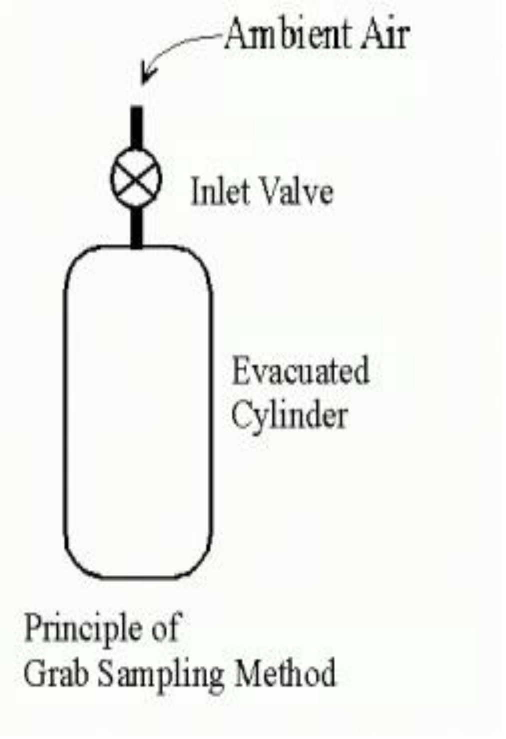
Grab Sampling

The grab sample is a discrete sample which is collected at specific location at a certain period of time. If the environment medium varies then a single grab sample is not representative and more samples are needed to be collected.



Grab Sampling

- Air sample is collected by filling an evacuated flask.
- This is very old and traditional Ambient Air Sampling Method.
- Plastic bags have been used for grab sampling for storage of gas & then subjected to analysis of grabbed sample.
- Grab sample may be taken using rigid wall containers made from glass or stainless steel.
- These containers first evacuated & then filled by air to fill the container.
- Alternatively, a container may be filled with water & then used as a collector simply by draining water which is replaced by filling air sample.



Absorption in Liquids

- Absorption of gaseous pollutants in liquid medium is one of the most common method for collecting air samples.
- To bring out high degree (pollutant) gas-liquid contact, impingers & midget type's devices are used.
- These devices can handle sample flow rates about 30 to 3 litres per minutes respectively.
- Particular absorbent-liquid (say 0.1 N NaOH) is filled inside Impinger. Flow is controlled with help of flow control devices.
- If done with sampling procedure, particular absorbent is then desorbed into lab for analysis & then concentration of (say, NOx) required gas is calculated.
- The absorbent, which is the collecting agent, may change either physically or chemically or both during the absorption process.
- Majority of Environmental Consultancy firms prefer this absorption in liquids among ambient air sampling Methods because of there is very negligible loss of degree of quality as well as quantity of pollutants while carrying it to laboratory.

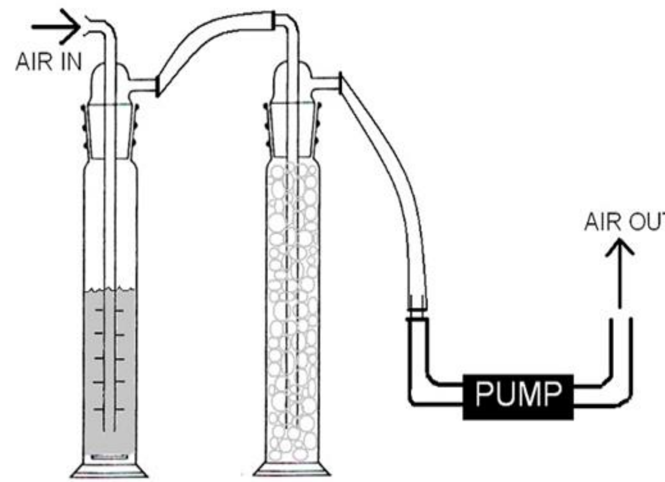
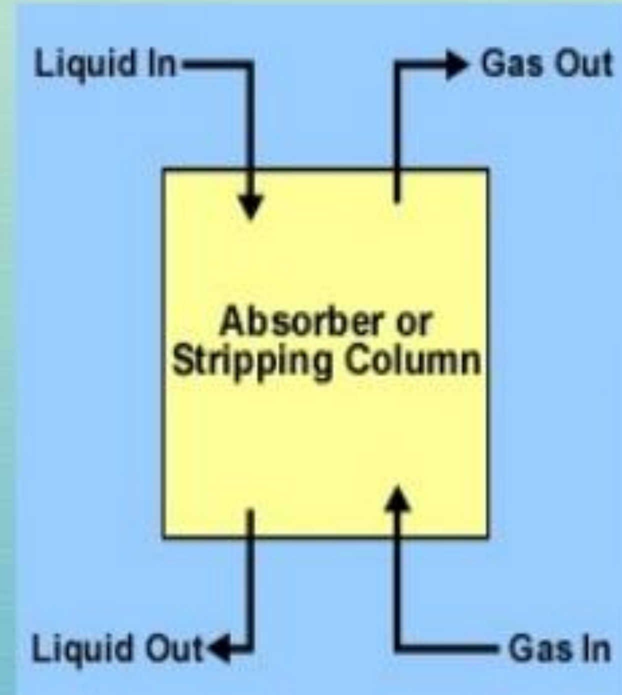


Fig: Fritted glass scrubber for sampling gaseous pollutants.

Absorption in Liquid

Absorption is defined as the process of separation of soluble gaseous impurities by dissolving in liquid solvent (Water).

- As the gas stream passes through the liquid, the liquid absorbs the gas, in much the same way that sugar is absorbed in a glass of water when stirred.



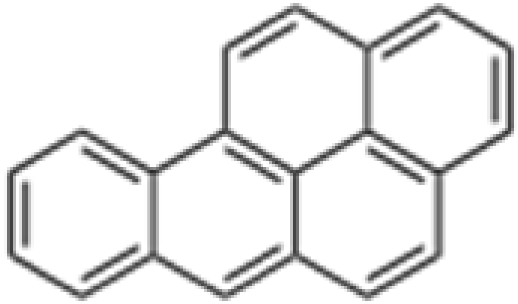
Gas	Solvent used for absorption
SO_2	Water or H_2O_2
O_3	Aqueous KI
NO_2	NaOH
CO	Ammonical Cuprous chloride
CO_2	Alcohlic KOH
O_2	Alkaline pyrogallol
Hydrocarbons	Oils

$$SO_2(g) + H_2O_2(liq) \rightarrow H_2SO_4(liq)$$

$$CO_2(g) + 2KOH \rightarrow K_2CO_3(s) + H_2O$$

Adsorption on Solids

- In this Ambient Air Sampling Method pollutant gas is absorbed on surface of solid.
- The air sample is passed though packed column containing finely divided adsorbent on whose surface pollutants are retained.
- Commonly used adsorbent is activated charcoal & silica gel.
- After sampling, sample gases are desorbed into lab for analysis.
- Large amount of gas can be sampled easily by this technique.
- This may be accomplished by washing adsorbent with liquid solvent.
- The main limitation with this technique is that polar substances cannot be desorbed easily from the solid adsorbent.
- Apolar, low volatile organics, such as Polycyclic aromatic hydrocarbons (PAHs) adsorb best on activated carbon.



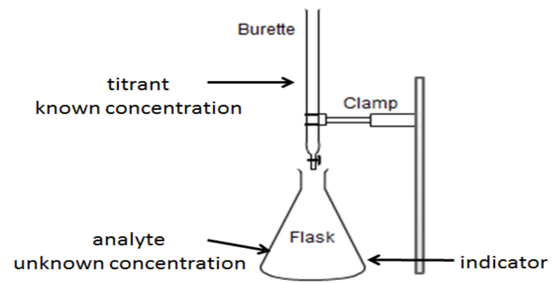
Benzo[a]pyrene:
A potential carcinogen

Freeze-out sampling (Condensation)

- Freeze-out sampling contains series of cold traps which being used to condensate air pollutants from air.
- The gaseous pollutants like volatile organic compounds (VOCs) can be removed from air by condensation.
- In this method, the air stream is made pass through the different collecting chambers of the condenser each maintained at progressively decreasing temperature (0 ^oC to -196 ^oC) i.e. ice bath to liquid nitrogen temperature.
- The traps are bought into laboratory, samples are removed, & analysis by means of mass spectrophotometry, Gas Chromatography, Spectrophotometry etc.

Volumetric analysis of air pollutants:

The concentration of chemical specie is estimated by doing titration. In a titration the test substance (analyte) in a flash reacts with the reagent added from the burette as a solution of known concentration. This is referred to as a standard solution and is called the titrant. The volume of the titrant required to just completely react with the analyte is measured. The end point of titration is indicated by the sharp change in the physical appearance of the contents of conical flask.



$$aA \quad + \quad tT \quad \longrightarrow \quad \text{product}$$

An example is the estimation of ammonia. The ammonia can be absorbed in a known volume of standard acid solution. The unused acid is then determined by back titration with standard base solution. The consumed acid is proportional to the amount of ammonia.

$$NH_3(g) \; + \; HCl \; \longrightarrow \; NH_4Cl$$

$$SO_2(g) \; + \; H_2O_2(liq) \; \longrightarrow \; H_2SO_4(liq)$$

$$CO_2(g) \; + \; 2KOH \; \longrightarrow \; K_2CO_3(s) \; + \; H_2O$$

Gravimetric analysis of air pollutants:

In this technique, the soluble analyte (gaseous pollutant) is converted into sparingly soluble form (precipitate) by treating with appropriate reagents. The precipitate is then weighed. From the mole relationship between the analyte and the precipitate, we can calculate the weight of the analyte. An example is analysis of CO_2. The gaseous CO_2 is absorbed in KOH tube of known weights. The increase in weight of tube is proportional to the amount of CO_2.

$$CO_2(g) + 2KOH \rightarrow K_2CO_3(s) + H_2O$$

Atomic absorption spectroscopy (AAS)

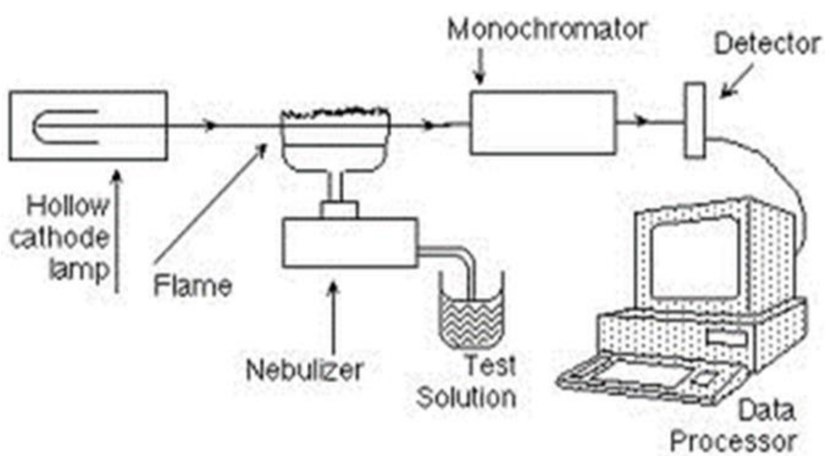
Principle

The electrons in the atoms can be promoted to higher orbitals (excited state) for a short period of time (nanoseconds) by absorbing radiation of a fixed wavelength. This wavelength is specific to a particular electronic transition in a given element and helps in the identification of element.

The amount of radiation absorbed at this particular wavelength helps to quantify the element present in the given sample. For this, the radiation flux without a sample and with a sample in the atomizer is measured using a detector and the ratio between the two values (the absorbance) is converted to analyte concentration or mass using the Beer-Lambert Law.

Instrumentation:

In order to analyze a sample for its atomic constituents, it has to be atomized. The atomizers most commonly used nowadays are flames and electrothermal (graphite tube) atomizers. The atoms should then be irradiated by optical radiation, and the radiation source could be an element-specific line radiation source or a continuum radiation source. The radiation then passes through a monochromator in order to separate the element-specific radiation from any other radiation emitted by the radiation source, which is finally measured by a detector.



Schematic diagram of AAS

Job of the nebulizer:

1. To suck up the liquid sample at a controlled rate
2. To create a line aerosol for introduction into the flame
3. Mix the aerosol, fuel and oxidant thoroughly into the flame

Job of the atomizer:

1. To destroy any analyte ions and breakdown complexes, if any
2. Create atoms of the elements of interest

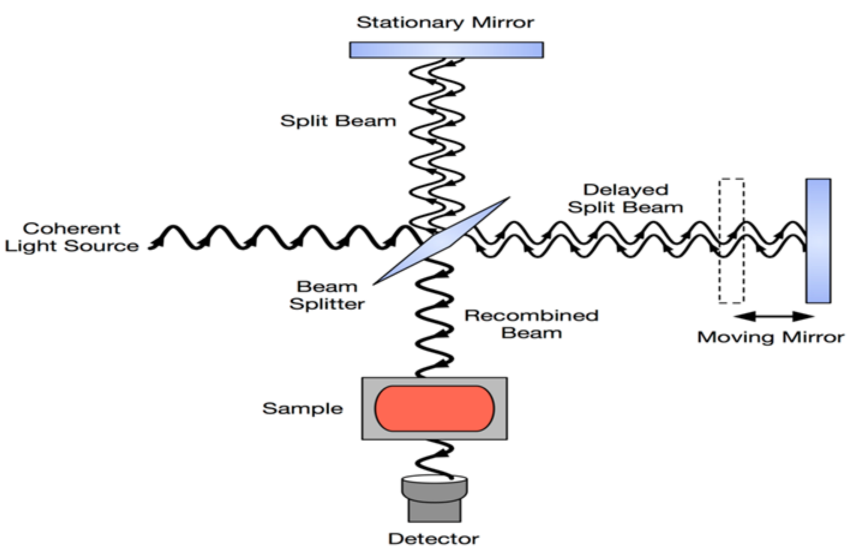
Job of the monochromator:

1. To isolate analytical lines photons passing through the flame
2. To remove scattered light of other wavelength from the flame

Job of the photomultuplier tube:

1. To convert the intensity of the photons of the analytical lines into current (signal)

Fourier Transform Infrared spectroscopy (FTIR): is a technique which is used to obtain an infrared spectrum of absorption of a solid, liquid or gas. With this technique it is possible to identify the types of chemical bonds and functional groups.



Schematic of FTIR instrument

Principle: The chemical bonds in molecules are elastic in nature and vibrate about the mean internuclear distance. The vibration frequency is decided by the force constant of the chemical bond and mass of the atoms involved. This frequency number is thus a characteristic of the chemical bond. The energy required to make vibrational transition is dependent on the vibration frequency of chemical bond and thus helps in the identification of the chemical bond. Also the intensity of absorption is directly proportional to the concentration of chemical bonds in a given sample.

Note: The vibration of chemical bonds must involve a change in dipole moment in order to give IR spectrum.

Analysis of SO_2

1. Analysis of SO_2 by PRA method: concentration of SO_2 in atmosphere can be determined by bubbling the test sample of air through a dilute solution of sodium tetrachloromercurate (II), ie $Na_2(HgCl_4)$, obtained by the action of $HgCl_2$ on NaCl in presence of sulphuric acid.

$$2NaCl + HgCl_2 \longrightarrow Na_2(HgCl_4)$$

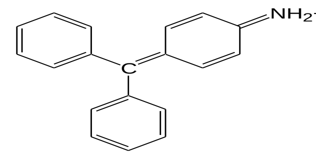
The sulphuric acid destroys only nitrogen oxide present in the air sample.

$$Na_2(HgCl_4) + SO_2 + H_2O \longrightarrow Na_2[HgCl_2(SO_3)] + 2HCl$$

Sodium dichlorosulphito mercurate (II)

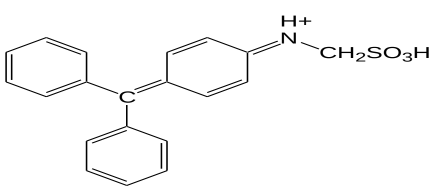
The above mixture is treated with a mixture of p-rosaniline dye (PRA), formaldehyde and phosphoric acid. The PRA is converted to p-rosaniline methylsulphonic acid

$Na_2[HgCl_2(SO_3)] + CH_2O + H_3PO_4 +$



p-rosaniline

$\downarrow$



$+ HgCl_2 + H_2O + Na_2HPO_4$

p-rosaline methylsulphonic acid (red violet color), At pH = 1, $\lambda max = 575nm$

2. Analysis of SO_2 by acid titration method: The SO_2 is absorbed in H_2O_2.

$$SO_2 + H_2O_2 \rightarrow H_2SO_4$$

The amount of H_2SO_4 formed can be determined by titrating it with a standard solution of NaOH and using phenolphthalein as an indicator. The end point is detected by a sharp change in color from colorless to pink color. HCl and HF interfere in this method.

