Environmental Engineering

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Environment

Definition of Environment

- Environment defined as the sum total of water, air, and land and interrelationships that exist among them and also with the human beings, other living organisms and materials. Environment includes all the physical, chemical, biological and conditions that surround and affect organisms during lifetime.

Environmental engineering is the integration of science and engineering principle to:

Improve	Provide	Clean up
Improve the environment	Provide healthy water, air, and land for human habitation and for other organisms	Clean up pollution sites

Pollution

Definition of Pollution

- Pollution is the introduction of contaminants substance (gas, liquid, solid, or mix) or energy (heat, light, noise, or radiation) into environment that cause damage and undesirable change in the physical, chemical, biological characteristics of the air, water, or land which then affect the health, survival or activities of human and other living organisms.
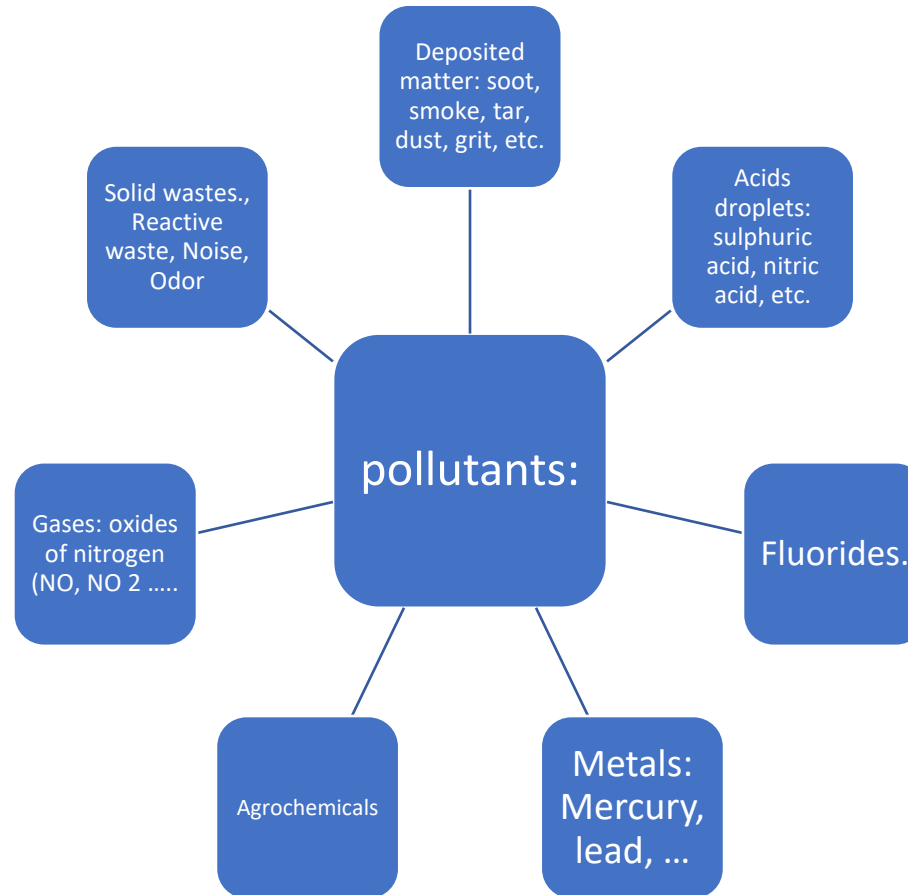
Pollutants

- A pollutant is any substance that causes pollution. Pollutants may be chemical, biological, thermal, radioactive or even mechanical (dust, sediment, grit, etc.). A pollutant has also been defined as any solid, liquid, or gaseous substance present in such concentration or energy as may be or tend to be injurious to the environment. These pollutants may be introduced into environment naturally or by human activity

Various air, water, land pollutants:

Kind of pollutants:

Pollutants can be classified into two basic types:

Pollutants can be classified into the:

Non-degradable pollutants:

- Those that either not degrade into simple or degrade only very slowly in nature and harmless substances. Some of these pollutants accumulate in the living organisms. Such as plastics, polyethylene, bags, insecticides, pesticides, mercury, lead, arsenic, heavy metals, synthetic fiber, glass objects, iron products and silver foil are non-biodegradable pollutants.

Biodegradable pollutants

- Those pollutants can be harmless substances in nature and can be broken down into simpler in due course of time by the action of micro-organisms like certain bacteria. They may great problems when they accumulate. Domestic waste (garbage), urine, faecal matter, sewage, agriculture residues, paper, wood, cloth, cattle, animal bones, leather, wool, vegetable stuff or plants are biodegradable pollutants

Forms of pollution

Air pollution.

• Air pollution is the release of chemicals and particulates into the atmosphere.

• Common gaseous pollutants included carbon monoxide, sulfur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxide produced by industry and motor vehicles. Photochemical ozone and smog crated by nitrogen oxide and hydrocarbons react to sunlight.

Water pollution.

Water pollution cause by:

- 1- Discharge of wastewater from commercial and industrial waste (intentionally
- or through spills) into surface water.
- 2-ischarges of untreated domestic sewage and chemical contaminants such as
- chlorine from treated sewage.
- 3- Release of waste and contaminants into surface runoff flowing to surface waters (including urban runoff and agricultural runoff, which may contain chemical fertilizers and pesticides).
- 4- Waste disposal and leaching into groundwater, eutrophication, and littering.

Soil pollution.

- Soil pollution occurs when chemicals are released by spill or underground leakage. The most soil pollutants are hydrocarbons, heavy metals, herbicides, pesticides and chlorinated hydrocarbons.

4 Marin pollution.

- Marin pollution occurs when polluted material entering the sea or ocean. These pollutants include most nutrients, sediments, pesticides, heavy metals, pathogens, and thermal pollution. The pollutants come from land-based sources, such as sewage, forestry, farming activities, industrial discharges, mining and landfill sites oil. 50% of oil pollution of the marine environment comes from land as runoff from cars, heavy machinery, industry and other land-based sources. Shipping of crude oil, oil spills resulting from accidents.

Noise pollution.

- Noise pollution is the disturbing or excessive noise that may harm the activity or balance of human or animal life. two type of noise:

1-The outdoor noise: the source of most outdoor noise worldwide is mainly cause by machines and transportation systems, motor vehicles, aircraft, and trains. The outdoor summarized by the environmental noise.

2-The indoor noise: this can cause by machines, building activities, and music performances, especially in some workplaces.

Radioactive contaminants.

- Radioactive pollution is the release the radioactive waste into the environment. This radioactive material emitted radiation. This radiation causing abnormal growth and possibly cancer, and this radiation remain in the atmosphere for years, slowly diminishing over time. The sources of radioactive pollution are the major sources of the radioactive wastes that are generated and are responsible for radioactive pollution are as follows:

- (a) Uranium mining

- (b) Production of nuclear fuel

- (c) Nuclear power reactors

- (d) Use of radioactive isotope in industries for various applications

- (e) Nuclear tests

- (f) Disposal of nuclear waste.

Water and Wastewater treatment

Water

- Water is the most abundant chemical component in the biosphere. It is important to all life on the earth including human life.

Source of Water

Main Sources of Water

Ground water

- Water : is the water that has percolated downward from the ground surface through the soil pores. Water is normally withdrawn from these reservoirs by well.

Surface water: All water on the surface of the Earth including lakes, ponds, rivers, streams and rainfall water.

Sea water

- it is a valuable in unlimited quantities. This can be converted into fresh water by a number of processes.

Reclaimed wastewater:

- is the water that has been treated sufficiently for direct reuse in industry and agriculture and for limited municipal application.

Utilization of water

Irrigation
- the amount of water required for irrigation purpose various with cli-mate of region and the type of crops that are raised.

Domestic water supply
- the requirements vary from season to season and fromrural to urban areas.

Power generation
- cooling is principal water use in thermal power generation and more than 99% of water used are required for condenser cooling.

Industrial water use
- industry is much dependent on adequate water supply. The enormous demand of industry for water is obvious such as H_2SO_4 production, oil refinery, milk products, etc.

Types of water pollutants and their effects

Oxygen demanding wastes:-

- Biological waste like food waste, dead plant, and animal tissue that consumed oxygen dissolved in water during its degradation by bacteria, thus oxygen required for survival of fish, other marine animals, and marine plants.

Pathogens:

- Pathogens are a disease-causing agents. Water is a potential carrier of pathogenic microorganisms. These pathogens are carried into the water bodies by sewage and waste from farms and various industries.

Types of water pollutants and their effects

Refractory organic compounds:
- These include pesticides, herbicides, phenols, synthetic organic chemical and detergents. These compounds in contrast to the organic waste are not biodegradable and may persist for a long periods.

Nutrients:
- Nutrients are the chemical material required to growth of aquatic life, Such as nitrogen and phosphorus.

Inorganic chemical:
- These include inorganic salts, mineral acids, and heavy metal compounds. Most of these are toxic and are capable of killing living organisms in the water bodies.

Sediments:
- These include soil, sand, and mineral particles or pulverized coal ash. Their effects increasing turbidity and consequently of reducing the amount of sunlight available to water plants

Types of water pollutants and their effects

Oils:

Oils are important commodity and virtual for every human activity now. Oil wastes enter rivers and other water bodies from several sources like industrialeffluents, oil refineries, storage tank, automobile waste oil, and petrochemical plants.

Radioactive substances:

Radioactive substances include radioactive material and radioactive waste .

Thermal pollution:

Power plant and industry use large quantities of water for cooling purpose.

Oxygen demanding waste

Dissolved oxygen is essential for sustaining the plant and animal life in any aquatic system. There are four processes which actually affected the DO content:
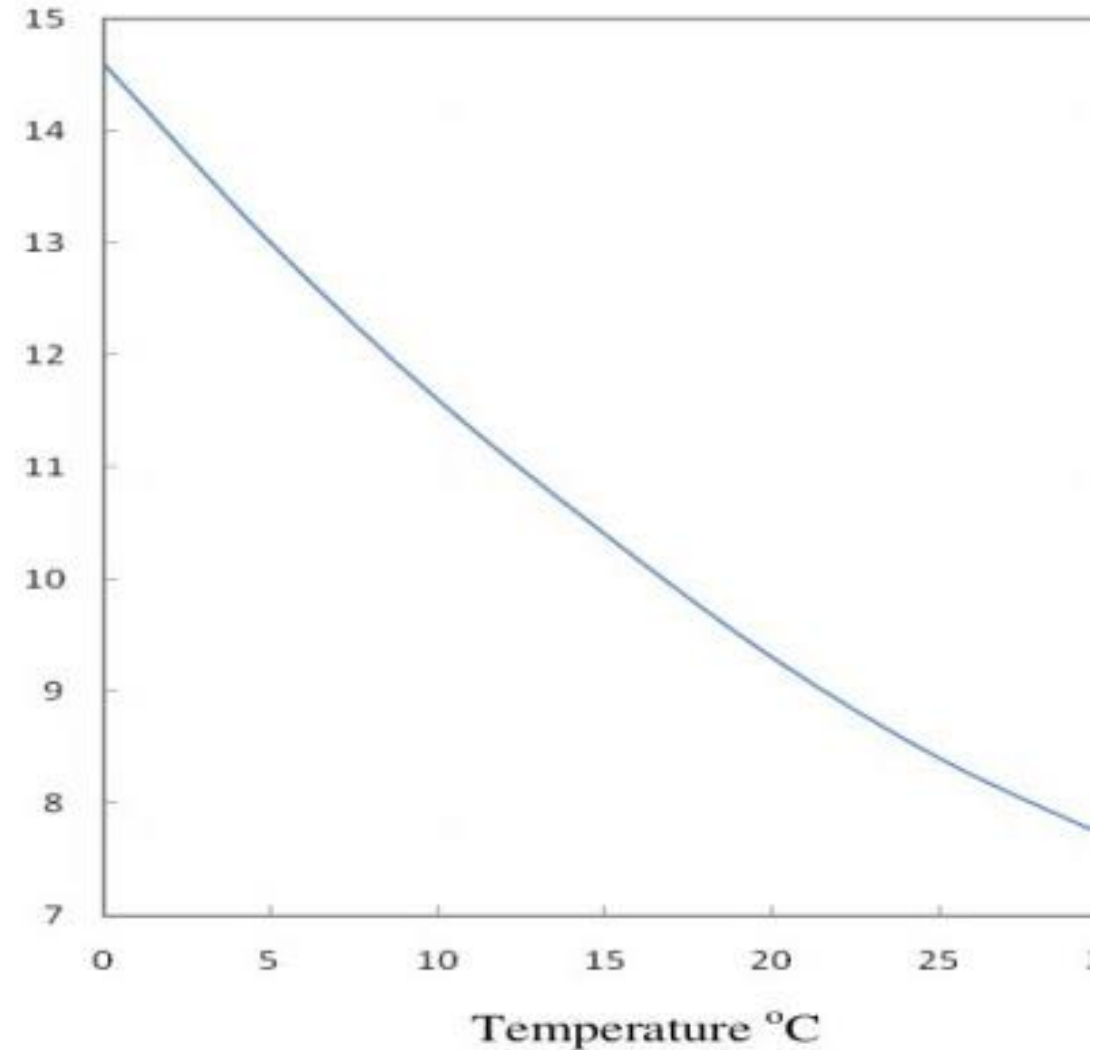
Reaeration

Photosynthesis

Respiration

Oxidation

Reaeration

- Reaeration is the process by which oxygen transfer takes place form atmosphere to water. The solubility of oxygen in fresh water at saturation point decreases with an increase in temperature, see Figure 2.1.
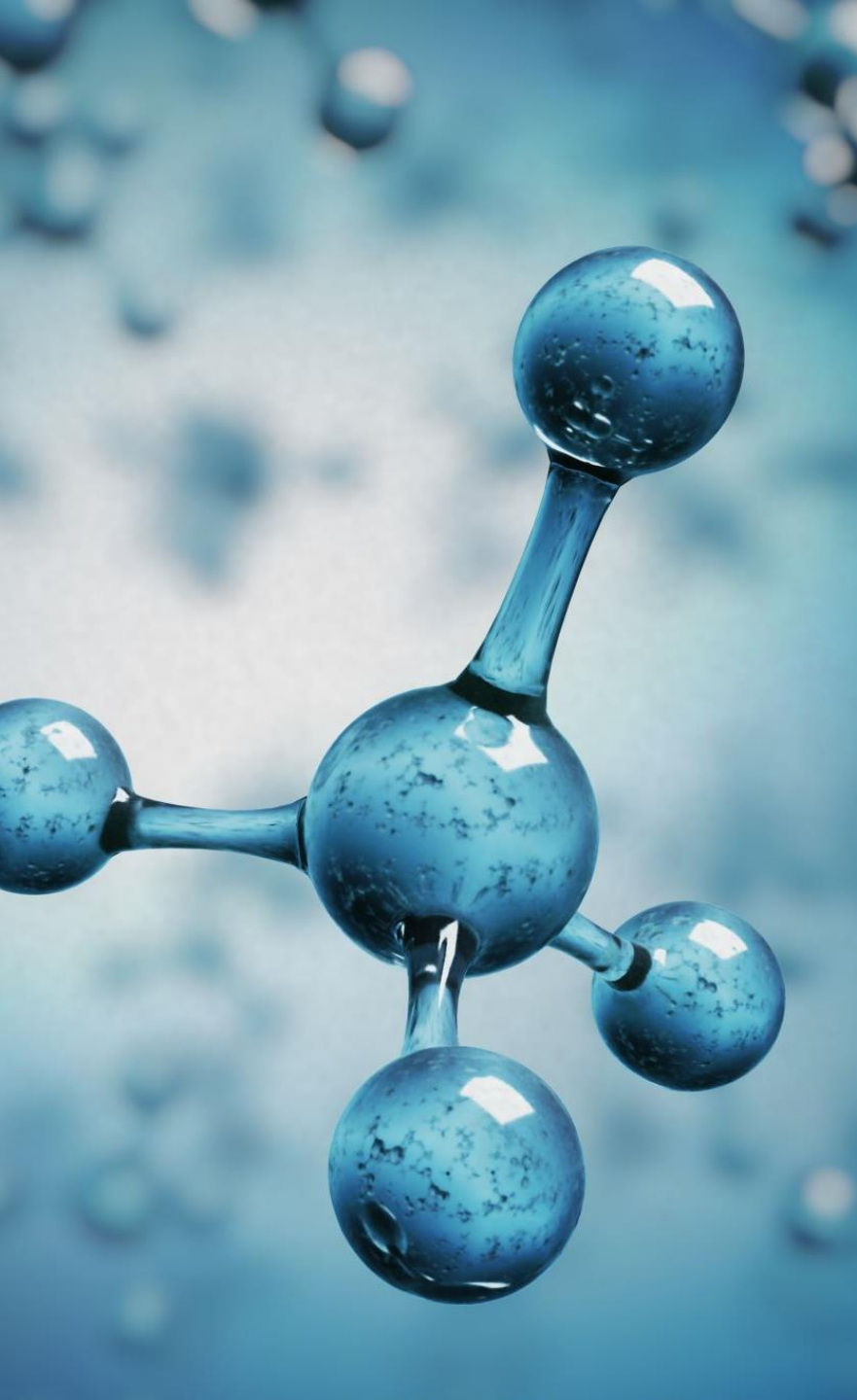
The rate of oxygen transfer (or rate of reaeration) depends on:

The rate of absorption through the air-water interface.

The rate of dispersion within the body of water near the surface.