3. Reduction method for SO_2 :

$$SO_2 + 4\,KI + 2\,H_2O = 4\,KOH + S + 2\,I_2$$

$$I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6$$

SO_2 reacts with KI and the liberated I_2 is titrated against standard solution of sodium thiosulphate. H_2S, O_3 and organic matter interfere.

4. Lead Candle method: In this method candle made of PbO_2 is exposed to SO_2 which reacts to give $PbSO_4$.

$$PbO_2 + SO_2 \rightarrow PbSO_4$$

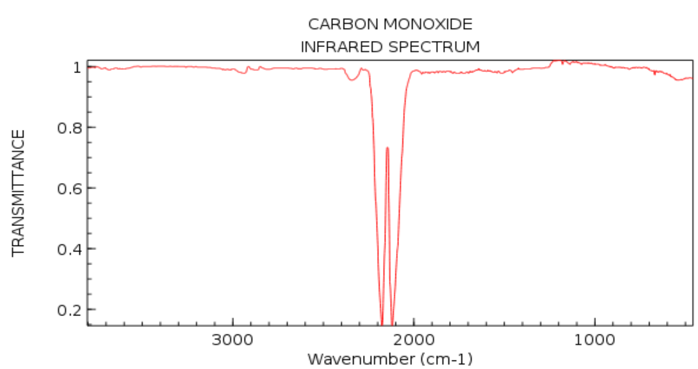
The change in weight of the candle gives the amount of SO_2 present in the air. Dust and particulates may be deposited to give erroneous results.

Analysis of CO

1. Hopcalite based CO monitoring: Hopcalite is a mixture of copper and manganese oxides used as catalyst to convert carbon monoxide into carbon dioxide when exposed to the oxygen in air. The conversion of CO to CO_2 is exothermic. The amount of heat raises the temperature and the change in temperature is measured. The change in temperature is proportional to the concentration of CO.

Alternatively CO_2 produced in the reaction may be absorbed in alcoholic KOH solution and the amount can be estimated acidimetrically.

2. FTIR for the estimation of CO: In this technique the extent of absorption of IR energy by a column of a sample of gas is measured. The peak absorbing wavelength of CO is ν=2169.7cm^{-1}. This method is used when the concentration of CO is up to a level of 150ppm. Dust and moisture must be absent.



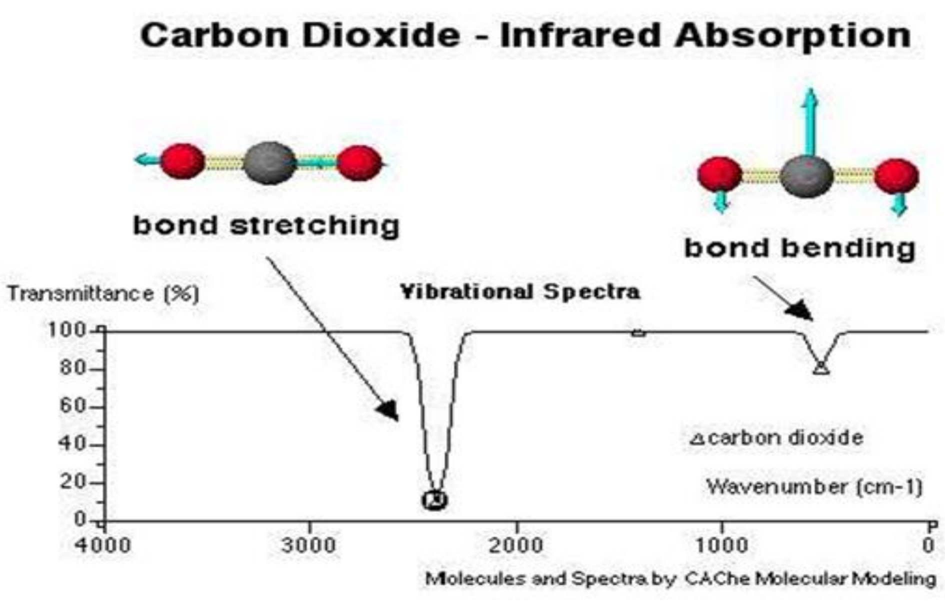
NIST Chemistry WebBook (http://webbook.nist.gov/chemistry)

Analysis of CO_2

1. Monitoring of CO_2: The CO_2 can be absorbed in a known volume of standard base solution. The unused base is then determined by back titration with standard acid solution. The consumed base is proportional to the amount of CO_2.

$$CO_2(g) + 2KOH \rightarrow K_2CO_3(s) + H_2O$$

2. Monitoring of CO_2 by FTIR: The antisymmetric stretching vibration of CO_2 appears at $2349.3 cm^{-1}$. The concentration of CO_2 can be estimated by measuring the intensity of absorption at this wavelength.



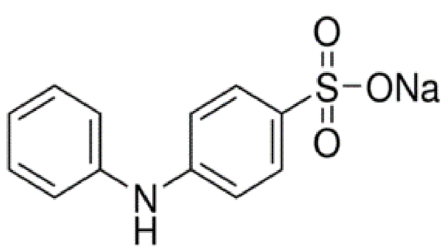
Analysis of O_3

1. O_3 by Iodide method: In this method O_3 is reduced with KI and liberated I_2 is determined by titrating with a standard sodium thiosulphate solution using starch as indicator.

$$O_3 + 2KI + H_2O \rightarrow O_2 + I_2 + 2KOH$$

$$I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6$$

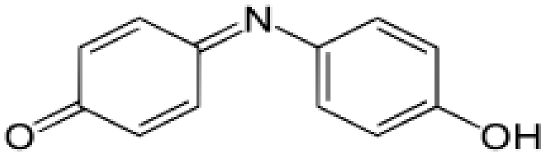
2. O_3 by diphenyl sulphonate method: When O_3 is reacted with $HClO_4$ and sodium diphenylamine, a red colored product is formed. The absorbance of this solution is measured at 590nm.



Oxidized form is red-violet in color and reduced form is colorless.

Analysis of Ammonia

1. **Indophenol method:** a sample suspected of containing ammonia is treated with sodium hypochlorite and phenol. The formation of indophenol is used to determine ammonia. The amount of indophenol formed can be estimated by the measuring the amount of light absorbed at 630nm. Working range 0.25-1μg/ml.



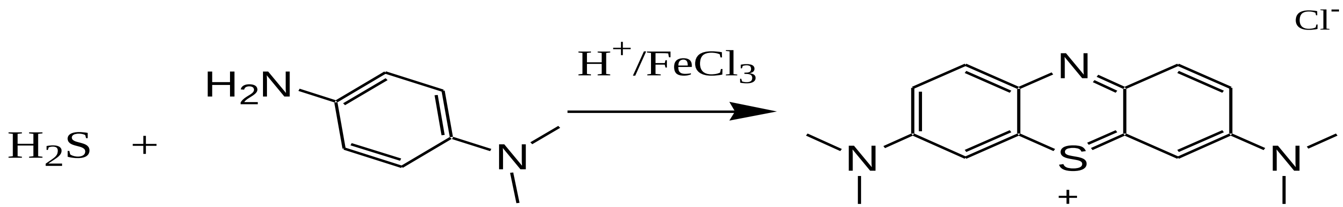
2. Nitrite method: It is based on the reaction of $(NH_4)_2SO_4$ with HOCl and Br_2 gas to give colored complex. The peak absorbing wavelength is 550nm.

3. Nessler method: In this method ammonia is absorbed in H_2SO_4 and is reacted with $HgCl_2$ and KI (in NaOH). The formation of brown color complex is measured at 450nm. Working range is 10-100μg/ml. Important reactions are:

$$HgCl_2 + KI \rightarrow HgI_4^{2-} + NH_3 + 3OH^- \rightarrow \underset{\text{(brown color)}}{NH_2Hg_2IO} + 7I^- + 2H_2O$$

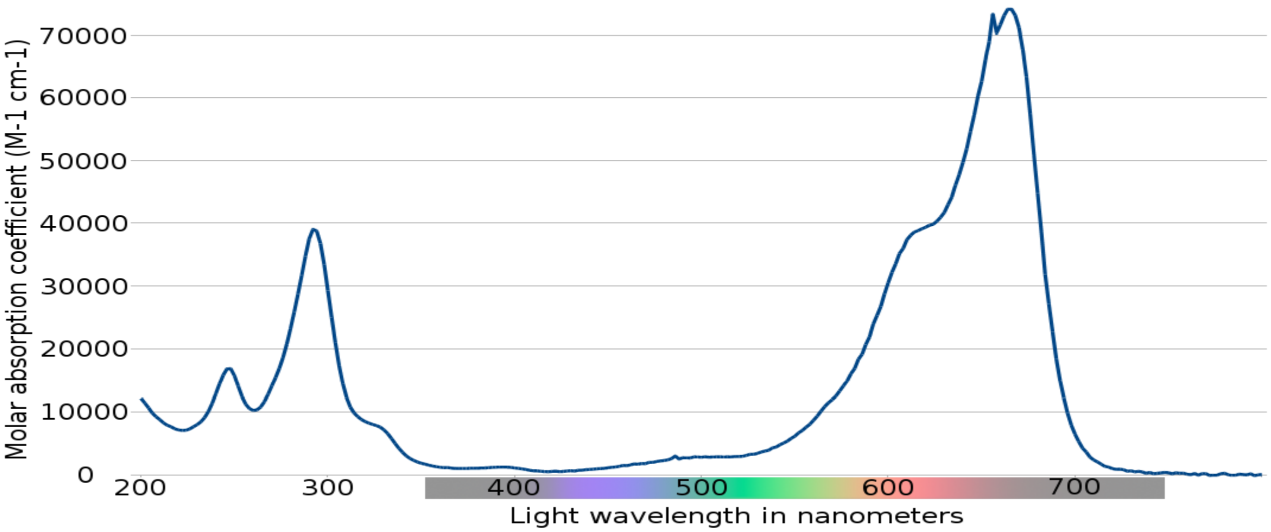
Analysis of H_2S

1. H_2S by methylene blue method: H_2S is treated with N,N'-dimethyl-4-phenylenediamine and dissolved in HCl. The dye (methylene blue) so formed in the presence of $FeCl_3$ is measured by spectrophotometry at 670nm. The molar extinction coefficient of the dye at 670nm is 95000 litre/(mol-cm).



Methylene blue

Working range is 1-10μg/ml. SO_2, O_3 and NH_3 do not interfere.



Absorption spectrum of methylene blue in terms of molar extinction coefficient.

2. **H_2S by titration:** H_2S is treated with KI and liberated I_2 is titrated with a standard solution of Sodium thiosulphate solution using starch as indicator. The color change from blue to colorless is the end point

$$I_2 + 2Na_2S_2O_3 \rightarrow 2NaI + Na_2S_4O_6$$

The method is applicable only in absence of SO_2.

UNIT 2

Meteorology (Study of Atmosphere)

Important meteorological parameters that influences air pollution can be classified into

1. Primary parameters
2. Secondary parameters

I. PRIMARY PARAMETERS

a) Wind direction and speed
b) Temperature
c) Atmospheric stability
d) Mixing height

II. SECONDARY PARAMETERS

a) Precipitation
b) Humidity
c) Solar radiation
d) Visibility

WIND DIRECTION AND SPEED:

The direction and speed of surface winds governs the drift and diffusion of air pollutants, discharged near the ground level. The higher the wind speed at or near the point of discharge of pollution, the more rapidly are the pollutants carried away from the source. The pollutants so dispersed will not exist at the same concentration but will rapidly be diluted with greater and greater values of air on the other hand when wind speeds are low, pollutants tend to be concentrated bear the area of discharge and the longer the periods of such light winds the greater will be the concentration of pollutants. Further, turbulence a very important characteristic of surface winds is directly proportional to its speed and determine the extent to which pollutants are mixed and diluted with the surrounding air. In rough terrain, it cannot be assumed that the wind direction and the speed near the source govern the subsequent motion of the contaminants. Hills may deflect the air flow either horizontally, vertically, or both, the amount of deflection depending on the vertical stability of the atmosphere. In valleys, the winds carrying a pollutant tend to flow either up or down the valley, following its meanderings. The deeper the valley the more pronounced is this channelizing effect.

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 1o 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.

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 rates 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 phenomena 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.

Different environmental lapse rates and their effects on dispersion of air pollutants:

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Kinds of plumes depending upon different environmental conditions:

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.

1) Looping
2) Coning
3) Fanning
4) Lofting
5) Fumigation
6) 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.

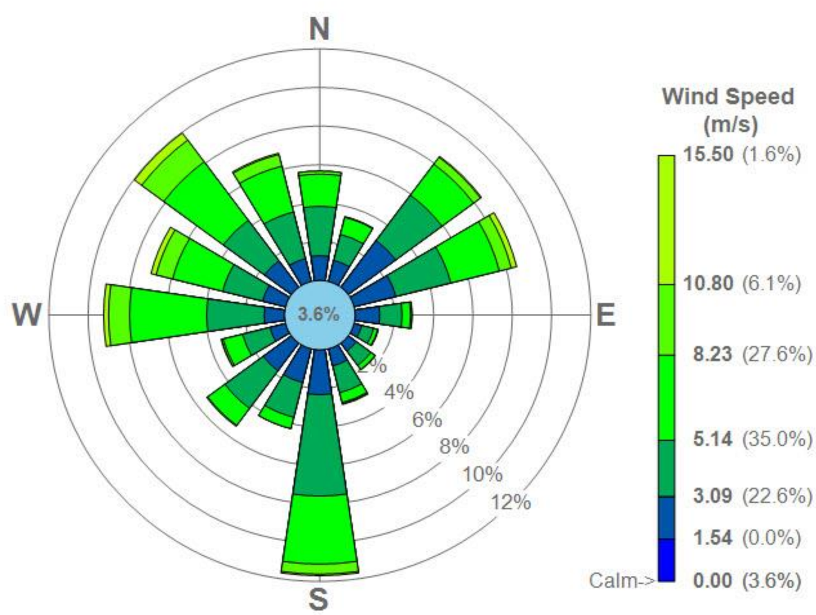
WIND ROSE DIAGRAM

Wind rose diagram is a tool which diagramatically represents wind speed, wind direction at a particular zone over a period of time. It is essentially used in the construction of airport-runways, as aircraft perform their best landing and take-offs pointing into the wind.

In general, a wind rose diagram consists of eight or sixteen emerging lines from a circle, and each emerging line indicates the wind direction. The length of each line specifies the frequency of wind in that direction. The frequency of calm condition is entered at the center of the diagram.

A wind diagram can be drawn based on various factors. Some of them are drawn by considering only the wind direction and some of them are drawn by considering other important mateorological factors, based on the purpose of the wind rose diagram.

wind roses may be drawn from the data obtained over the period of time, the time interval may be several months or a year or a season. In wind roses, the mateorological factors are to be converted into wind direction refers to the direction from which the wind is blowing. The frequency of winds blowing from the north indicated by a line or bar extending to the north on the wind rose diagram.wind rose diagram is prepared using an appropriate scale to indicate the percentage frequencies of wind direction and appropriate index shades, lines etc...to represent various wind speeds.



Control of Air Pollution

T. Naga Srinu, Assistant Professor, ACE Engineering College

Methods To Control Air Pollution

There are two primarily classified methods to control air pollution. They are given below

1) Preventive Methods

2) Control Technologies

Preventive Methods

NOTE: Preventive methods are nothing but control of air pollution at source.

a) Substitution of raw materials
b) Change of process and technologies
c) Use of tall stack
d) Zoning of community
e) Strict and stringent legislations

Control Technologies

1) Particulate Control Technologies

   A) Dry Control Devices

   B) Wet Control Devices

2) Gaseous Control Technologies

Dry Control Devices

a) Gravity settling chamber
b) Cyclone separator
c) Electro-static separator/precipitators
d) Fabric filters

Wet Control Devices

(Scrubbers)

a) Spray towers

b) Cyclone scrubber

c) Venturi scrubber

NOTE: Dry control devices are preferred over wet control devices.

Gaseous Control Technologies

1)Adsorption
2)Absorption
3)Combustion

Let us discuss

one by one.!

Preventive Methods

a) Substitution of raw materials
b) Change of process and technologies
c) Use of tall stack
d) Zoning of community
e) Strict and stringent legislations

Substitution of raw materials

Use of low Sulphur coal shall reduce the emissions of Sulphur oxides during combustion.

Fossil fuels can be substituted by Electric, solar, nuclear, thermal energy.

Change of process and technologies

- NO_X are formed by combination of Nitrogen(N_2) and Oxygen (O_2) of the air at high combustion temperatures, but by suitably modifying the operations, their formation can be minimized.

- Modifications like Fuel Gas recirculation, water Injection, Two stage combustion (Very Effective) and Low-Excess air firing.

Use of tall stack

The long stack will reduce the ground level concentration of pollutants by facilitating their discharge away from the ground, and making available more ground, making available more depth of the atmosphere for their dispersion and dilution.

Zoning of Community

- Industries should be located far away from the existed residential communities.

- Forests should not get effected to this industrial or auto mobile pollution which is releasing into the atmosphere.

Strict and stringent legislations

- The effective height of the stack should be more than two and a half times of the height of the tallest building near the source.

- Industry should maintain proper control methods to dilute pollutants from the industry (to get the permissions)

Control Technologies

1) Particulate Control Technologies

A) Dry Control Devices

(i) Gravity settling chamber
(ii) Cyclone separator
(iii) Electro-static separator/precipitators
(iv) Fabric filters

Gravity Settling Chamber

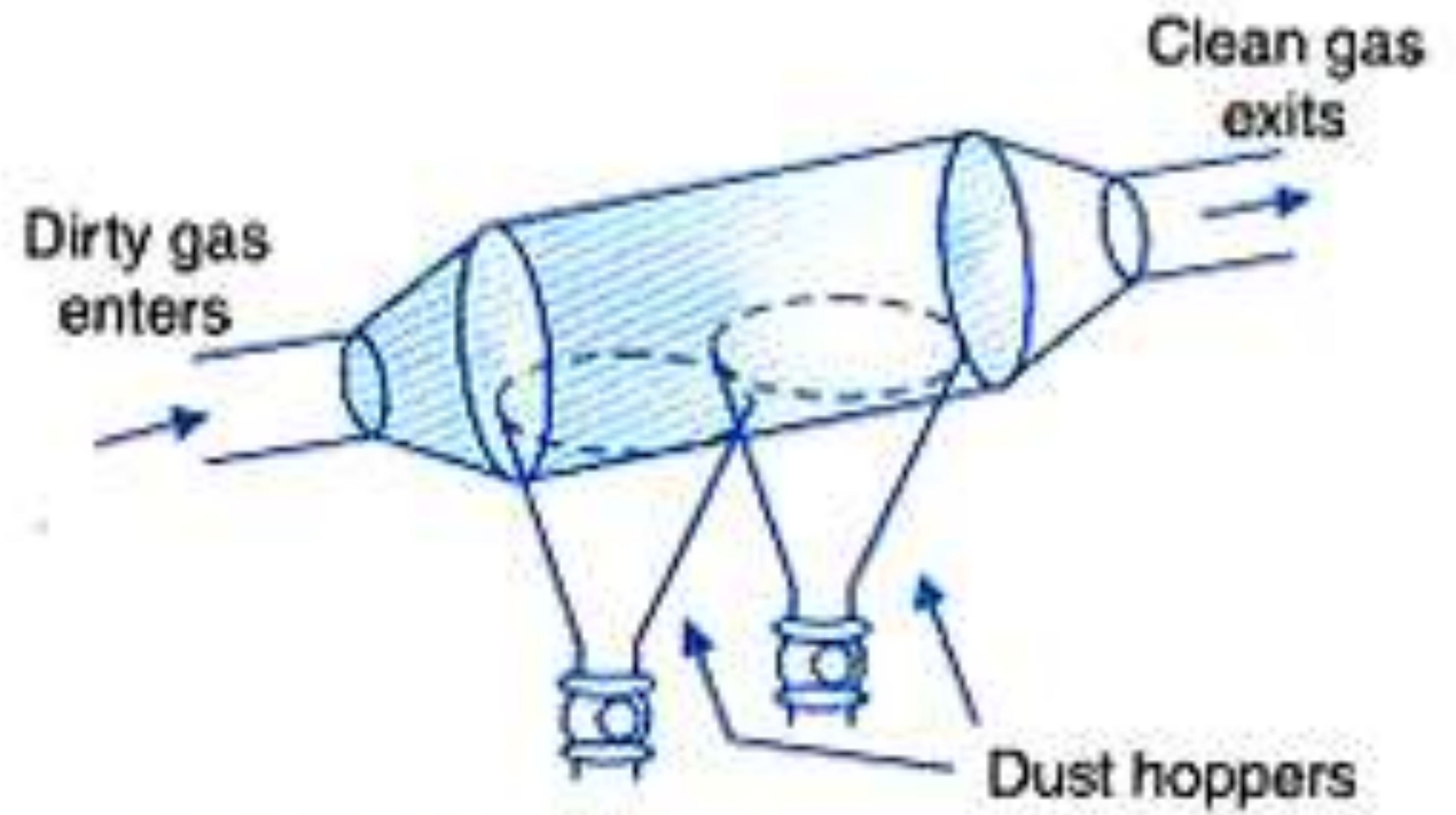


Fig. 5.3. Gravity settling chamber

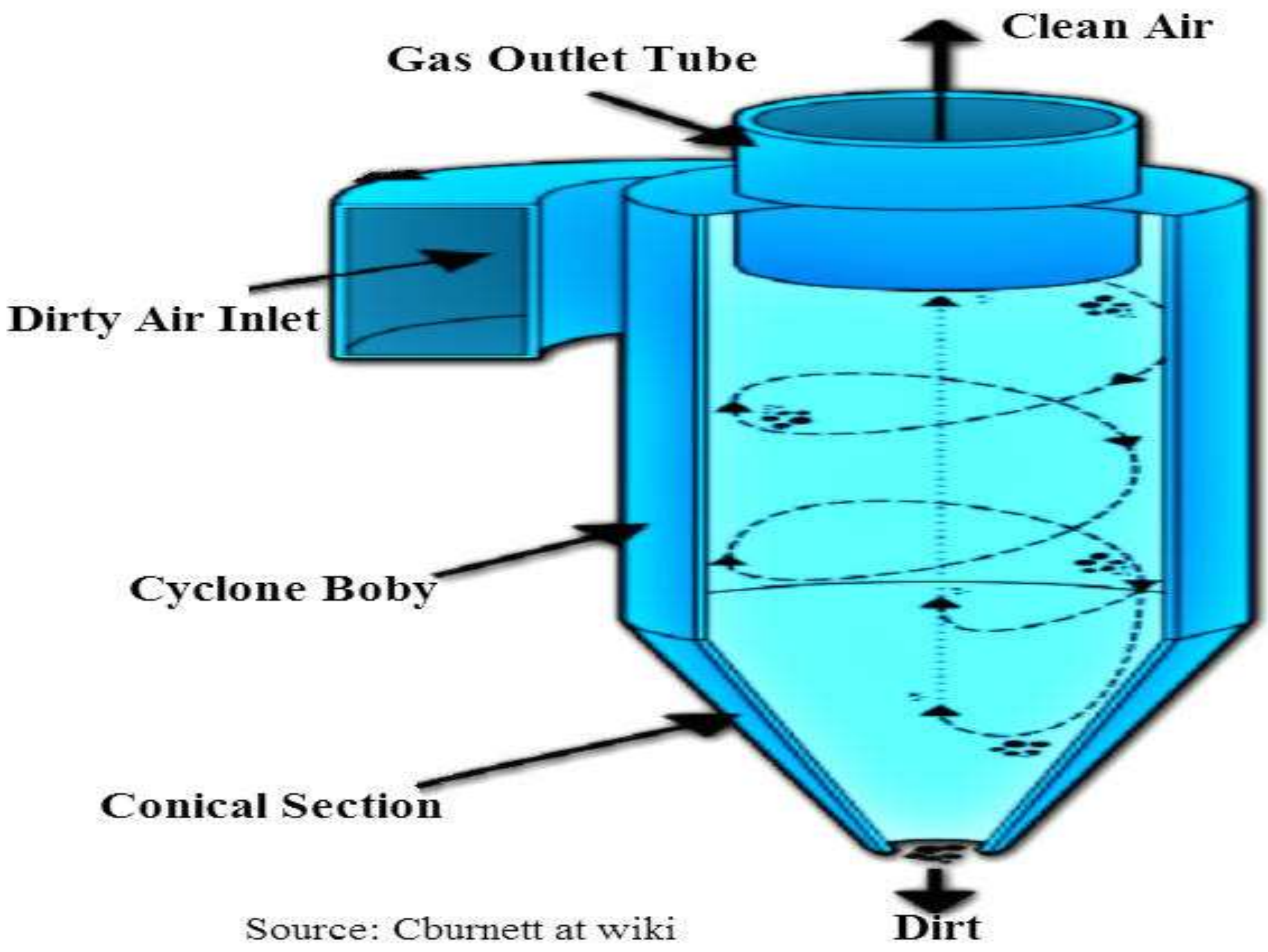
Gravity Settling Chamber

- When air enters inside the chamber suddenly the velocity of the gas decreases therefore gas particles and particulate matter comes down and settles.

- Diameter of particles capture > 50 μm

- Efficiency of particle capture < 50%

Cyclone Separator



Cyclone Separator

- The main principle applied in a cyclone separators is the spinning of particles by a centrifugal force to separate them from the carrier gas.

- Diameter of particles capture = 5 - 25μm

- Efficiency of particle capture = 50 - 90%

Electro-Static Precipitators

Main principle of ESP:

The electro static precipitators, the dust particles are electrically charged by producing a high voltage discharge, and then collecting them on the collecting plates by electro static forces.

- Diameter of particles capture ≥ 1 μm
- Efficiency of particle capture = 95 – 99 %

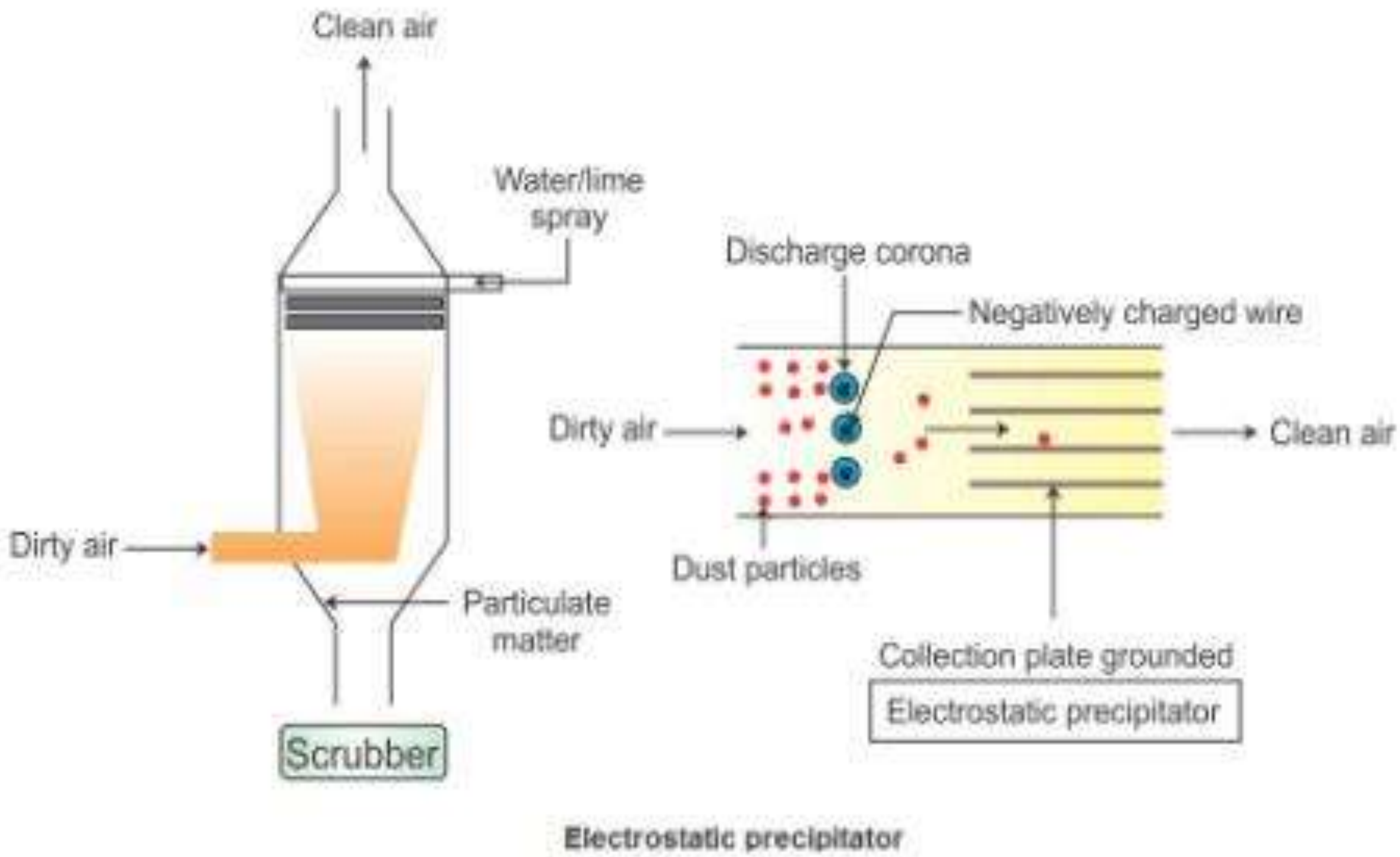
Electro-Static Precipitators

- Employed at Thermal power stations to control Fly-Ash emission.