Reaeration

• Since the solubility of oxygen in water is very low, the main resistance to mass transfer is on the liquid side of the interface so that the absorption is liquid-film controlled. The rate of oxygen transfer across unit area of surface in unit time, N, so that:

$$N = k_L(C_S - C_L)$$

where:

N= Oxygen transfer rate, $kg \cdot m^{-2} \cdot s^{-1}$

C_S= Saturation concentration of dissolved oxygen in water, $mg \cdot l^{-1}$

C_L= Actual concentration of dissolved oxygen in water, $mg \cdot l^{-1}$

If the oxygen is transferred into a volume of water, V, having a total interfacial area, A, in contact with the gas phase, then the rate of oxygen transfer per unit volume of water is given by:

$$\frac{dC_L}{dt} = K_L \frac{N_A}{V}(C_S - C_L) = r(C_S - C_L)$$

$\frac{dC_L}{dt} =$ Oxygen transfer rate, $kg \cdot m^{-2} \cdot s^{-1}$

$K_L \frac{A}{V} =$ Reaeration or reoxygenation rate constant, 1/day

$(CSCL) =$ The deference between the saturation concentration of DO and the actual concentration of DO presented in water.

This deference $(C_S - C_L)$ is often referred as the oxygen deficit, D:

$$D = C_S - C_L$$

$C_S - C_L$

Photosynthesis

- Photosynthesis requires solar energy radiation. During the process, the green plants such as algae utilize carbon dioxide and the inorganic nutrient in the water to synthesis organic materials and liberate oxygen. Since the process occurs only during the present of sun-light, the DO level in the water increases during the day.

Respiration

- At night the algae and the micro-organisms compete with each other for both dissolved oxygen and organic compounds (See Figure 2.2). This bacterial respiration is responsible for the production of carbon dioxide and subsequent depletion of dissolved oxygen
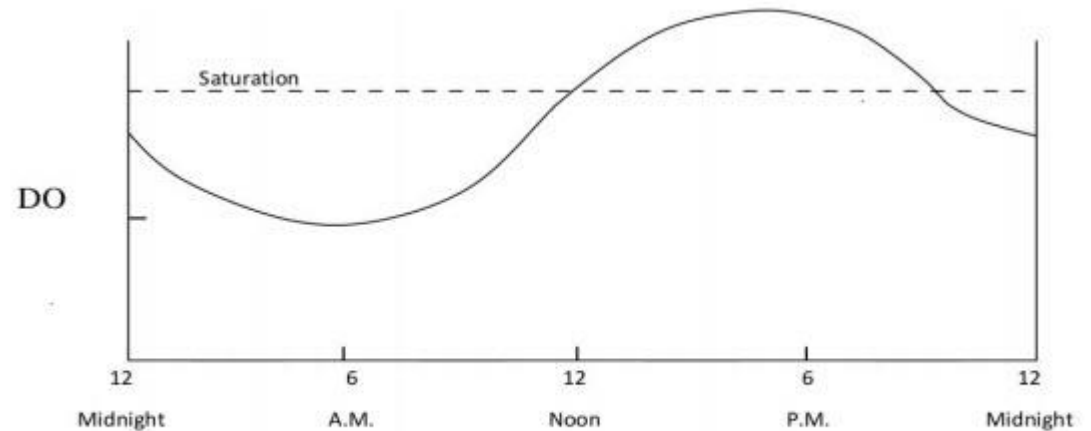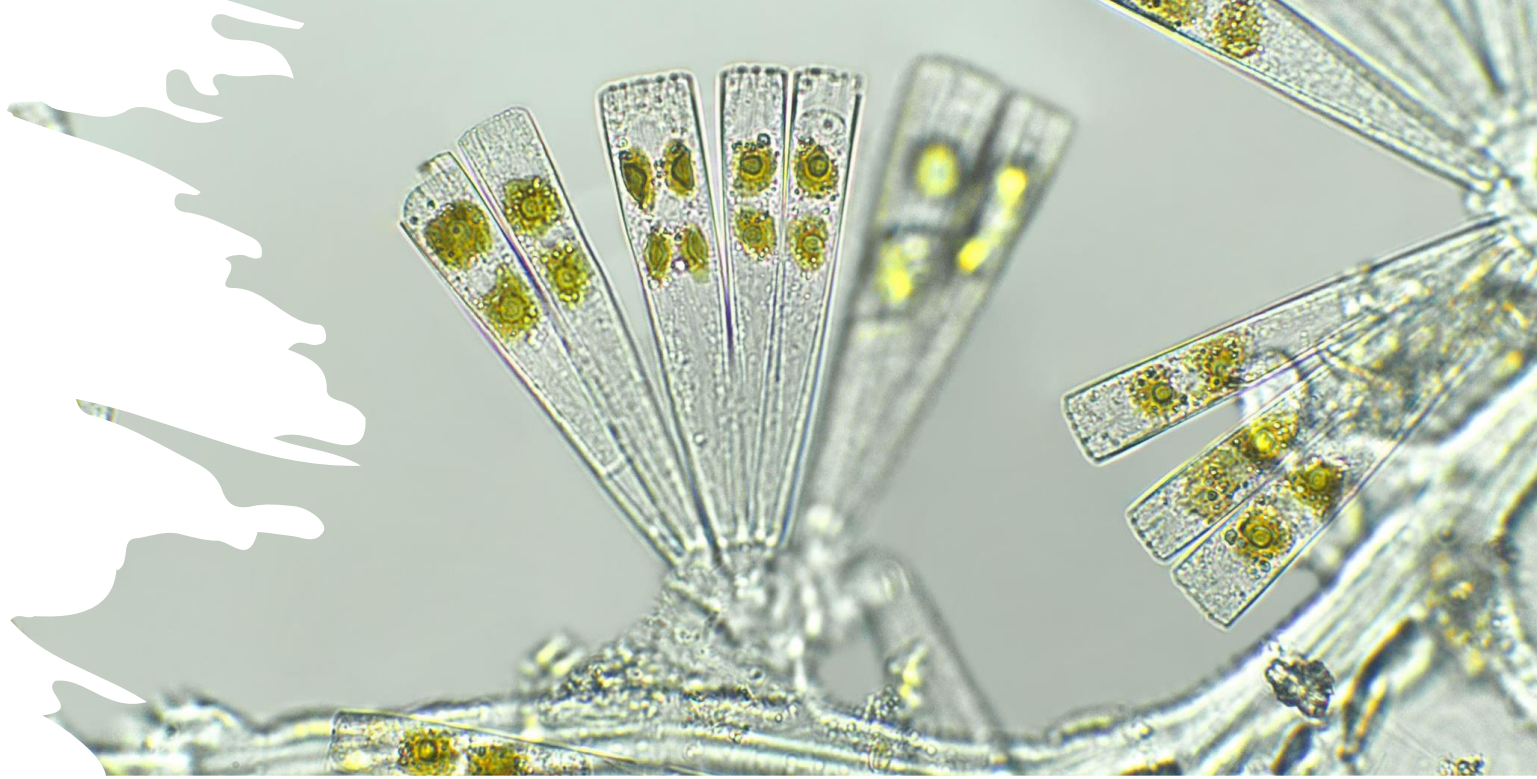
Figure 2.2: Diurnal variation of dissolved oxygen

Combination of the three effects of respiration, photosynthesis and reaeration results in a diurnal variation in dissolved oxygen concentration from the values that far exceed saturation during the day to much lower values or depletion at night.
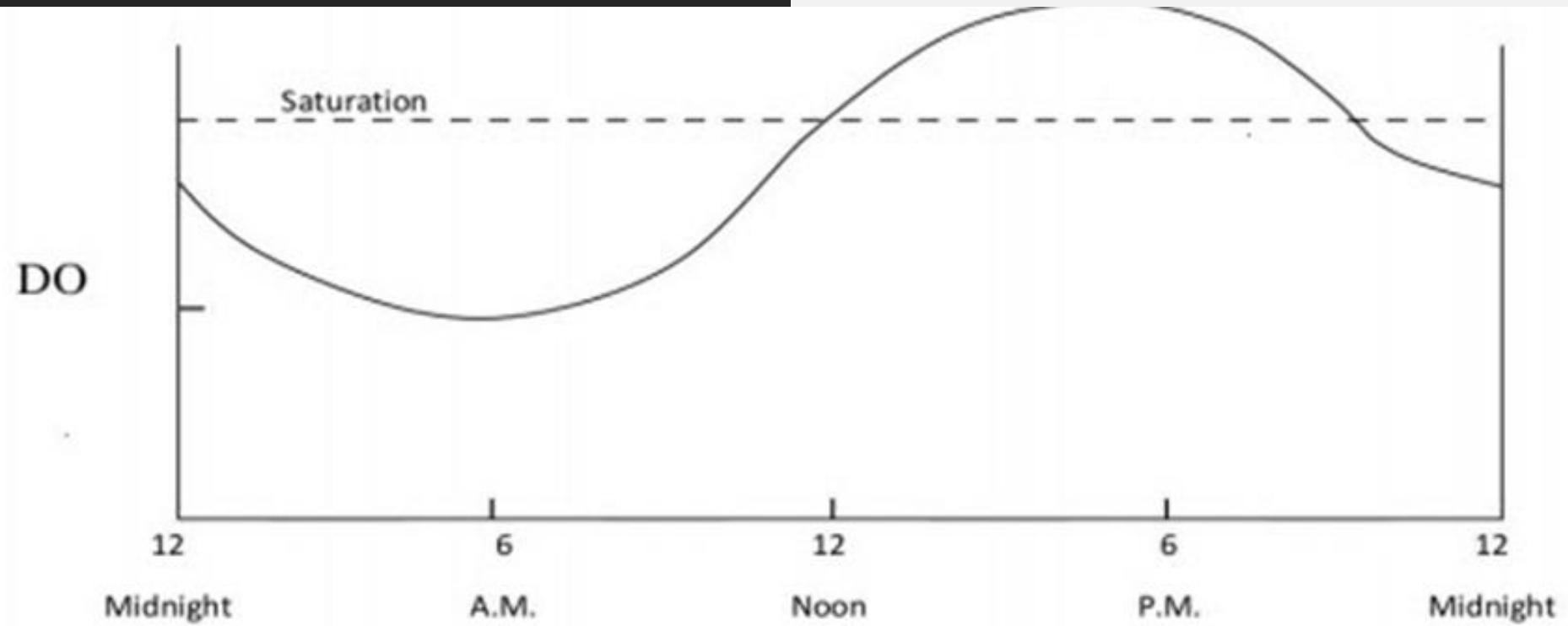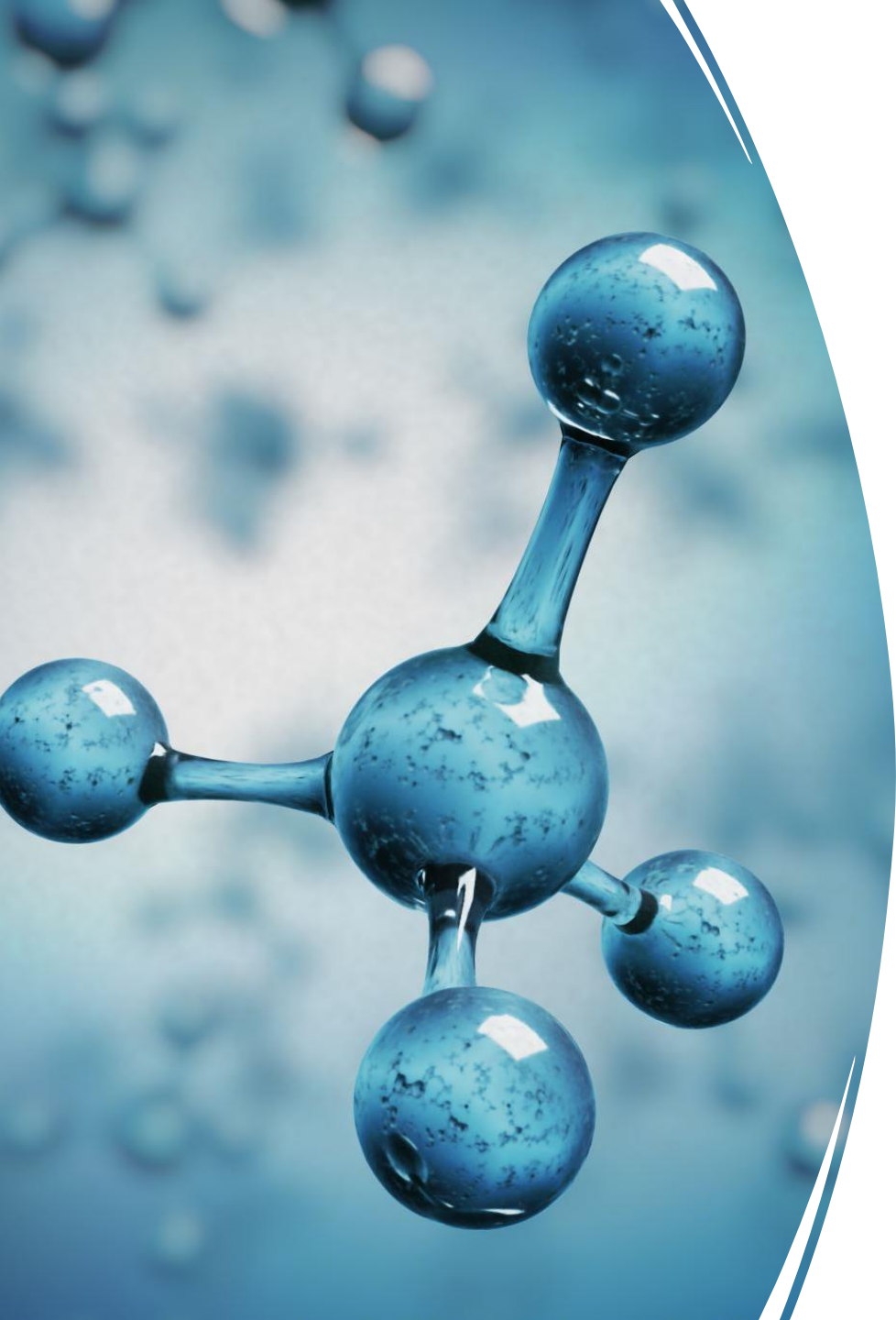
Oxidation

- In this process the oxygen is depleted by micro-organism during the oxidation of organic material. Pollution results when the oxygen demand exceeds the available oxygen.

Biochemical Oxygen Demand, BOD

- BOD is the measure of the oxygen utilized by micro-organism during the oxidation of organic material. BOD is the measurement for the water pollution.

Biochemical Oxygen Demand, BOD

- If a given amount of organic matter is introduced, the rate of oxidation of organic matter (the rate of decline of BOD) can be approximated as a first-order chemical reaction whose may be expressed as:
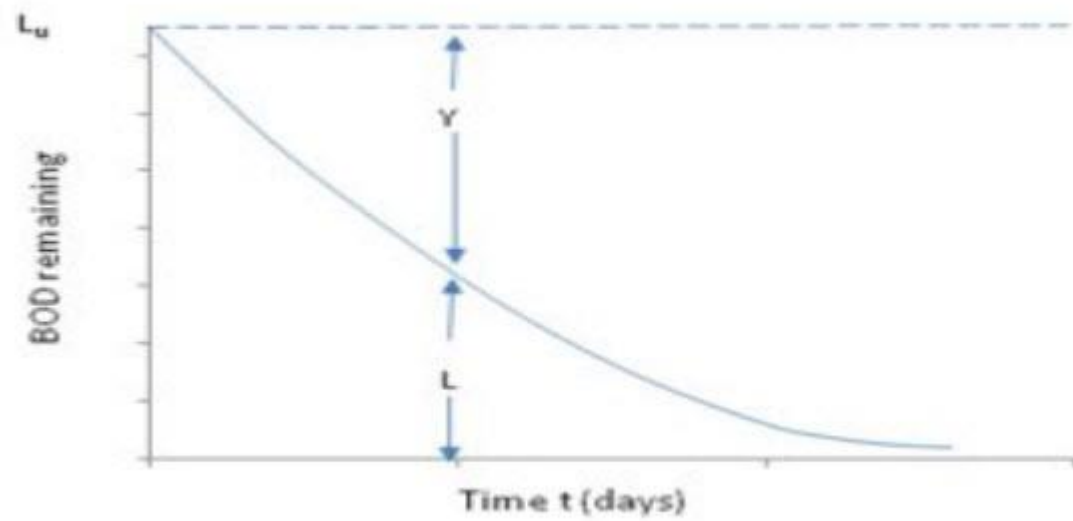
$$\frac{dL}{dt} = -k_1 \cdot L$$
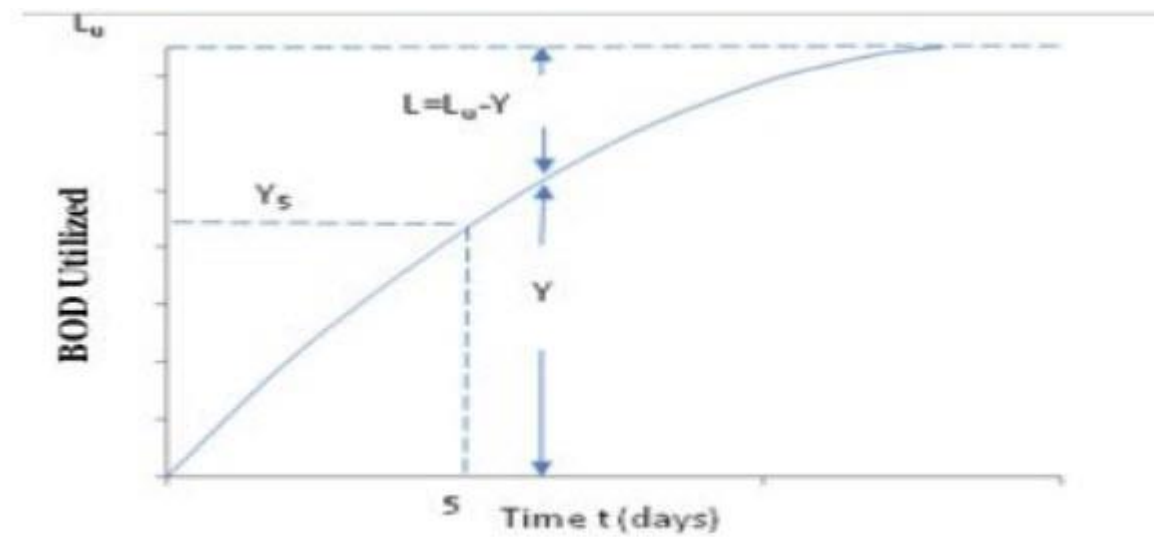
Figure 2.3: BOD remaining vs time.