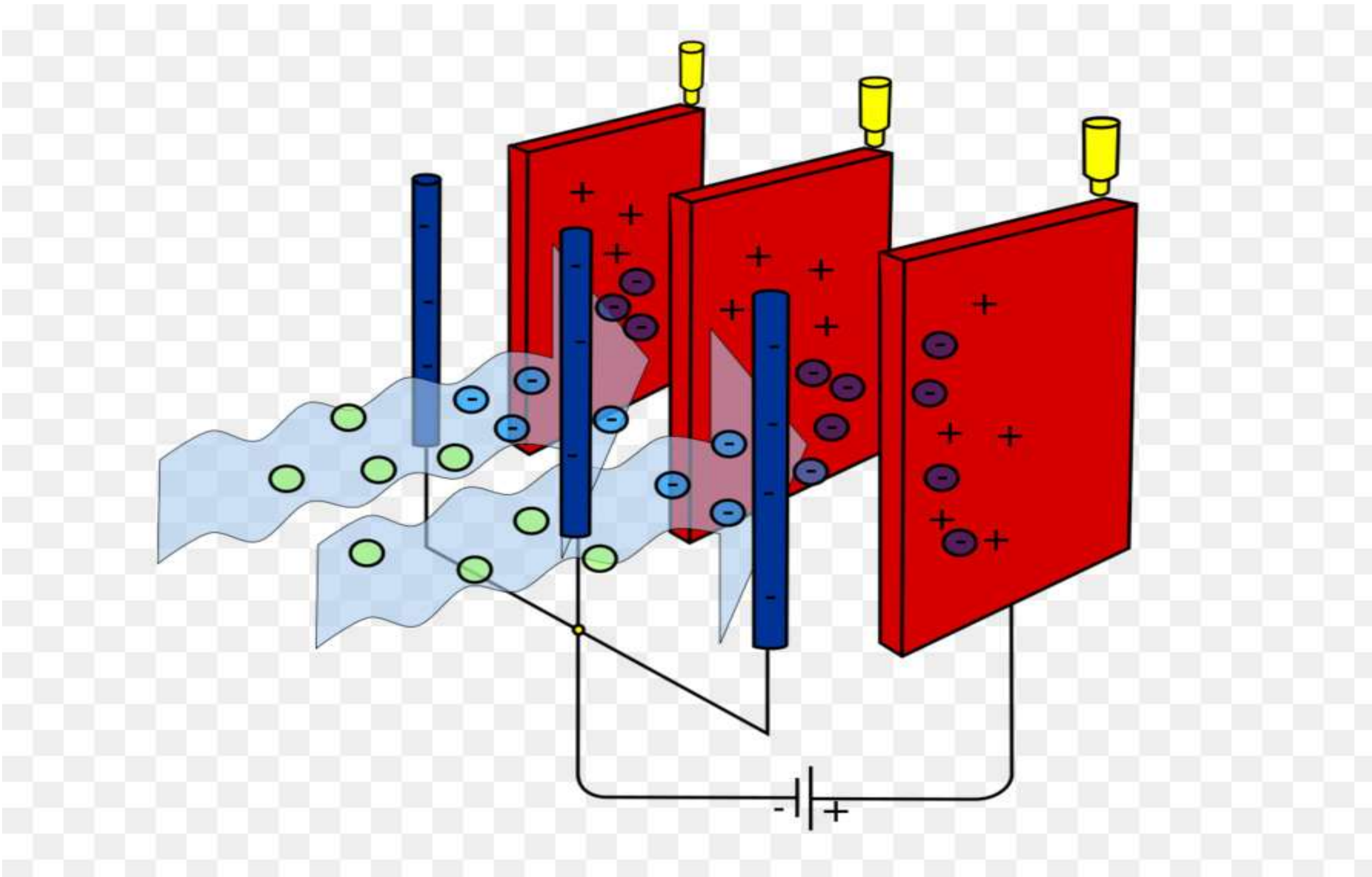
- Basically of two types

  1) Cylindrical ESP
  2) Parallel plate ESP

Cylindrical ESP



Parallel Plate ESP



Fabric filters

- In the fabric filter systems for collecting particles, the dirty gases passed to woven fabric or felted fabrics so as to retained the particles, and allowing clean gases to pass out.

- Diameter of particles capture ≤ 1 μm
- Efficiency of particle capture ≥ 99 %

Control Technologies

1) Particulate Control Technologies

A) Dry Control Devices

B) Wet Control Devices (Scrubbers)

(a) Spray towers

(b) Cyclone scrubber

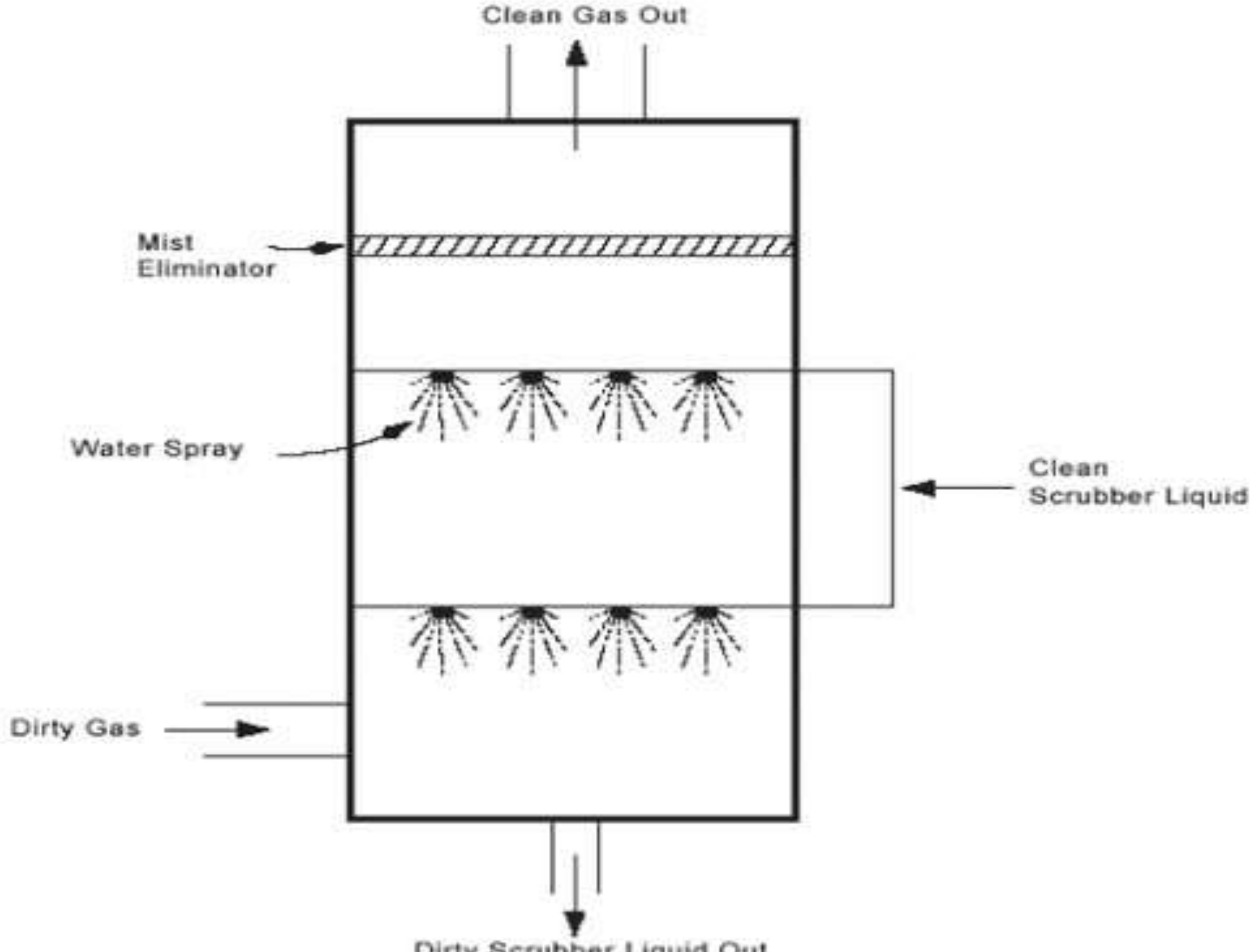
(c) Venturi scrubber

Spray towers

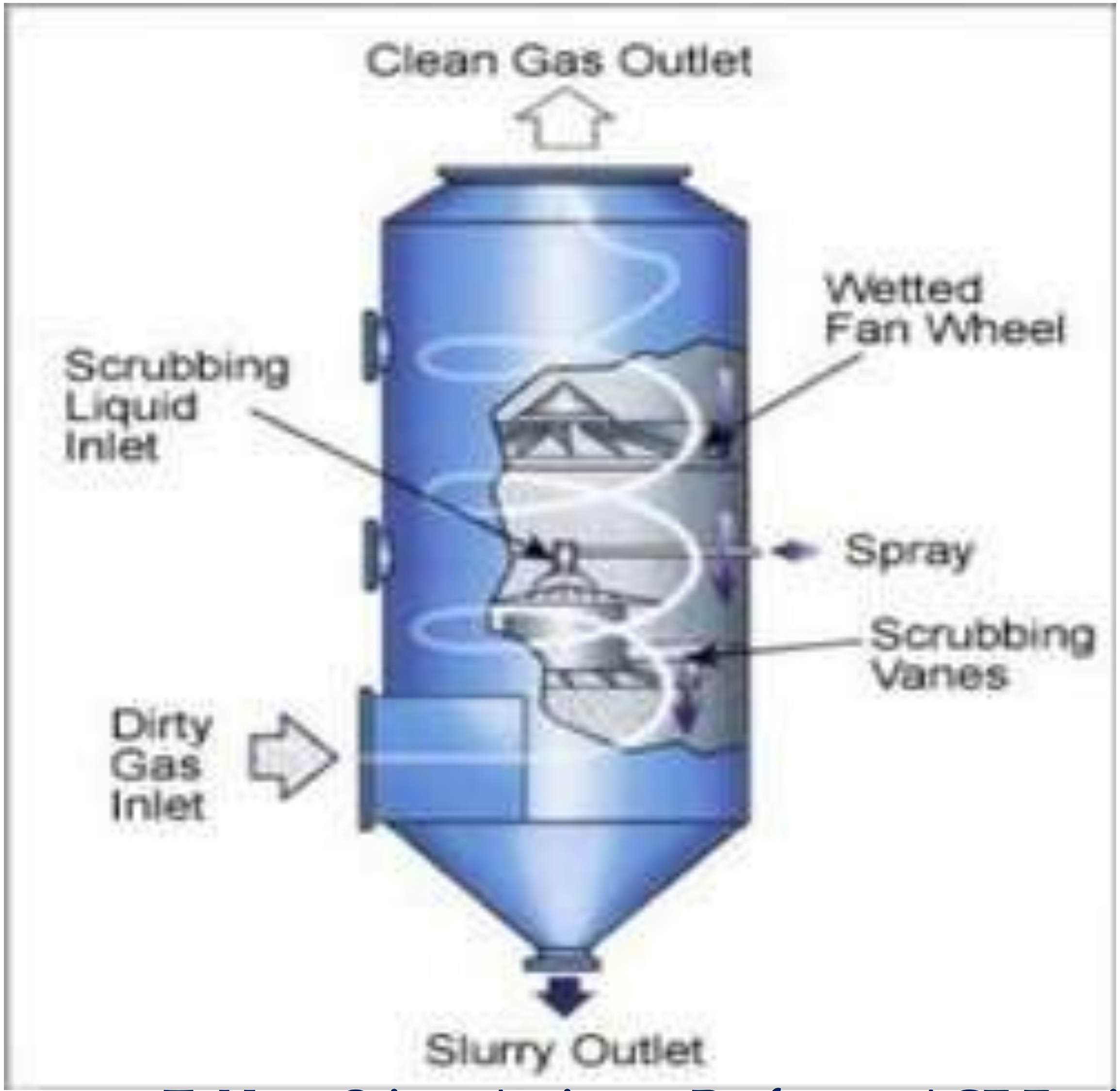
Principle:

This is one of the most simple device consist of a tower in which the dirty gases rise from the bottom, while water is sprayed from a number of nozzles on to the entered air so that water droplets falling due to the gravity hold (as they become heavier) the particles present in the dirt air.