Figure 2.4: BOD utilized versus time

Problem 2.1

The following BOD results are observed for a sample of raw sewage at 20 °C:

Table 2.2

T (days)	0	1	2	3	4	5
Y(BOD) mg/l	0	65	109	138	158	172

Calculate the reaction-rate constant k_1' and the ultimate BOD, L_u?

A plot of $(\frac{t}{Y})^{1/3}$ versus time t will give a straight line whose slope, b and intercept a can be used to calculate k_1 and L_u.

$$k_1^{'} = 2.61\frac{b}{a} \qquad\qquad (2.13)$$

Air Pollution

Air pollution may be defined as any atmospheric condition in which certain substances are present in such concentration that can produce undesirable effects on human and his environment. These substances include gases, particulate, radioactive materials, and many others. Most of these materials are naturally present in the atmosphere in low concentrations and are usually considered to be harmless.
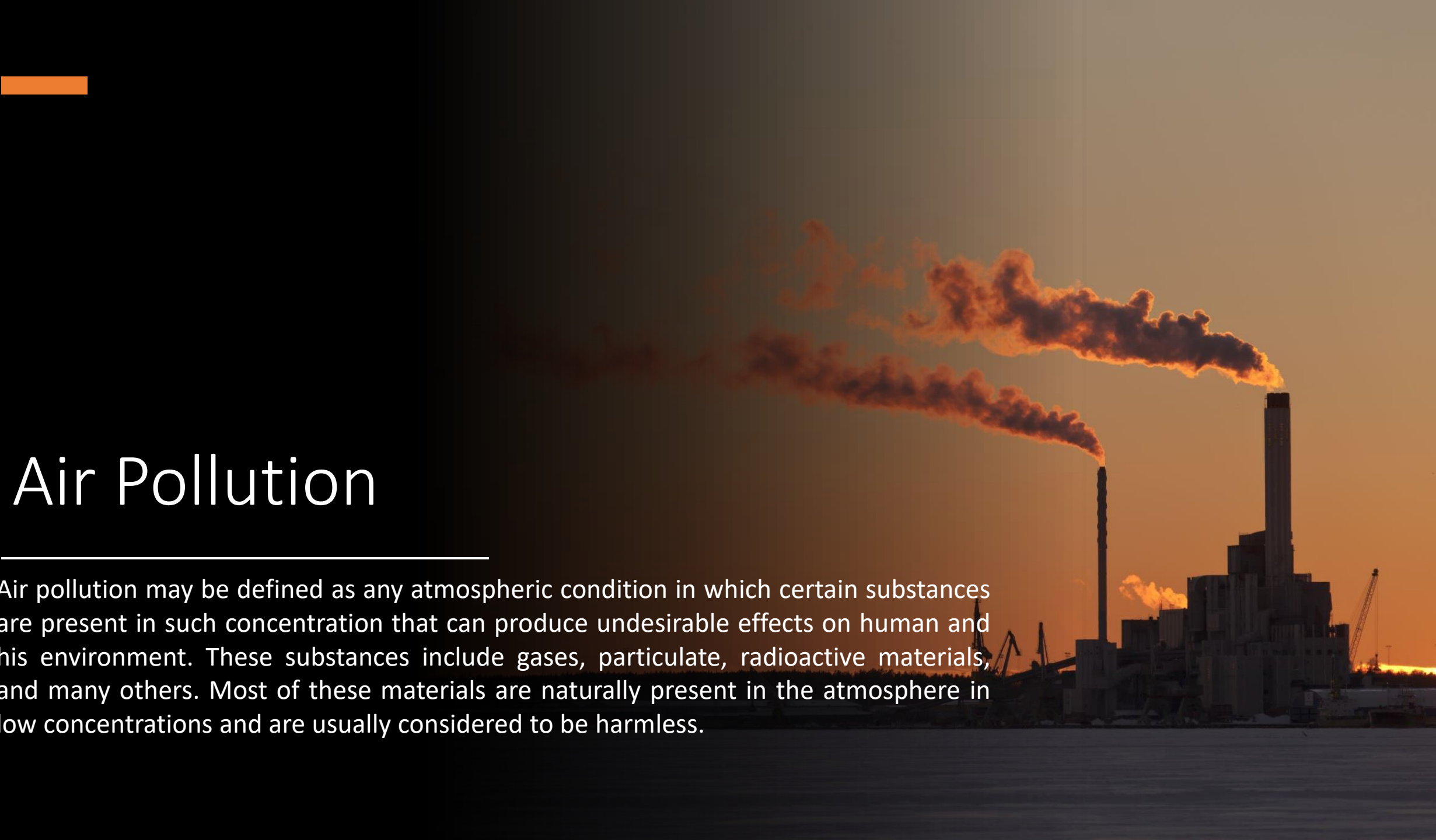
Classification of air pollutants

The air pollutants may be classified
in different ways as follows:

According	According to the origin
According	According to the chemical composition
According	According to the state of matter

According to the origin

- 1- Primary pollutant are those that are emitted directly from the sources into the atmosphere. A general list of primary air pollutants are:

Particulate matter such as ash, smoke, dust, fumes, mist, fog, spray, and aerosol.

Inorganic gases such as sulfur dioxide, hydrogen sulfide, nitric acid, ammonia, carbon monoxide, carbon dioxide, and hydrogen fluoride.

Radioactive compound.

Olefin and aromatic hydrocarbons.

According to the origin:

- 2- Secondary pollutants are those that are formed from chemical and photochemical interactions among primary pollutants and normal atmospheric constituents in the atmosphere. Pollutants such as sulfur trioxide, nitrogen dioxide, PAN (peroxyacetyl nitrate), ozone, aldehydes, ketenes and various sulfate and nitrate salts.

According to the chemical composition:

Organic pollutants , e.g. hydrocarbons, aldehydes, ketones, amine, and alcohols.

Inorganic pollutants
1. Carbon compounds (e.g. CO and carbonates)
2. Nitrogen compounds (e.g. NOx and NH3)
3. Sulfur compounds (e.g.H2S,SO2 , SO3 , and H2SO4)
4. Halogen compounds (e.g. HF, HCl and metallic fluorides)
5. Oxidizing agents(e.g. O3)

Particulates e.g. fly ash, silica, asbestos and dusts from transport mining, metallurgical and other industrial activities

According to state of matter:

Gaseous

- Gaseous pollutants which get mixed with air and do not normally settle e.g., CO, NOx, and SO2.

Particulates

- Particulates pollutants which comprised of finally divided solids or liquids and often exist in colloidal state as ash, smoke, dust, fumes, mist, fog, spray, and aerosol.

Sources of air pollution

Industrial waste

- There are numbers of industries which are sources of air pollution. Petroleum refinery are the major source of gaseous pollutants, Cement factories emit plenty of dust, stone crushers , food and fertilizers industries which emit gaseous pollutants, and chemical manufacturing industries which emit acid vapors in air.

Thermal power stations:

- The chief pollutants are fly ash, SO 2 , and other gases and hydrocarbons.

Automobiles:

- the source of emission of vehicles exhaust. This exhaust produced many air pollutants such as CO, NOx lead oxides

Air Pollutants and their effects

Carbon compounds:

- These are mainly CO_2 and CO, the former (CO_2) released by combustion of fossil fuels (coal, oil, etc.) and the latter (CO) by automobile exhausts.

Sulfur compounds:

- These include SO_2, H_2S, and H_2SO_4, mostly released by burning of fossil fuel (coal, etc.) in the thermal power plants and industrial units such as manufacturing of sulfuric acid, fertilizers and refineries.

Nitrogen oxides:

- These include chiefly NO, NO_3, HNO_3. Mostly released by automobiles, power plants and chemicals as well as other industries.

Ozone (O_3):

- Its level may rise in atmosphere due to human activities.

Fluorocarbons:

- These come from industries, insecticides spray, etc.

Hydrocarbons:

- These are chiefly benzene, etc., which are mostly discharged by automobile and industries.

Metals:

- These include chiefly lead, nickel, arsenic, tin, vanadium, titanium, cadmium, etc., present in air as solid particles or liquid droplets or gases. They are produced metallurgical processes, automobile, etc.

Particulate matter:

- These are fly ash, dust, grit and other suspended particulates matter (SPM) released from power plants and industries (stone crushers, etc.). These also bacterial cells, fungal spores, and pollens in air as biological particulates pollutants.

Particulate matter

- Particulate refers to all atmospheric substances that are not gases. They can be suspended droplets or solid particles or mixture of the two. Particulates can be composed of inert or extremely reactive materials ranging in size from 100 µm down to 0.1 µm and less.

- The inert materials do not make any changes in the environment as a result of combustion or any other process, whereas the reactive materials could be further oxidized or may react chemically with the environment.

Air borne particulate

Smoke
It contains fine particles of the size ranging from 0.01 to 1 µm, which are they liquid or solid, and are formed by combustion or by other processes.

Dust
It contains particles of the size ranging from 1 to 200 m. These are formed by natural disintegration of rock and soil or by the mechanical process of grinding and spraying. They have large settling velocities and are removed from the air by gravity and other process.

Fume
These are solid particles of the size ranging from 0.1 to 1 µm and are normally released from chemical or metallurgical processes.

Mist
It is made up of liquid droplets generally smaller than 10µm, which are formed by condensation in the atmosphere or released from industrial operations.

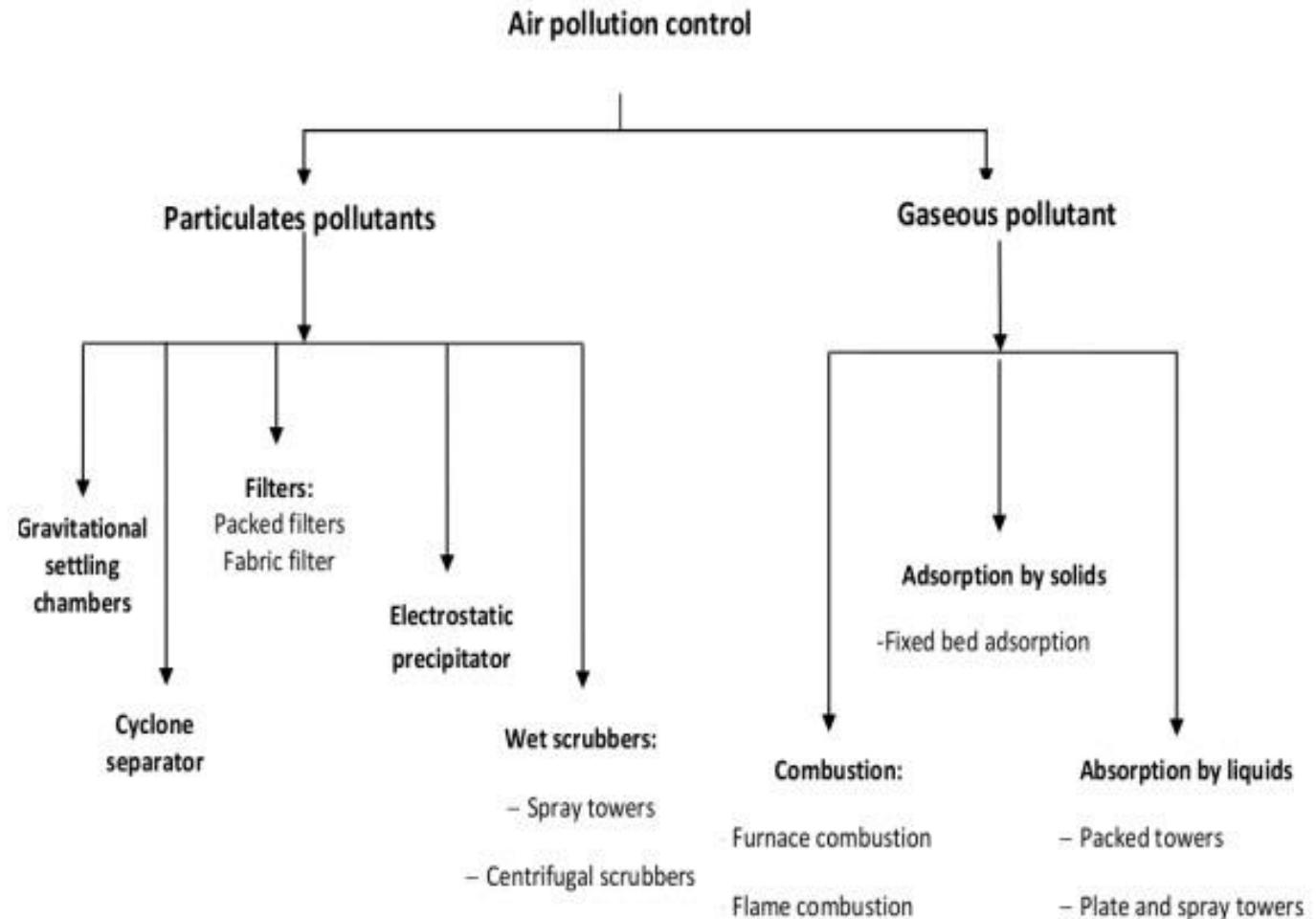**Fog**
It is the mist in which the liquid is water.

Aerosol
These included all air-born suspensions either solid or liquid. These are generally smaller than 1µm.

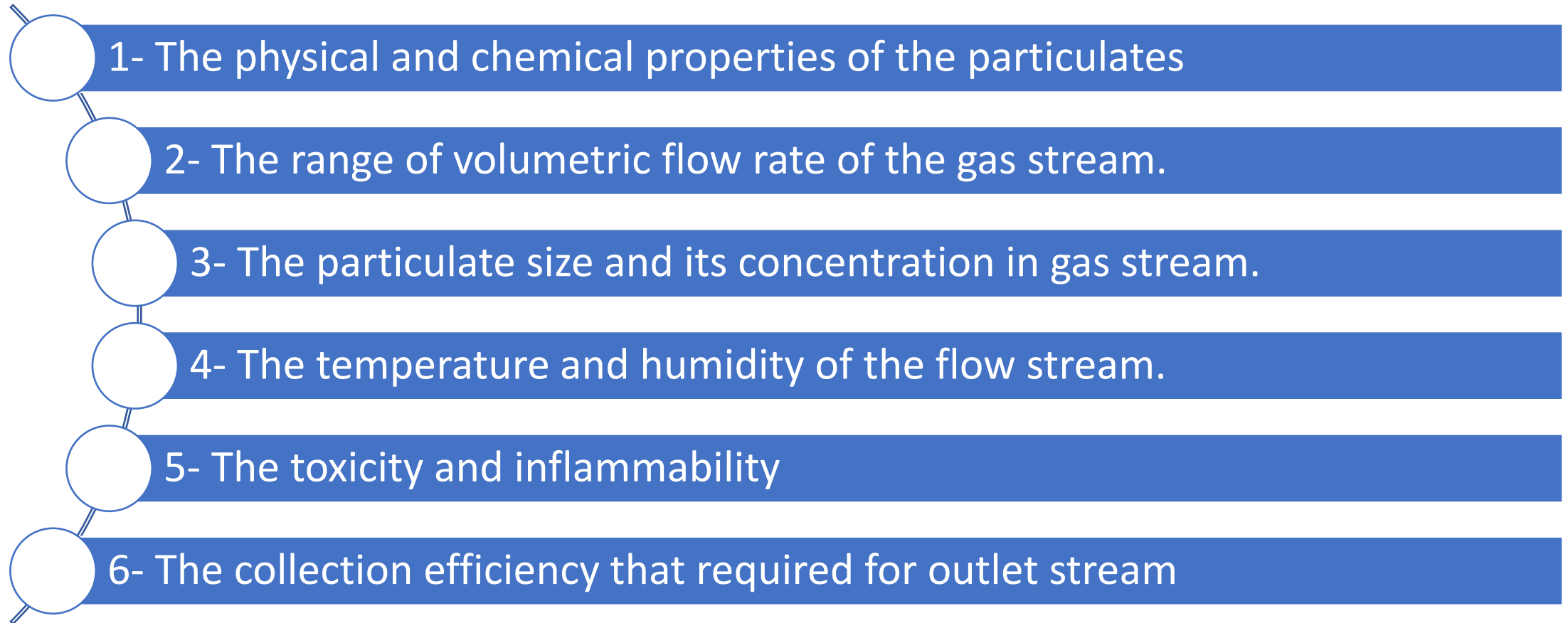# Air pollution control equipment

Dr. Omar Al-Kubaisi

The most commonly equipment deal with air pollution control from stationary sources

Particulate control equipment

- Particulate matter emitted in gaseous streams consists of discrete and minute suspended particles. Particle sizes range from 100 μm to 0.1 μm and even less.

The choice of collection devices depends upon several factors:

1- The physical and chemical properties of the particulates

2- The range of volumetric flow rate of the gas stream.

3- The particulate size and its concentration in gas stream.

4- The temperature and humidity of the flow stream.

5- The toxicity and inflammability

6- The collection efficiency that required for outlet stream

Gravitational settling chambers

- Gravitational force may be employed to remove particulate in settling chambers when the settling velocity is greater than about 25 ft/min (13 cm/s).

The basic characteristic of selling chambers:

They are generally used to remove of coarse particles larger than 50 m from gasstreams, but their efficient are quite small for particles smaller than 50m.

Since most of particles in the gas stream are much smaller sizes than 50 m, these devices are used as a primarily prior to passing the gas stream through high efficiency devices.

They offer low pressure drop and required simple maintenance.