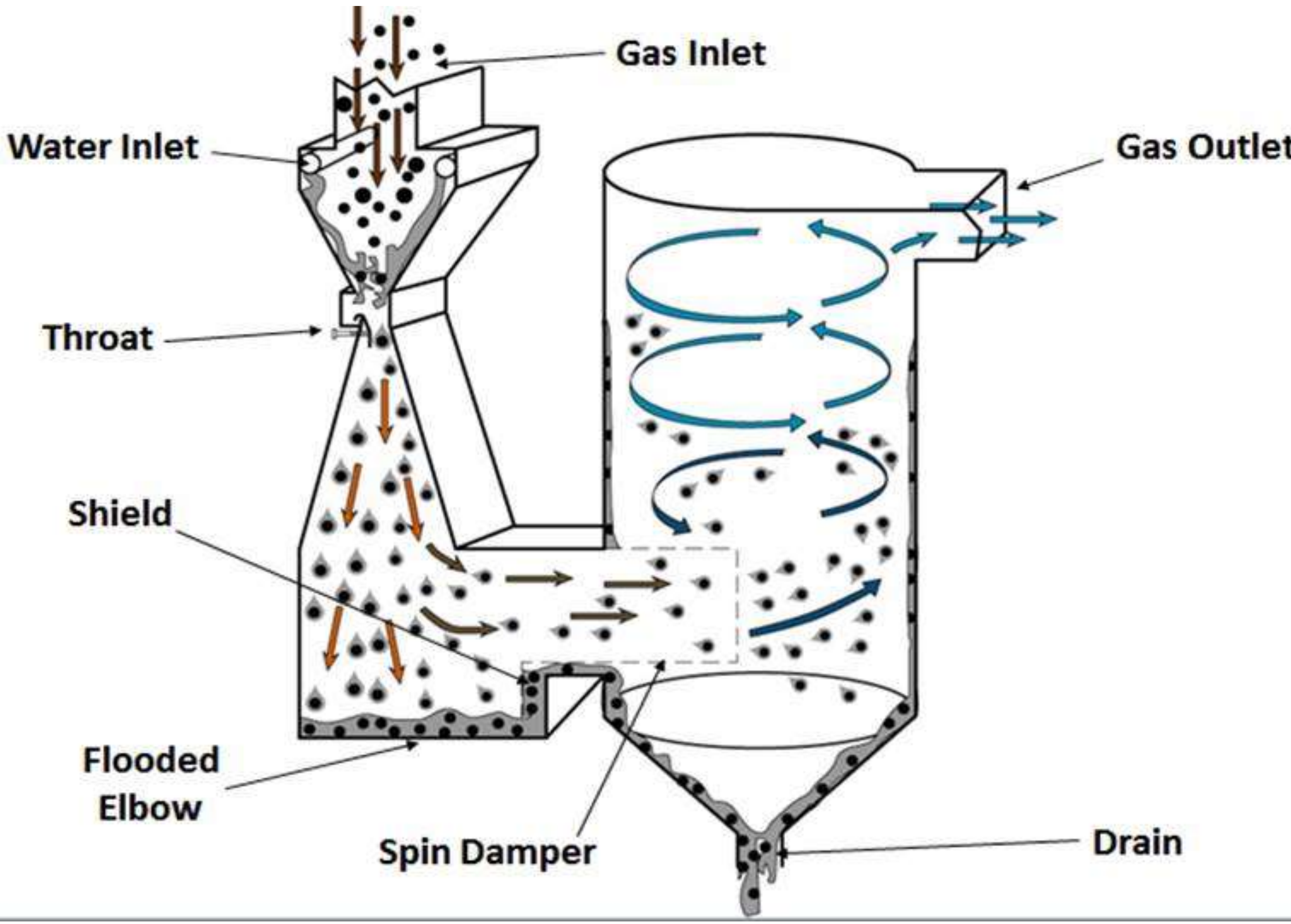
Spray towers



Cyclone scrubber



Venturi scrubber



Gases Control Technology

1)Adsorption

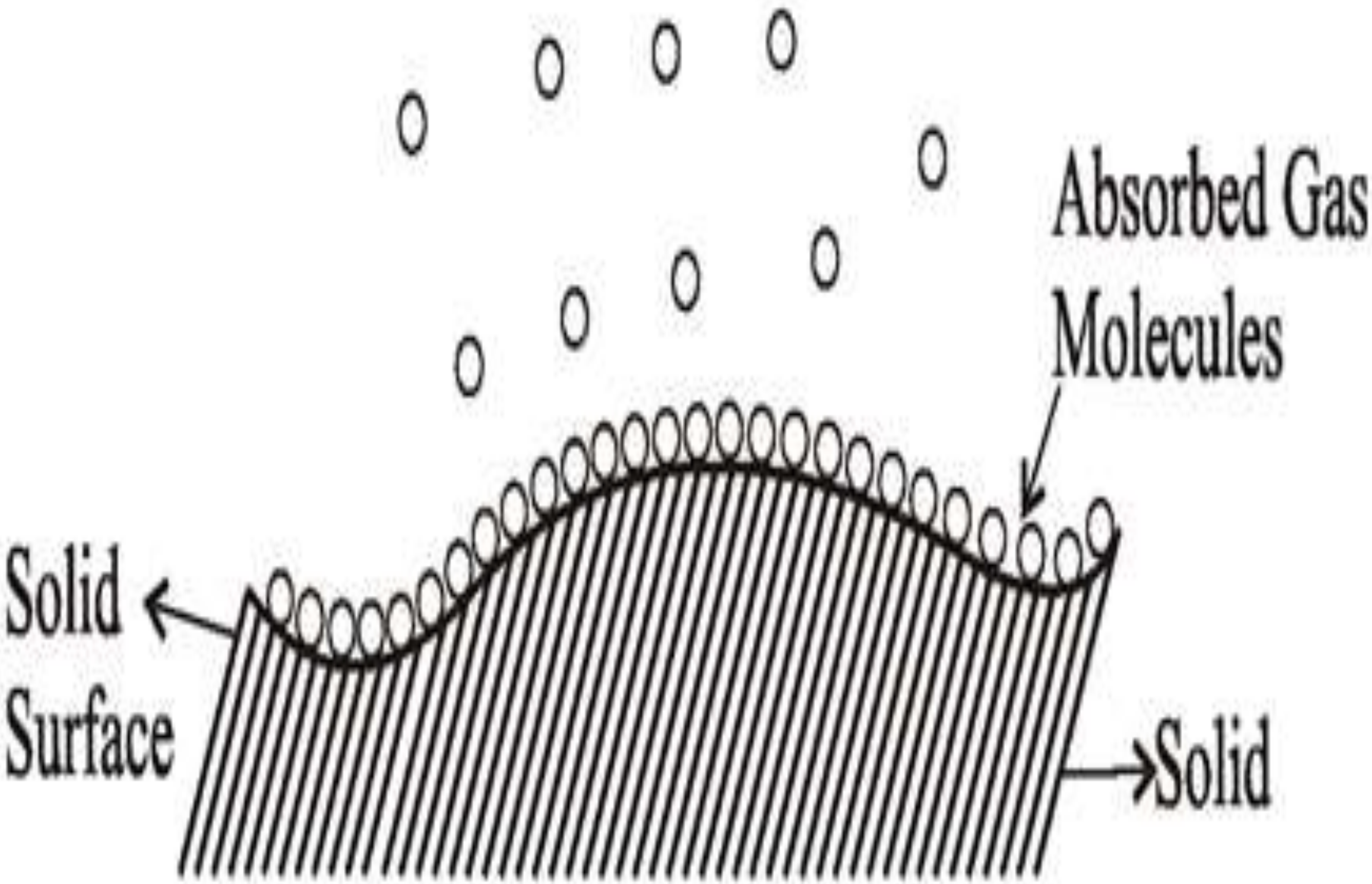
2)Absorption

3)Combustion

Adsorption

- In adsorption units, the dirty gases are allowed to pass through the beds of adsorbent (Solid) materials, in which the gaseous pollutants are completely adsorbed and removed.

- **Common Adsorbents used:** Activated Carbon, Activated Alumina, Silica Gel. (These materials have very high surface area per unit weight.)

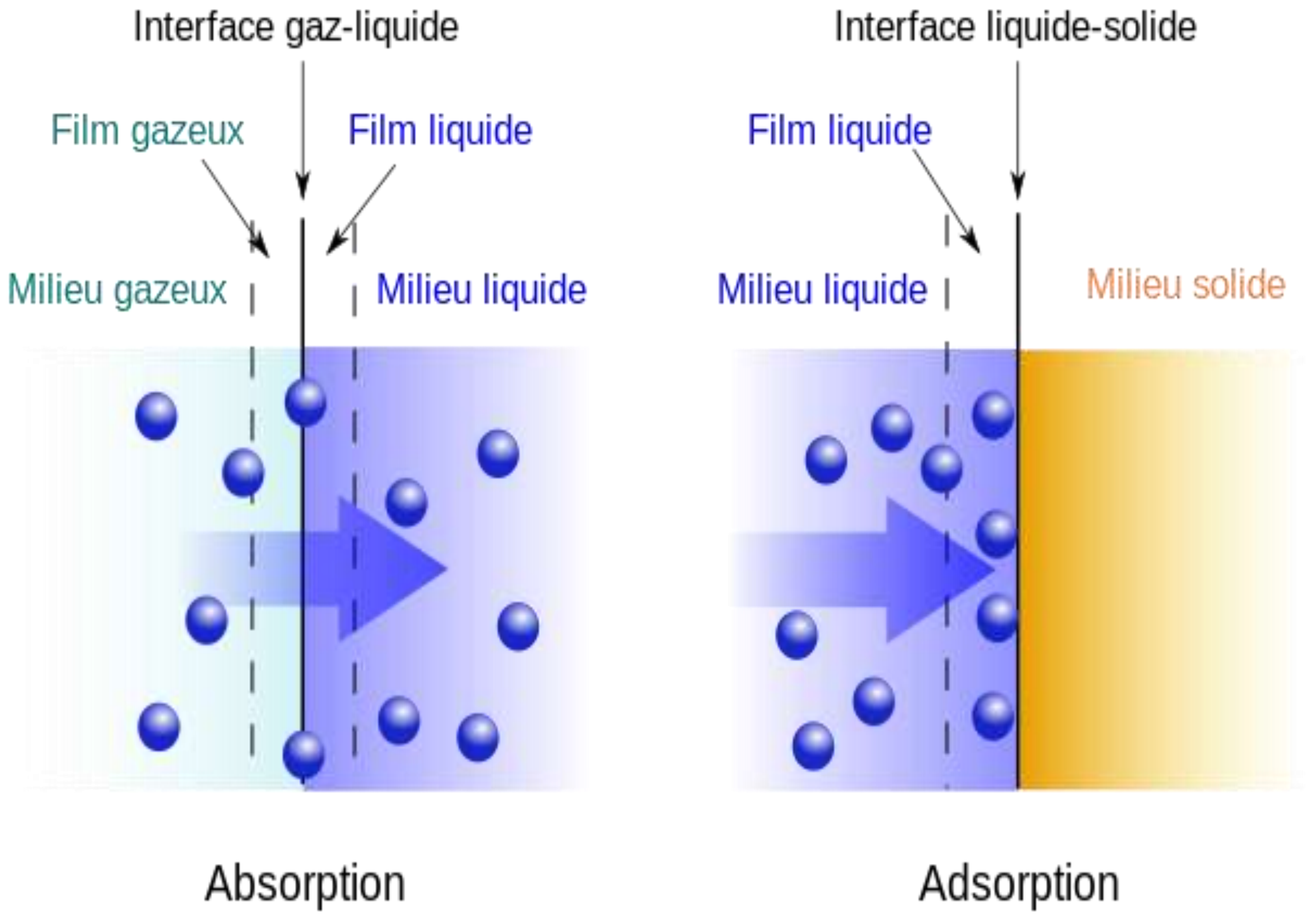

Absorbed Gas
Molecules
Solid
Surface
Solid

Absorption

- Absorption units work on the principle of transfer of the pollutants form the gaseous phase to the liquid phase.

- The pollutants from the dirty gas, gets absorbed by the liquid, through which the gas is allowed to pass, in the absorption units.

- Water as a solute, gases like NH_3, Cl_2 and SO_2 are removed. (Spray Towers)


Interface gaz-liquide
Interface liquide-solide
Film gazeux
Film liquide
Film liquide
Milieu gazeux
Milieu liquide
Milieu liquide
Milieu solide
Absorption
Adsorption

Combustion

Combustion is one of the air pollution control measure, in which the toxic gaseous pollutants are removed from dirty air by means of oxidation. This method is applicable, when the gaseous pollutants in the dirty gas are oxidisable to an inert gas.

5.1 Automobile (Vehicular) Pollution & Control

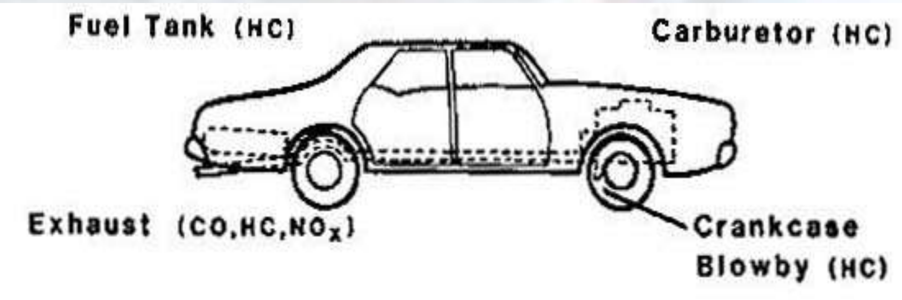
T. Naga Srinu, Assistant Professor, ACE Engineering College

Major Emissions

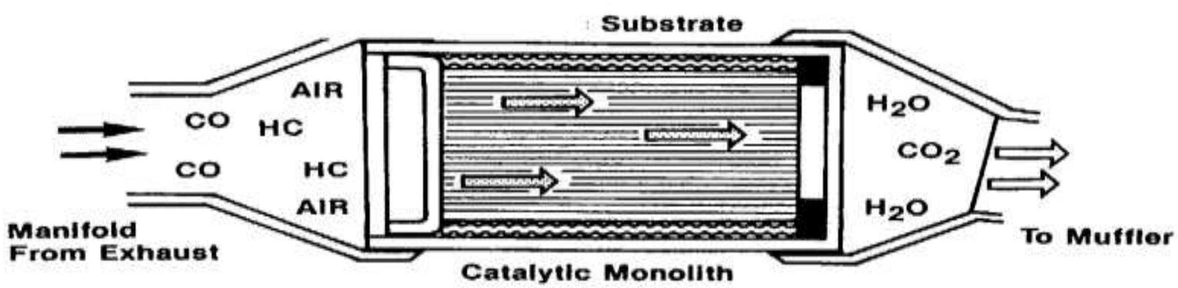
- CO
- HC's
- NO_x

CO and HC's Control

- Modify engine design to improve combustion
- Use of catalytic converters to monolithic designs (Smoke Exhaust)



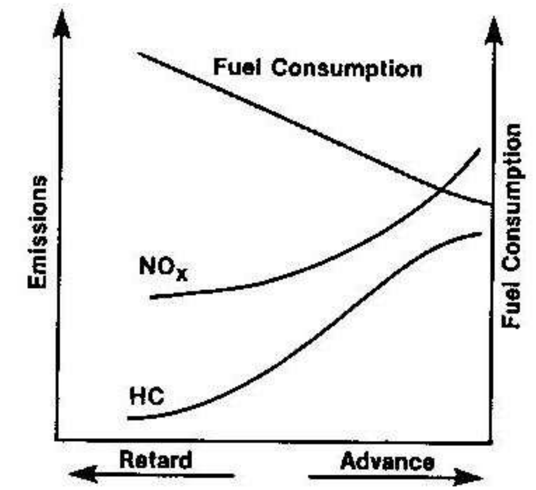
Emissions and emission sources associated with a light-duty motor vehicle.



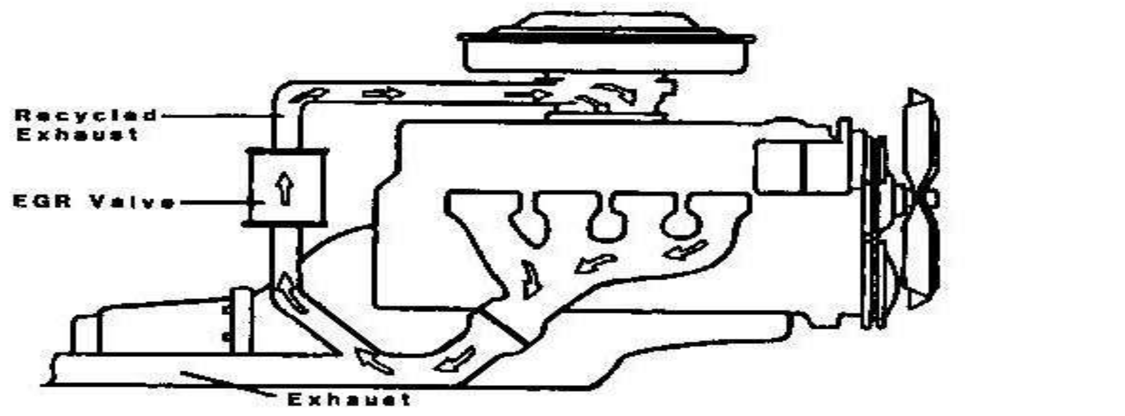
Catalytic converter--monolithic design

Control of NO_x Emission

- Generally more difficult to control, mainly to decrease combustion temperature
  - Retardation of spark (Timing)
  - Decreased compression ratio
  - exhaust has recirculation



The effect of spark timing on NMHC & NO_x emissions and fuel composition.



Application of an exhaust gas recirculation (EGR) system to control emissions of NO_x.

Petrol and Diesel Engine

- Air-fuel ratio: higher ratio for diesel
- Ideal Air-Fuel Ratio is 14.7:1
- Also Known as “Stoichiometric Ratio”

	CO	HC	NO_x	PM
Petrol	High	High	Low	Low
Diesel	Low	Low	High	High

Sources of Emission & Control

- Tall stacks
- Fuel-use changes
- Fugitive emission containment
- Pollution prevention
  - Substitution
  - Process equipment changes
  - Plant operating practices
  - Maintenance
  - Process changes
  - Energy conservation
- "End of the pipe" control

Control Technologies

- **New control technologies**
  - dual and three-way catalytic converter (NO_x ->N_2)
- **Alternative fuels:**
  - Conventional gasoline contains a mixture of paraffinic, and aromatic HC compounds
  - Octane rating: When combustion is too rapid, a sharp metallic noise called knock is produced. Component that reduces the knock has the octane quality.
  - Historically lead alkyls have been added to boost octane ratings.
  - In unlead gasoline, aromatic HCs are added.

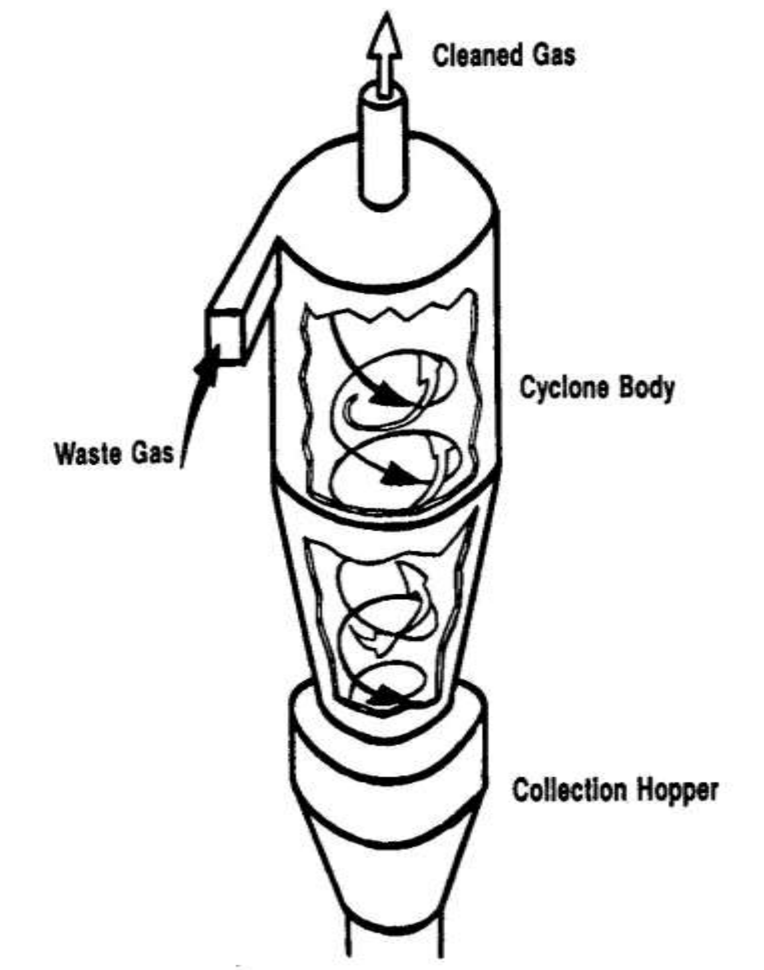
Control Technologies

- **Reformulated gasolines and oxygenated additives**
  - oxygenated additives such as MTBE, ETBE, methanol, ethanol (to boost the octane rating due to reducing aromatics)

- **Compressed and liquefied gases**
  - Natural gas (mainly contains methane)
  - Liquefied petroleum gas (largely propane)
  - limited supply and higher exhaust reactivity

Particle Collection Systems

- **Cyclone collectors**
  - In general, collection efficiency increases with increased particle size and density, dust loading, and collector size.
  - Multiple tubes collectors can be used to increase collection efficiency
  - Cyclones are often used to control relatively large particles, and often are used in series as pre-cleaners for more efficient collectors.