Note:

The efficiency of equipment depends on the residence time of the gas in the

settling chamber which is related to the velocity of the gas flow and the chamber

volume.
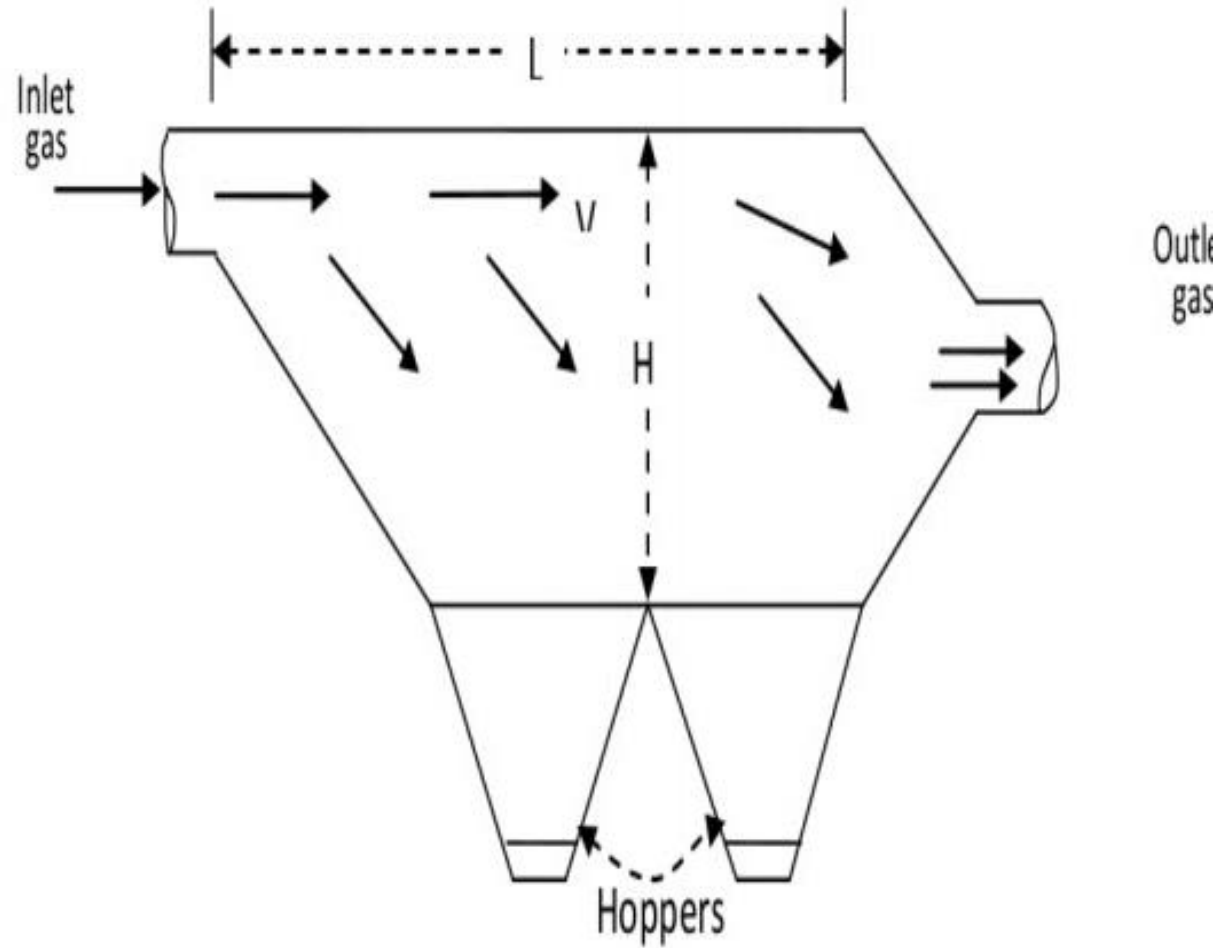
A gravitational settling chamber:

Cyclone separator

- Cyclone separators utilize a centrifugal force generated by spinning gas stream to separate the particulates 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 settling chambers and required much less space to handle the same gas volumes.

Clean gas

Feed   dirty
gas

Solids out
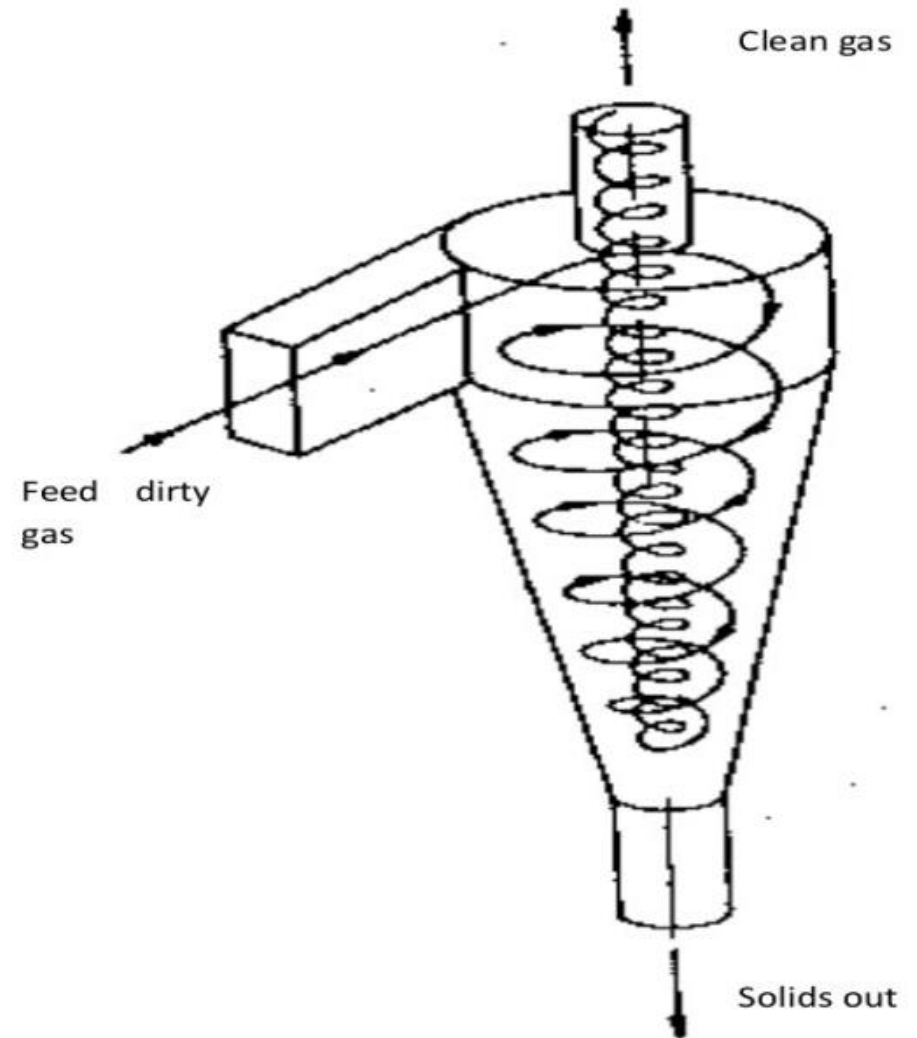
| Conventional cyclones	High efficiency cyclones	High volume cyclones
It is applied to remove of particles of 25 μm or larger with an efficiency greater than 90%.	The inlet gas velocity is higher, thereby importing a higher centrifugal force. These types are effective with particle sizes down 5μm.	Particle size are generally larger than 50 μm are collected with great efficiency. They can handle larger flow.
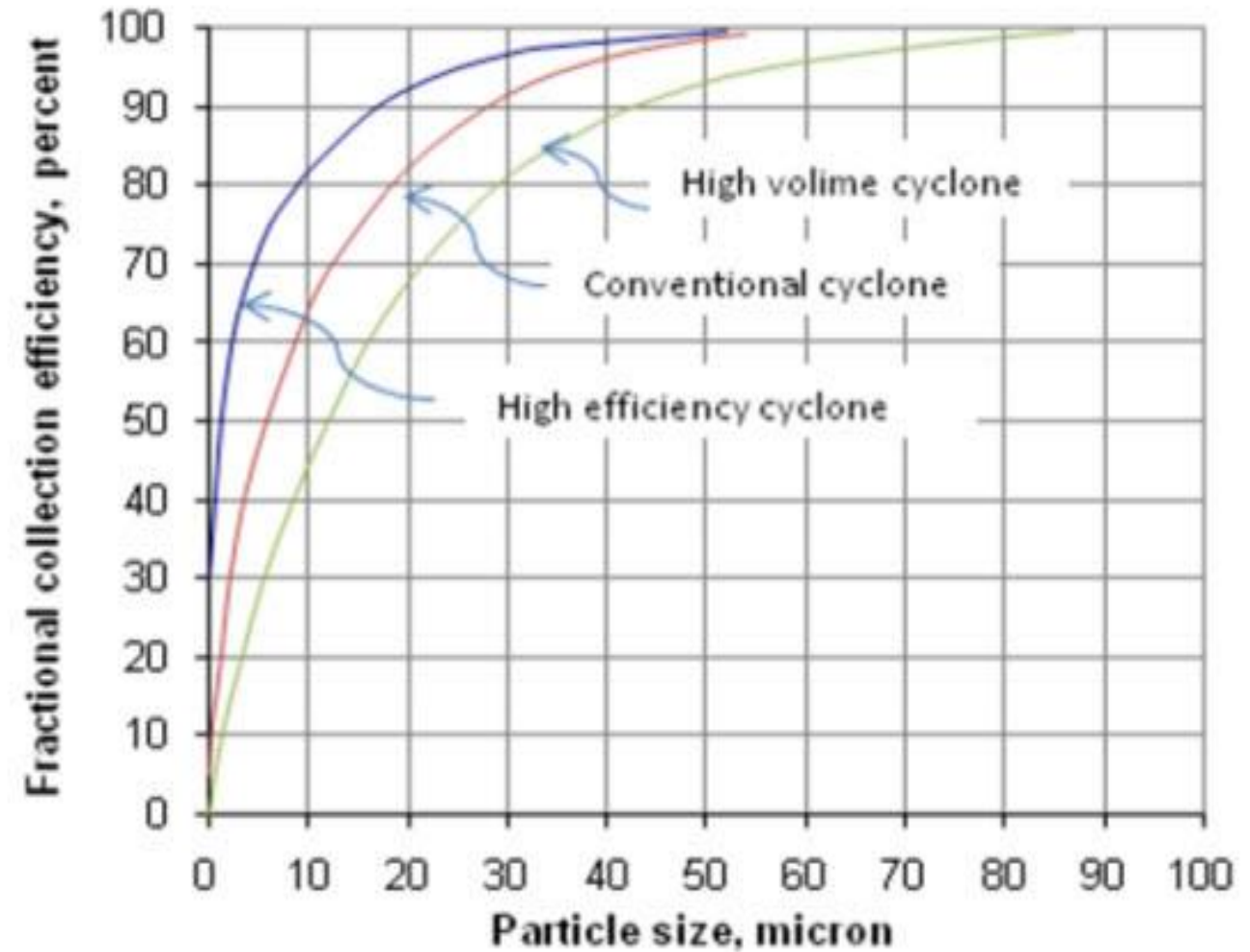
Fabric filter (or bag filter)