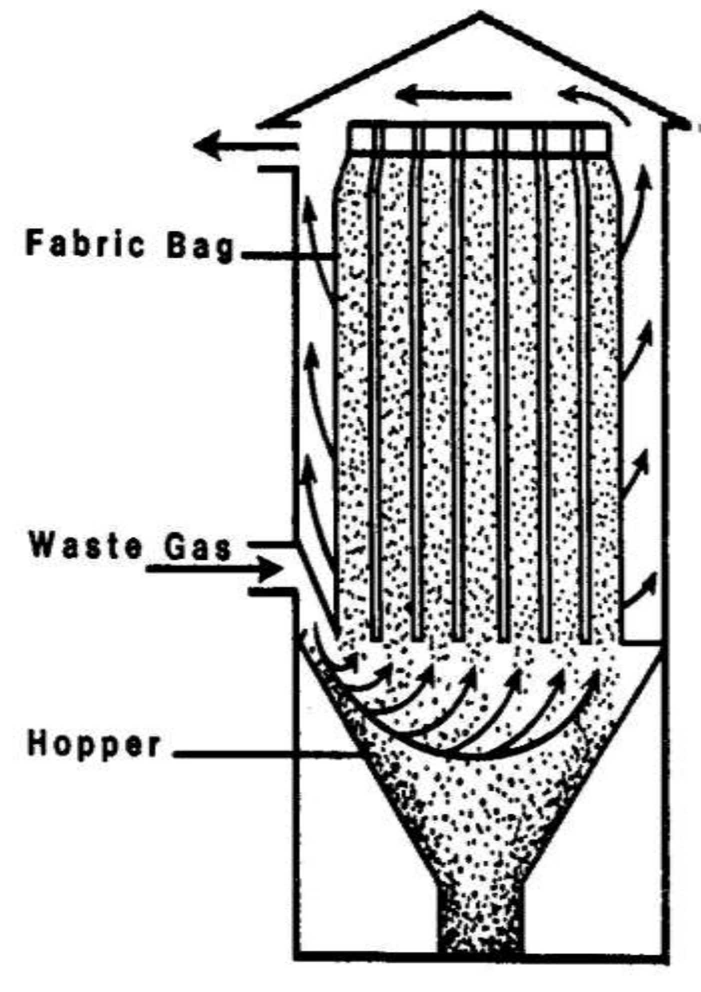


Schematic diagram of a common cyclone particle/dust collector.

Fabric Filters

- Fabric filters are commonly used to control particle emissions where dust loading are higher, particle sizes are small, and high collection efficiencies are needed.

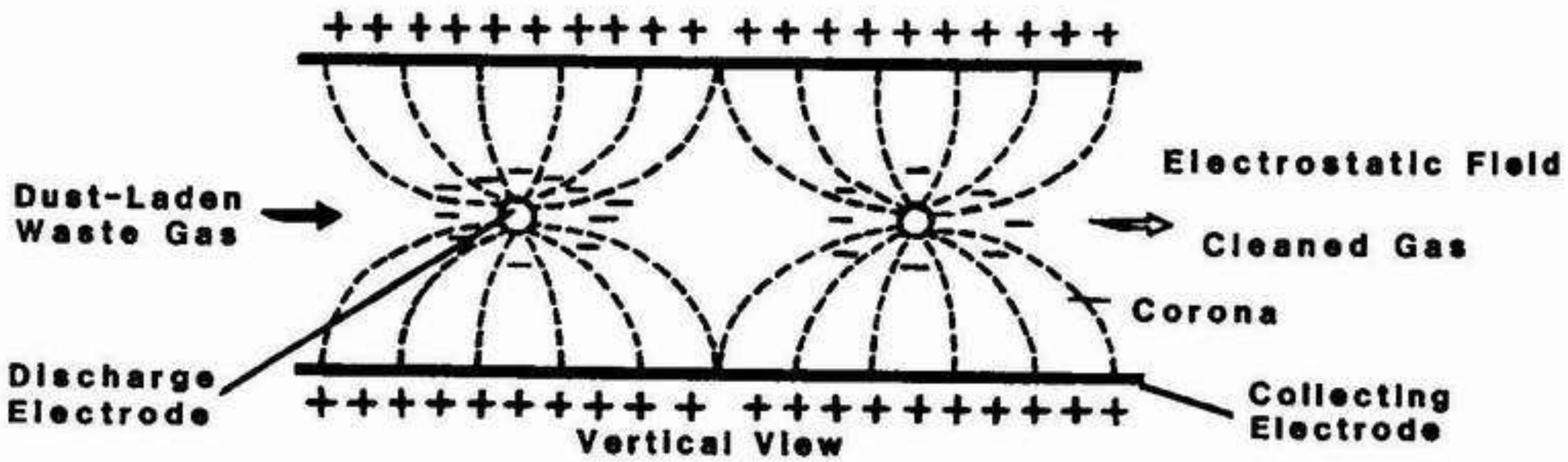
- Limitations include high capital costs, flammability hazards for some dusts, high space requirements, flue gas temperature limited to 285 °C, and sensitivity to gas moisture.



Fabric filter (baghouse) particle/dust collector.

Electrostatic Precipitator

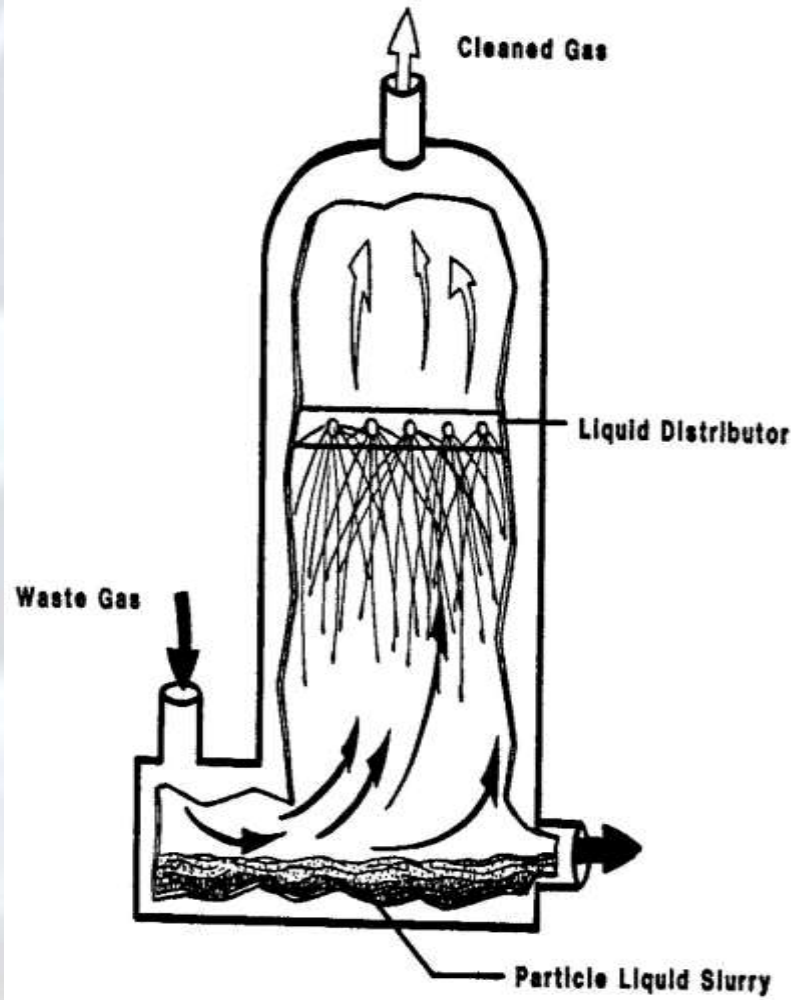
- High collection efficiencies for all particle sizes, low operating and power requirements; But high capital costs and space requirement.



Discharge and collection electrodes of an electrostatic precipitator.

Wet Scrubbers

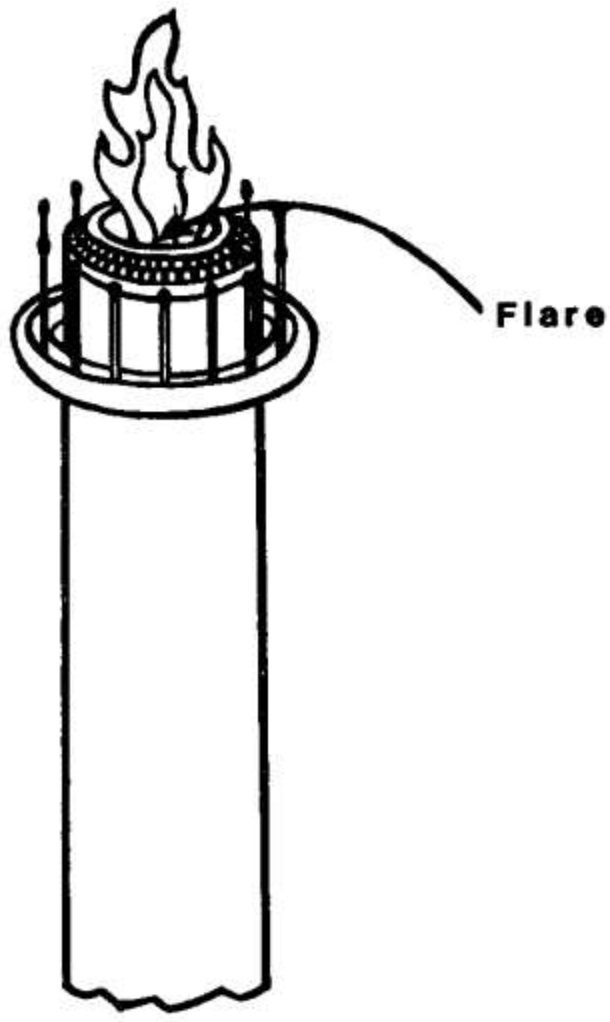
- **Spray Tower**
  - Venturi Scrubber
  - Almost exclusively used to remove fine particles
  - Capital costs are low, but operating costs are high (energy and disposal of waste liquid)



Schematic diagram of an open spray tower particle/dust scrubber.

Control of Gaseous Emissions

- More complex technologically than control of particles. Control techniques for a specific gas pollutant needs to be developed.
  - Combustion
  - Adsorption
  - Absorption

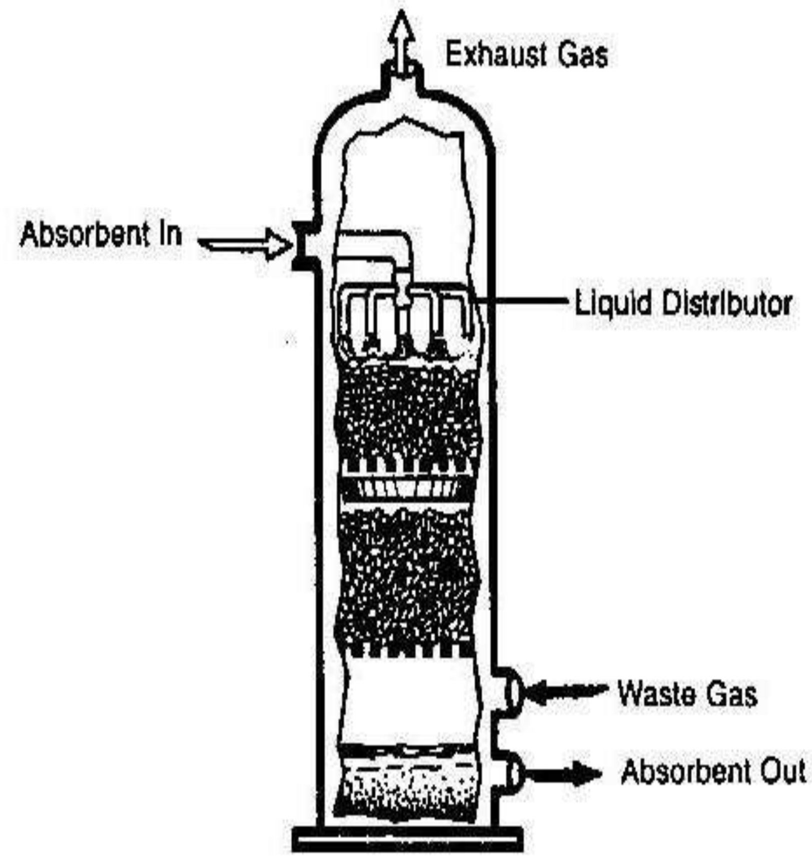


Flare incinerator.

Control of Gaseous Emissions

- **Adsorption**
  - Gas pollutant being adsorbed by the surfaces of solids such as molecular sieve, activated carbons etc

- **Absorption**
  - Absorbed by liquids



Schematic diagram of a fixed-bed packed scrubbing tower.

Indoor air quality (IAQ): Rural and urban perspectives

Why IAQ is Important?

Air is essential for life and we cannot survive more than 2 minutes without air…

…and the quality of air we breathe directly impacts our health & performance

Why IAQ is Important?

It is estimated that we spend about
80-90% of time indoors....

And on an average an office employee spends >8 hours indoors

Indoor Air Quality (IAQ)

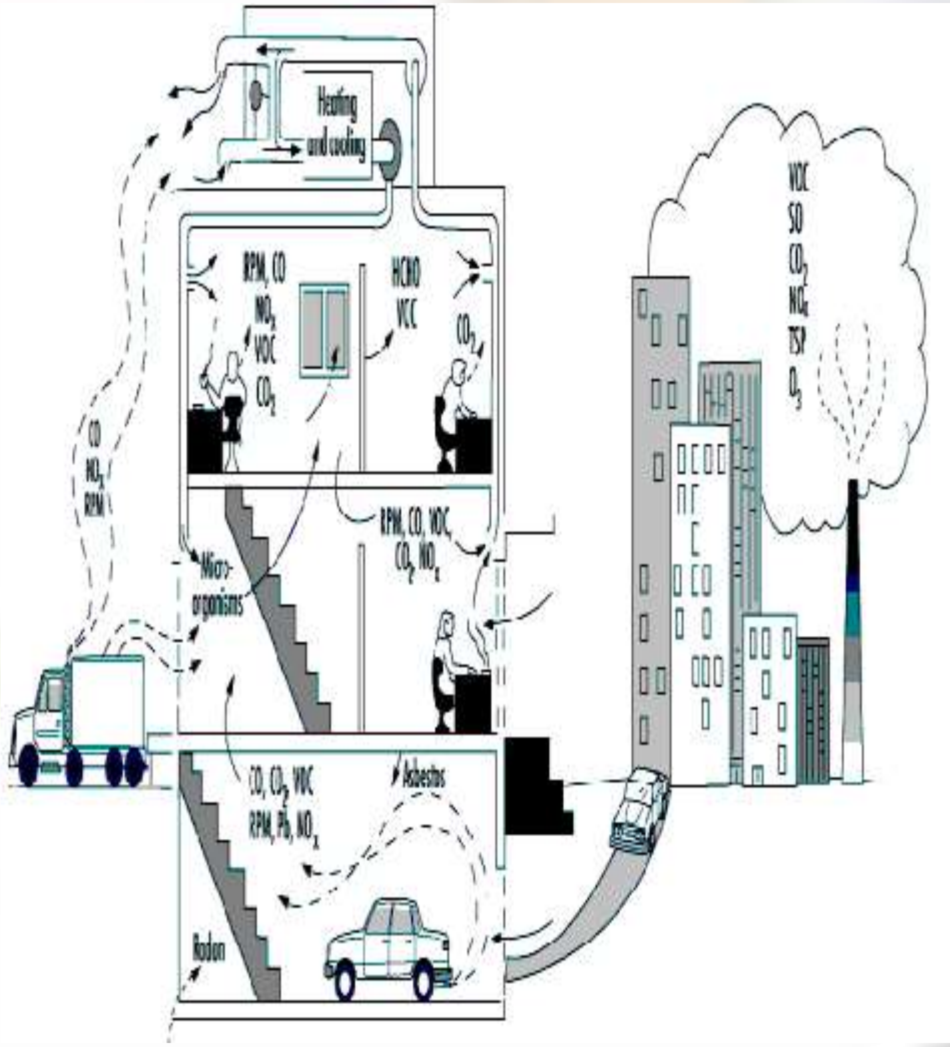
- “Air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants”- EPA
- IAQ can significantly impact the health, productivity and sense of wellbeing of employees at workplace.
- Prolonged exposure to the indoor air pollutants could also lead to Sick Building Syndrome which could result in decrease in productivity.

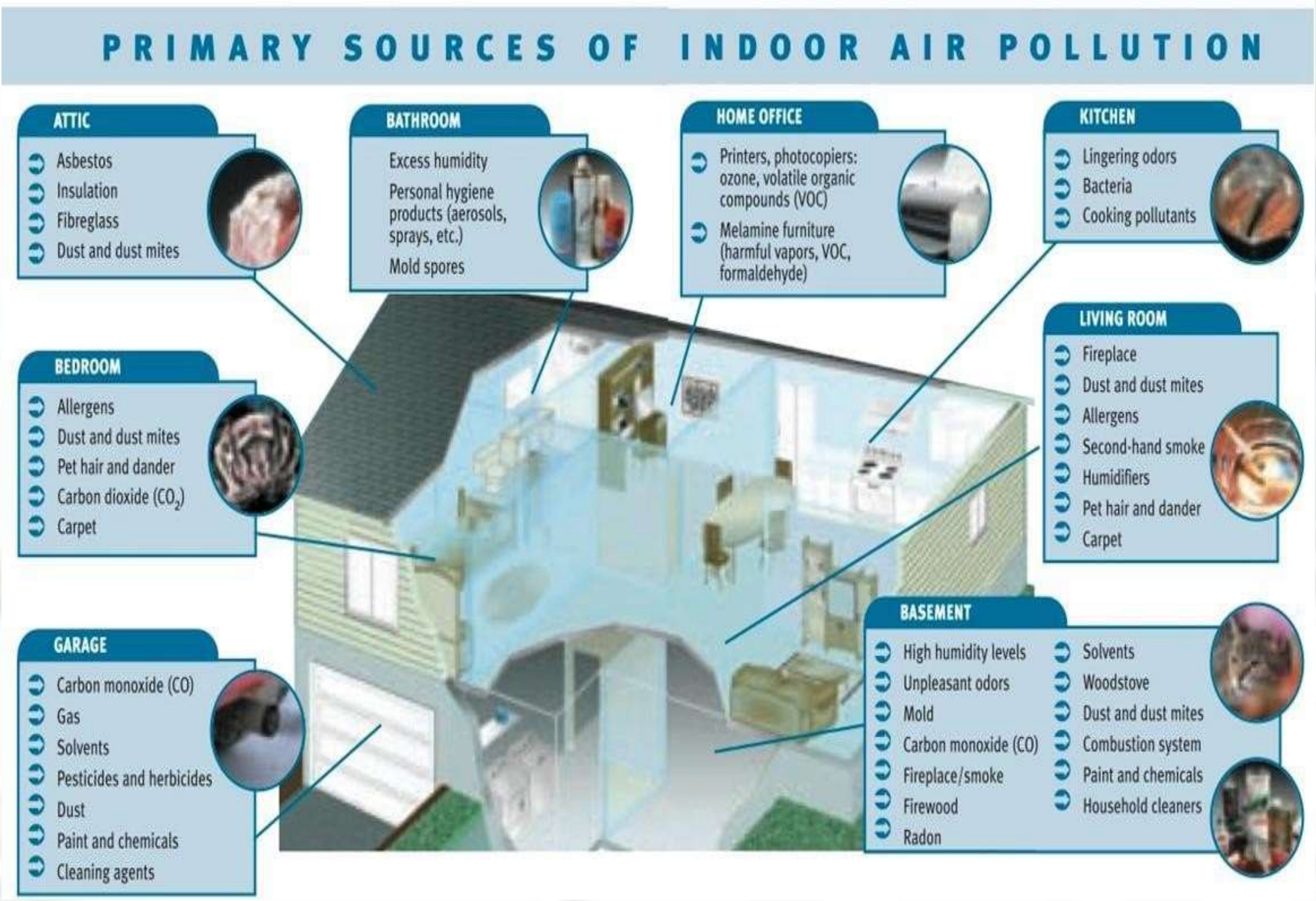
IAQ – an area of concern

- While ambient air quality is slowly attracting attention, Indoor air quality is still ignored.
- US EPA: indoor air pollution poses a greater risk than outdoor air pollution – people spend 80-90% of their time indoors (Yu and Browers, 2013)
- IAQ is directly linked to health of the occupants of a building
- IAQ is an important concern – both rural and urban
- VOCs indoors could be 2 to 5 times higher than outdoors
- IAP is a global issue due to adverse effects on human health (Tsakas, Siskos and Siskos, 2011)
- IAP ranked among the top five environmental health risks to the public by EPA.

Sources of Indoor Pollutants

- Base on Specific Building
- Combustion activity
- Furniture
- Chemical
- Building materials
- Food
- Water
- Smoking activity
- Outdoor air pollution





Source: ww.standardheating.com

Pollutants & Sources

Location	Sources	Pollutant
Offices, government buildings	HVAC systems, carpets, painting & polishing , household cleaners, aerosols, insecticides, pesticides and personal care products	Primary: PM, VOCs Additional : CO, NOx, SO2
Parking areas	Vehicular movement	Primary : PM, CO, NOx, HC Additional : SO2, PAHs,
Public places such as restaurants, hotels, libraries, shopping malls (misc. sources	HVAC systems, carpets, painting & polishing , insecticides, pesticides, smoking, constriction activities	Primary: PM, VOCs, Nicotine Additional : CO, NOx, SO2
Rural households using biomass	Biomass burning for cooking, heating, waste burning. Kerosene burning for lighting,	Primary: PM, CO, BC Additional : VOCs

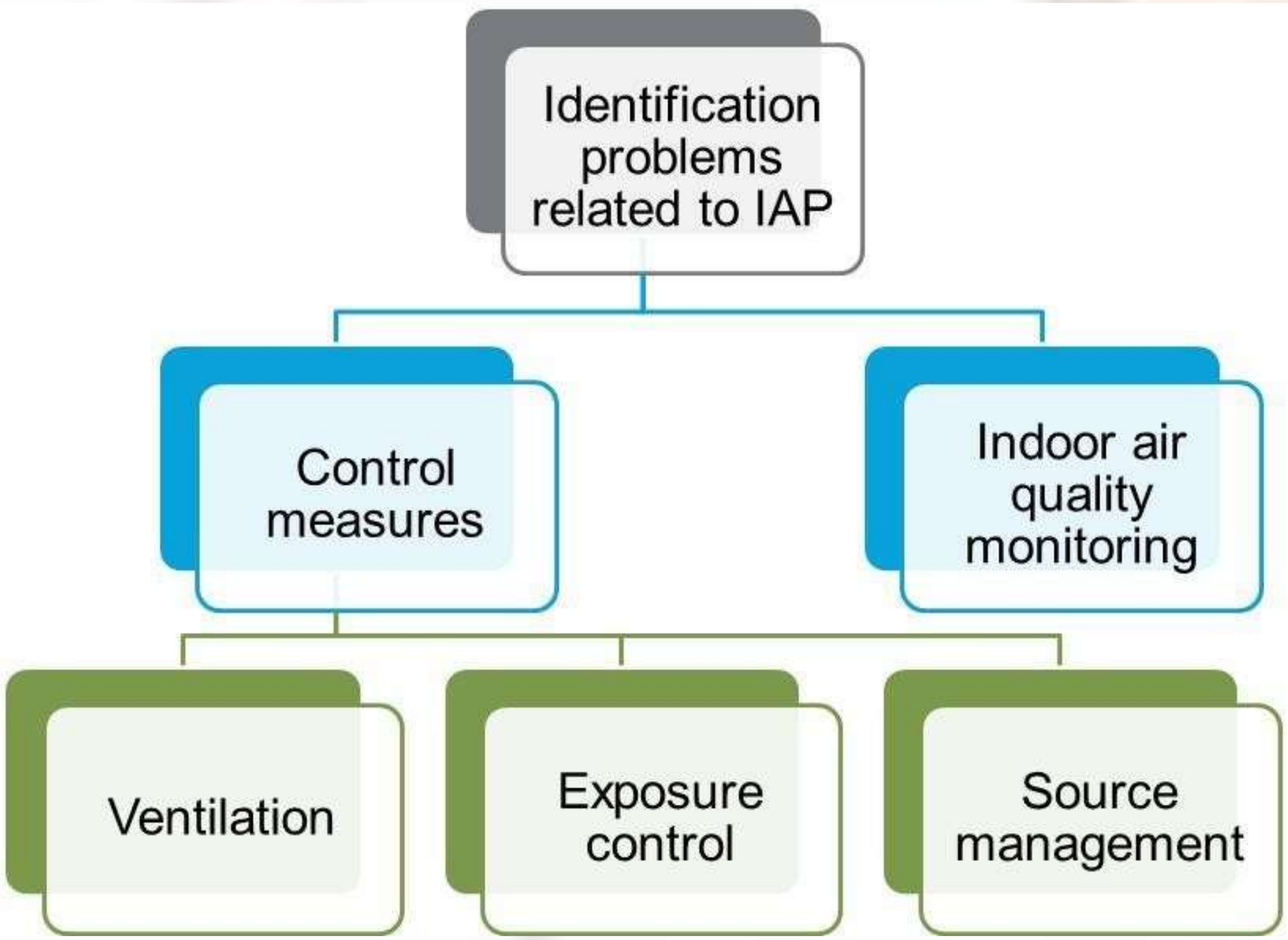
NOx + VOC + Sunlight = OZONE

Other problems of IAQ

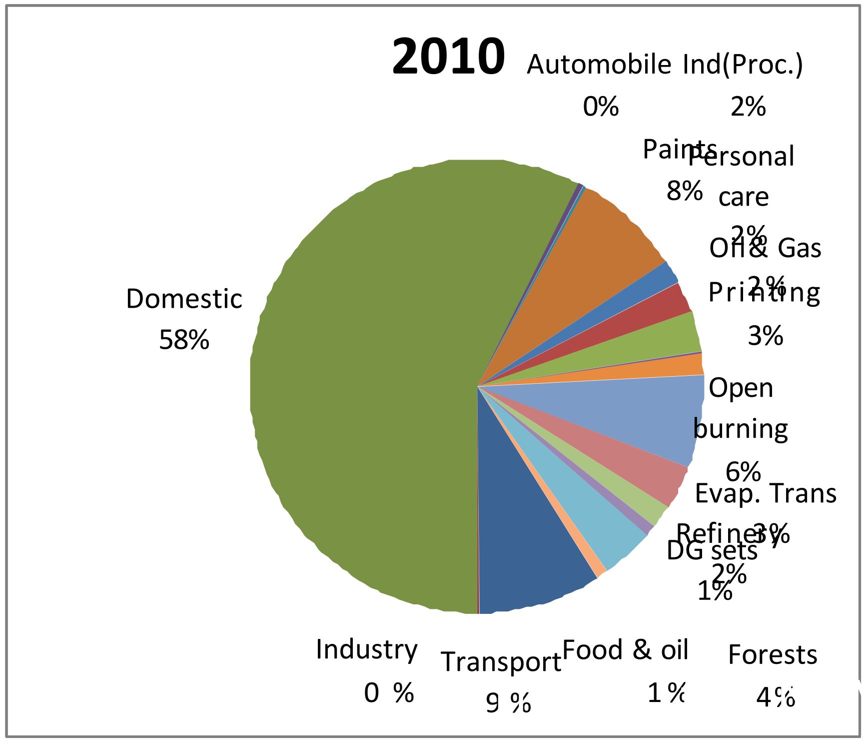
Enclosed space inhabited by humans produce the following effects

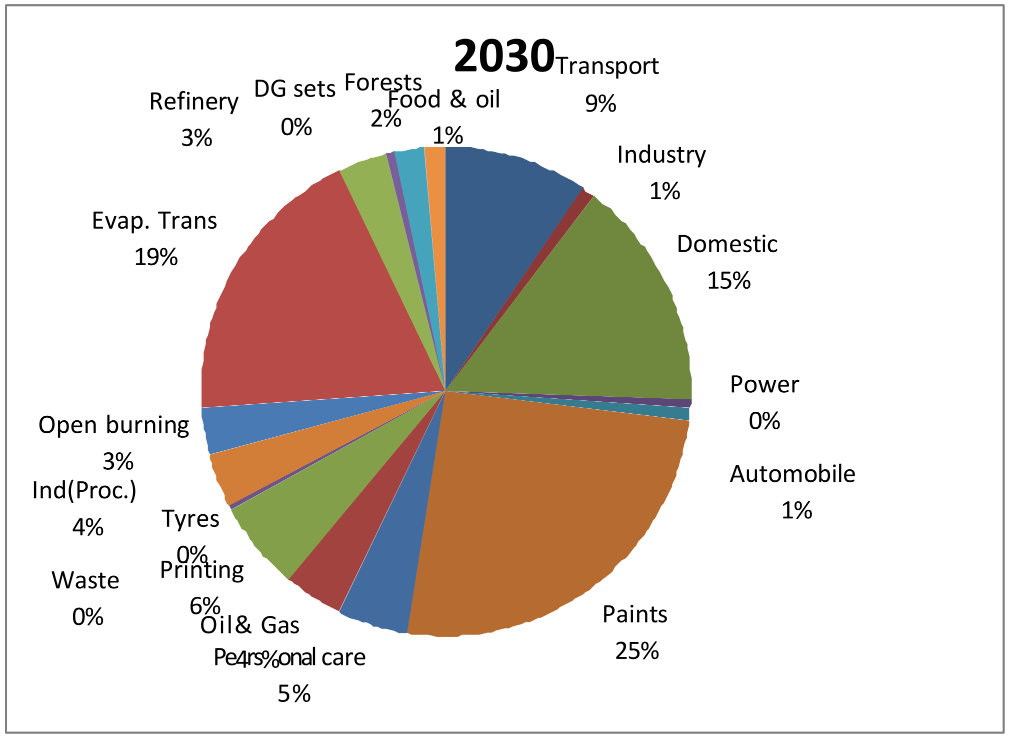
- ↓ Oxygen level or ↑ CO_2 level
- Increase in temperature and humidity
- Increase in bio-aerosol and odor
- Accumulation of air pollutants

Indoor air quality management



NMVOC emissions in India





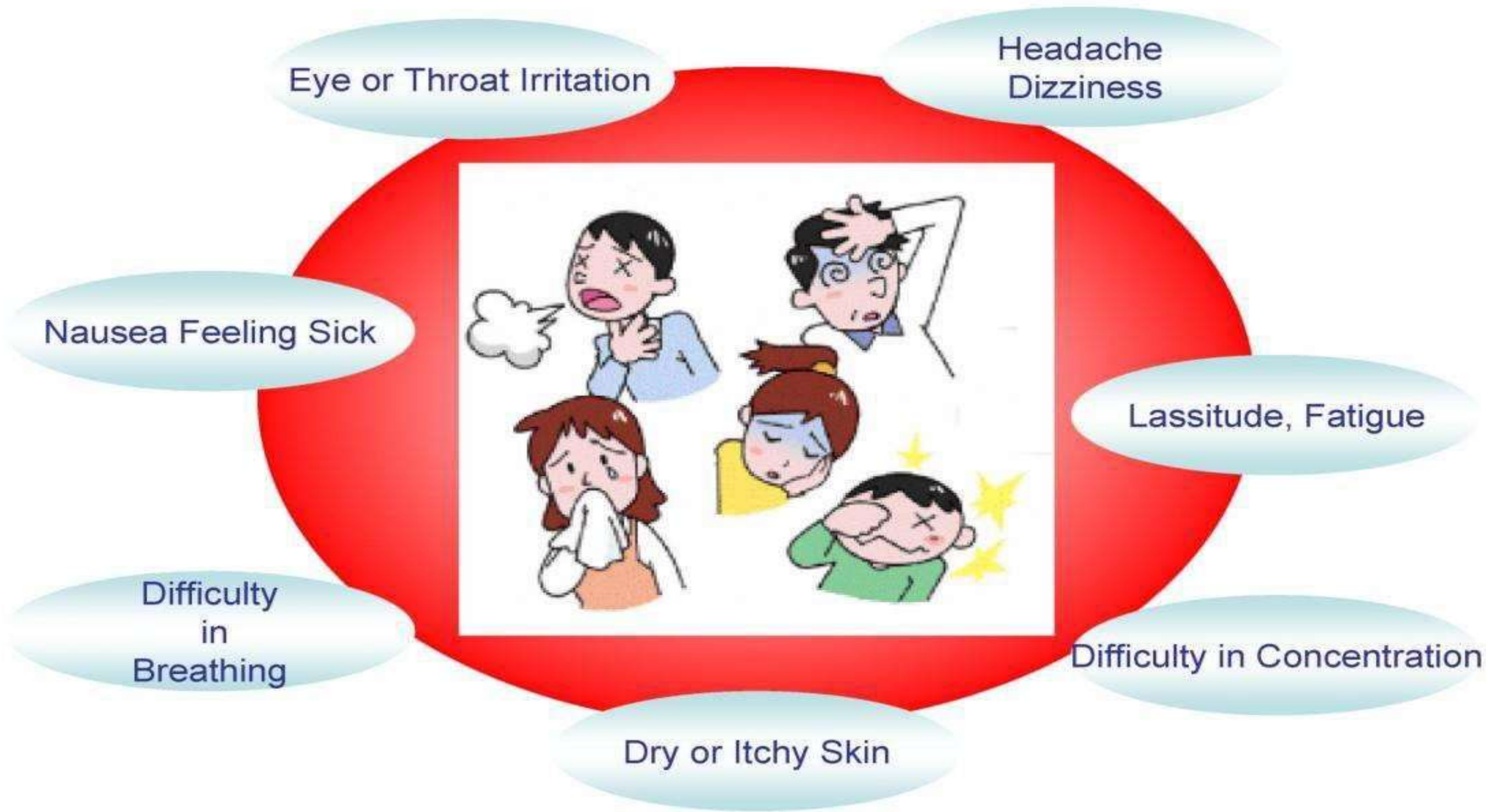
- In next 20 years, the share is about to grow to 25%.
- This has implications over outdoor and indoor air quality.

IAQ – Rural measurements

IAP and health

Pollutant	Health effects
NO_2	Type: Immediate: Causes: irritation to the skin, eyes and throat, cough etc
CO	Type: : Immediate; Causes: headache, shortness of breath, higher conc. May cause sudden deaths.
VOCs	Type: : Immediate; Causes: Liver, kidney disorders, irritation to the eyes, nose and throat, skin rashes and respiratory problems.
RSPM	Type: : Cumulative, Causes: Respiratory Illness (upper and lower), Acute (Asthma) and chronic (COPD), Lung cancer,
Pesticides	Type: : Immediate; Causes: Skin diseases
SO_2	Type: : Immediate; Causes: lung disorders and shortness of breath
Asbestos	Type: : Cumulative; Causes: Lung cancer
O_3	Type: : Immediate; Causes: eyes itch, burn, respiratory disorders, lowers our resistance to colds and pneumonia.

Symptoms of SBS



Effect of temperature, RH and CO2

Temperature

- direct impact on **perceived comfort** and, **concentration** and **productivity**
- As per **ASHRAE Standard 55**, recommended temperature ranges termed "**comfortable**" are 22.8 to 26.1°C in the summer and 20.0 to 23.6°C in the winter.

Relative humidity

- Too high RH can contribute to the growth and spread of biological contaminants
- RH below 25% – increased discomfort and drying of skin and mucous membrane
- As per **ASHRAE Standard 55**, indoor humidity levels to be maintained between **30 - 65 percent** for **optimum comfort.**

CO_2

- Provides good indication of ventilation rates
- Generated in indoor primarily through human metabolism
- CO_2 build up in indoor is attributed to in-efficient or non-functioning of ventilation system
- As per ASHRAE, above 1000ppm CO_2 - requires adjustment of building's ventilation system
- Building shows SBS symptoms if CO_2 concentration > 1000 ppm

Summary of guidelines

Parameter	WHO guideline value*	ASHRAE**	OSHA***	NAAQS/EPA (2000)****
PM_{10}	50µg/m³ (24-hr mean)	--	15mg/m³ (total)	150µg/m³ (24-hr)
$PM_{2.5}$	25µg/m³ (24-hr mean)	--	5mg/m³(resp.)	65µg/m³ (24-hr)
SO_2	20µg/m³ (24-hr mean)	--	5ppm (8-hr)	140ppb (24-hr) 75ppb (1-yr)
NO_2	200µg/m³ (1-hr) 40µg/m³(annual mean)	--	5ppm (8-hr)	53ppb (annual) 100ppb (1-hr)
CO	10ppm (8-hr)	9ppm (8-hr)	50ppm (8-hr)	9ppm (8-hr)
CO_2	--	1000ppm (8-hr)	5000ppm	
Humidity	--	30% - 65%	--	
Temperature	--	68˚F - 74.5˚F (20-23.6°C)(winter) 73˚F - 79F˚ 22.8-26.1°C)(summer)	--	

WHO – World Health Organisation (Same as CPCB)

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers

OSHA – Occupational Safety and Health Administration

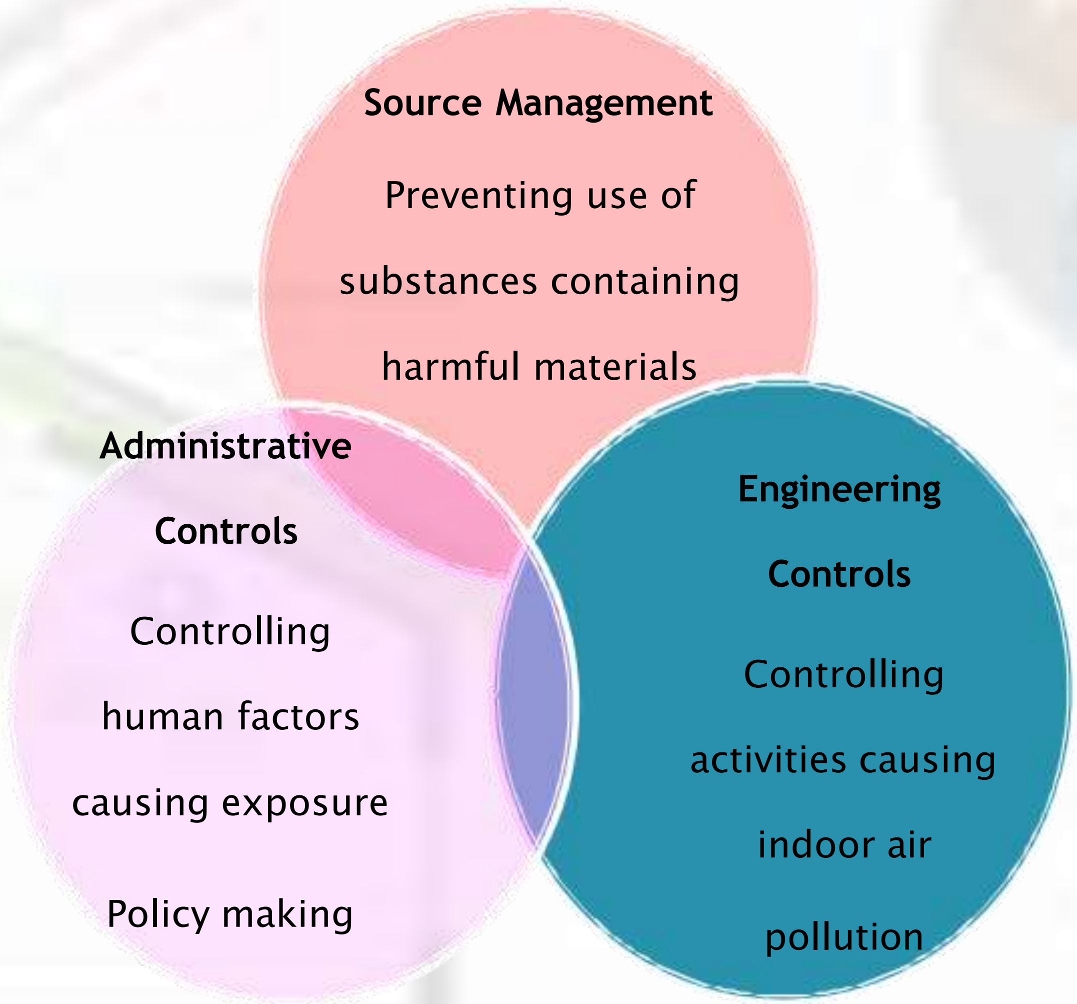
NAAQS/EPA - National Ambient Air Quality Standards/Environmental Protection Agency

Comparison of Regulations & Guidelines Pertinent to Indoor Environments

	Enforceable and/or Regulatory Levels			Non-Enforced Guidelines and Reference Levels			
	NAAQS/EPA (Ref. B-4)	OSHA (Ref. B-5)	MAK (Ref. B-2)	Canadian (Ref. B-8)	WHO/Europe (Ref. B-11)	NIOSH (Ref. B-13)	ACGIH (Ref. B-1)
Carbon dioxide		5,000 ppm	5,000 ppm 10,000 ppm [1 h]	3,500 ppm [L]		5,000 ppm 30,000 ppm [15 min]	5,000 ppm 30,000 ppm [15 min]
Carbon monoxide [c]	9 ppm [g] 35 ppm [1 h] [g]	50 ppm	30 ppm 60 ppm [30 min]	11 ppm [8 h] 25 ppm [1 h]	90 ppm [15 min] 50 ppm [30 min] 25 ppm [1 h] 10 ppm [8 h]	35 ppm 200 ppm [C]	25 ppm
Formaldehyde[h]		0.75 ppm 2 ppm [15 min]	0.3 ppm 1 ppm[i]	0.1 ppm [L] 0.05 ppm [L] [b]	0.1 mg/m^3 (0.081 ppm) [30 min][p]	0.016 ppm 0.1 ppm [15 min]	0.3 ppm [C]
Lead	1.5 µg/m^3 [3 months]	0.05 mg/m^3	0.1 mg/m^3 1 mg/m^3 [30 min]	Minimize exposure	0.5 µg/m^3 [1 yr]	0.1 mg/m^3 [10 h]	0.05 mg/m^3
Nitrogen dioxide	0.05 ppm [1 yr]	5 ppm [C]	5 ppm 10 ppm [5 min]	0.05 ppm 0.25 ppm [1 h]	0.1 ppm[1 h] 0.004 ppm [1 yr]	1 ppm [15 min]	3 ppm 5 ppm [15 min]
Ozone	0.12 ppm [1 h][g] 0.08 ppm	0.1 ppm	j	0.12 ppm [1 h]	0.064 ppm (120 µg/m^3) [8 h]	0.1 ppm [C]	0.05 ppm[k] 0.08 ppm[l] 0.1 ppm[m] 0.2 ppm[n]
Particles[e] <2.5 µm MMAD[d]	15 µg/m^3[1 yr][o] 65 µg/m^3 [24 h][o]	5 mg/m^3	1.5 mg/m^3 for <4 µm	0.1 mg/m^3 [1 h] 0.040 mg/m^3 [L]			3 mg/m^3
Particles[e]<10 µm MMAD[d]	50 µg/m^3[1 yr][o] 150 µg/m^3 [24 h][o]		4 mg/m^3				10 mg/m^3
Radon	See Table B-2[f]				2.7 pCi/L [1yr]		
Sulfur dioxide	0.03 ppm [1 yr] 0.14 ppm [24 h] [g]	5 ppm	0.5 ppm 1 ppm [i]	0.38 ppm [5 min] 0.019 ppm	0.048 ppm [24 h] 0.012 ppm [1 yr]	2 ppm 5 ppm [15 min]	2 ppm 5 ppm [15 min]
Total Particles[e]		15mg/m^3					

***Unless otherwise specified, values re given in parts per million (ppm)**
***Where no time is specified, the averagingis eight hours.**

Mitigation strategies



1. Source management

- Lot of indoor air pollutants directly linked to items of daily use
  - Cleaning items (low VOC products)
  - Fuels and cook-stoves (Clean fuels)
  - Building materials and furnishings (low VOC products)

- Building occupants may be the source of pollutants - perfumes or colognes, cigarette smoke (OSHA, 2011)

2. Administrative controls

Work schedules	• Eliminate or reduce the amount of time a worker is exposed to a pollutant • Reduce the amount of chemicals being used by or near workers • Control the location of chemical use
Education and Awareness	• Inform about the sources and effects of pollutants • Inform about proper operation of ventilation system • Awareness about clean alternatives, mitigation solutions
Housekeeping	• Prevent dirt from entering the environment • Dispose garbage timely • Store food properly • Choose cleaning products, methods that minimize introduction of pollutants into the building

3. Engineering controls

- HVAC (heating, ventilation, and air conditioning systems) control and management
- IAQ improving plants
- Air purifiers

Indoor plants

Pollutants	µg/h of pollutants removed
Benzene	579 (English ivy) – 4486 (Barberton daisy)
Formaldehyde	183 (Chinese evergreen) – 3196 (Bamboo palm)
Trichloro ethylene	298 (English Ivy) – 1622 (Barberton Daisy)

Plants are

- **effective in removing VOCs**
- **Reduce microbes and molds**
- **Increase humidity**

Recommended indoor plants

Sr No.	Common Name	Scientific name	↓ Pollutant	Watering	Shade	Planting Practice
1	Snake Plant	*Sansevieria trifasciata*	• CO_2 • Formaldehyde • Nitrogen dioxide	Do not water them too much, especially during the winter	Minimal light	6 days indoors 1 Day in bright sunlight
2	Areca palm	*Dypsis lutescens*	• CO_2	Water until the soil is evenly moist	Partial shade (low-light conditions)	4 days indoor 1 Day in bright sunlight
3	Aloe vera	*Aloe vera*	• CO_2 • Formaldehyde • Benzene	Water until the soil is evenly moist	Bright light	2 days indoor 1 Day in bright sunlight
4	Money plant	*Epipremnum aureum*	• Volatile Organic Compounds (VOC)	Once in 4-5 days	Partial sunlight	4 days indoor 1 Day in bright sunlight
5	Dragon Tree	*Dracaena marginata*	• Benzene, Formaldehyde, Toluene • Xylene	Allow the plants to dry between watering	Bright light	2 days indoor 1 Day in bright sunlight
6	Peace lily	*Spathiphyllum wallisii*	• Benzene, Formaldehyde, Toluene • Xylene	Water until the soil is evenly moist	Part shade to full shade	4 days indoor 1 Day in bright sunlight

Recommended indoor plants

Sr No.	Common Name	Scientific name	↓ Pollutant	Watering	Shade	Planting Practice
7	Flamingo flower	Anthurium andraeanum	• Benzene • Formaldehyde • Toluene • Xylene	Should not be kept continuously moist.	Partial Sun	4 days indoor 1 Day in bright sunlight
8	Common ivy	Hedera helix	• Benzene • Formaldehyde • Toluene • Xylene	Water until the soil is evenly moist	Full Sun to partial shade	4 days indoor 1 Day in bright sunlight
9	Red ivy	Hemigraphis alternata	• Benzene • Formaldehyde • Toluene • Xylene	Water until the soil is evenly moist	Bright indirect sun to Part shade	2 days indoor 1 Day in bright sunlight
10	Rubber plant	Ficus robusta	• CO2 • Eliminates bacteria and mold spores • formaldehyde	Once the soil becomes slightly dry to touch	Bright indirect sunlight	2 days indoor 1 Day in bright sunlight