- Filtration is one of the oldest and most widely used methods of separating particulate from a carrier gas.

- A filter generally is a porous structure which tends to retain the particulate as the carrier gas passes through the void of filter and allowing clean gas to pass out.
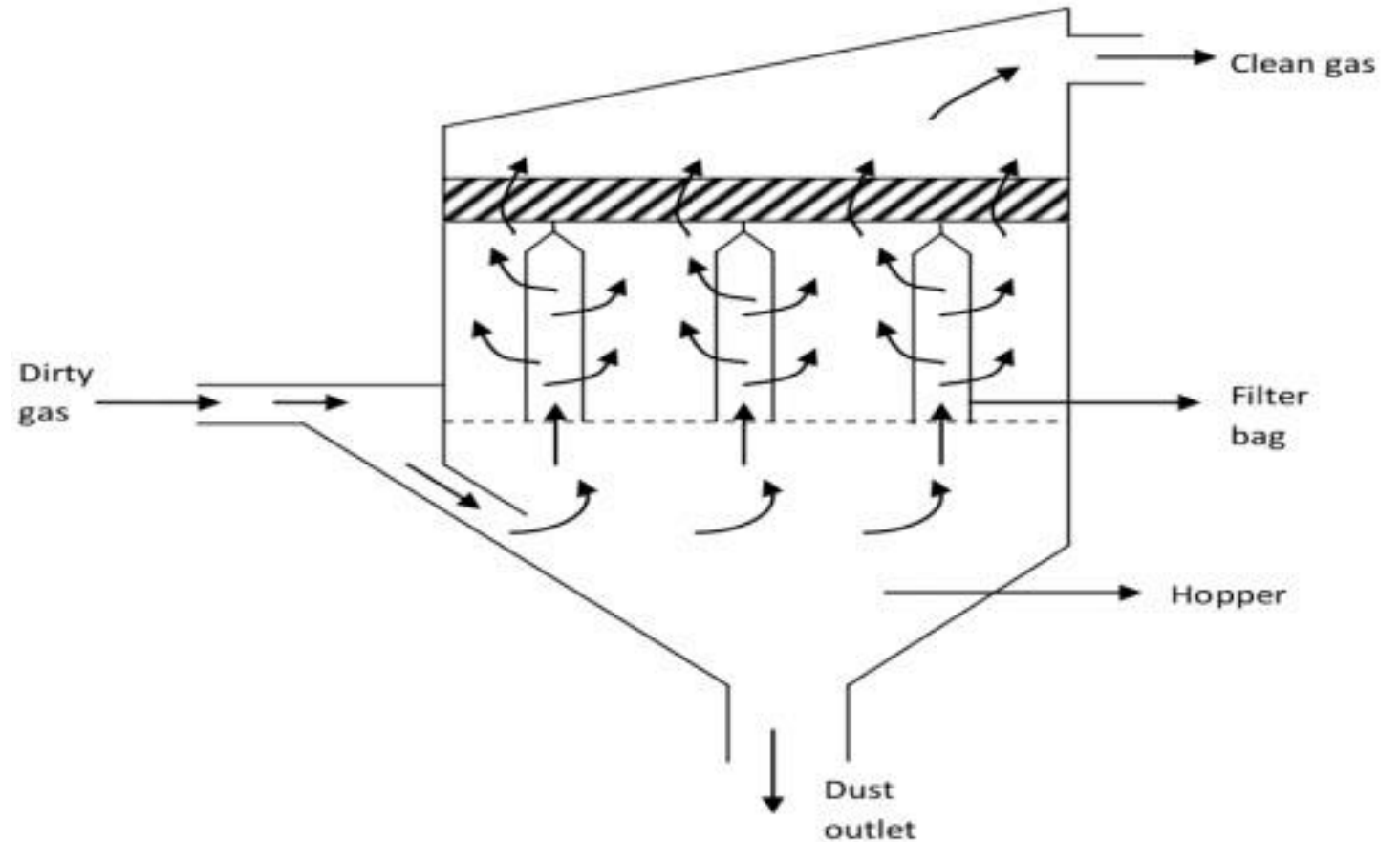
How Filter bag works?

Listen to the video carefully ....
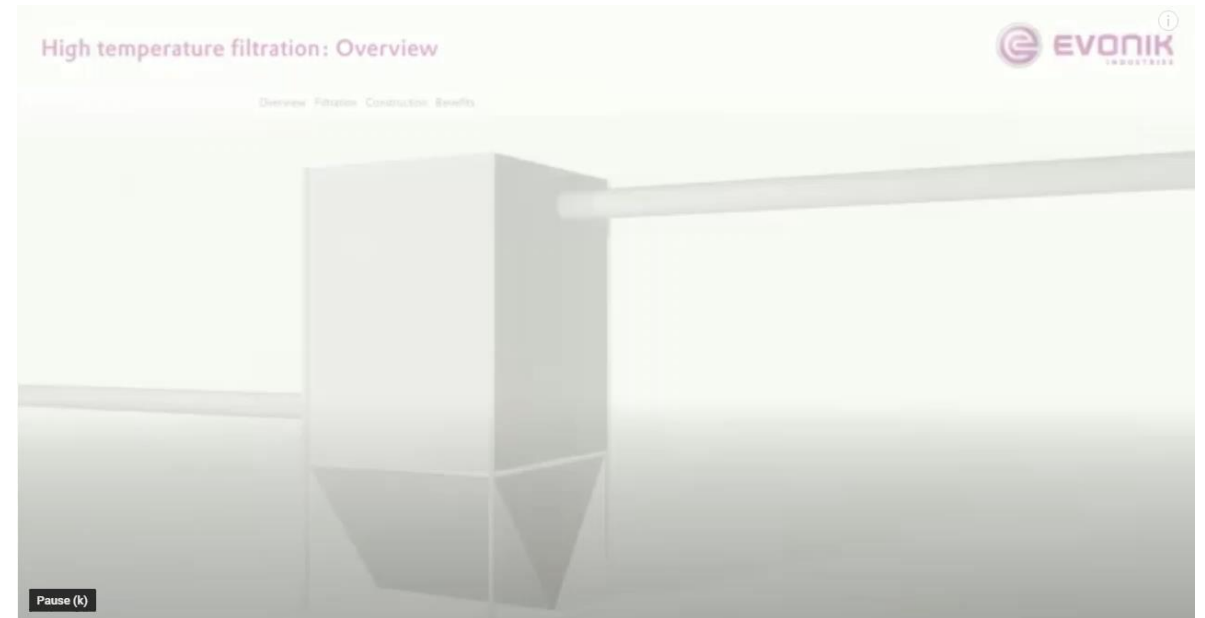
The advantages of fabric filter:

High collection efficiency over broad range of particle size.

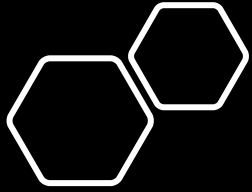Retention of finest particles.

Relatively low pressure drops.

Collection of particulates in dry form.

The main disadvantages of fabric filter

Their large size.

High construction costs

Hydroscopic material cannot be handling
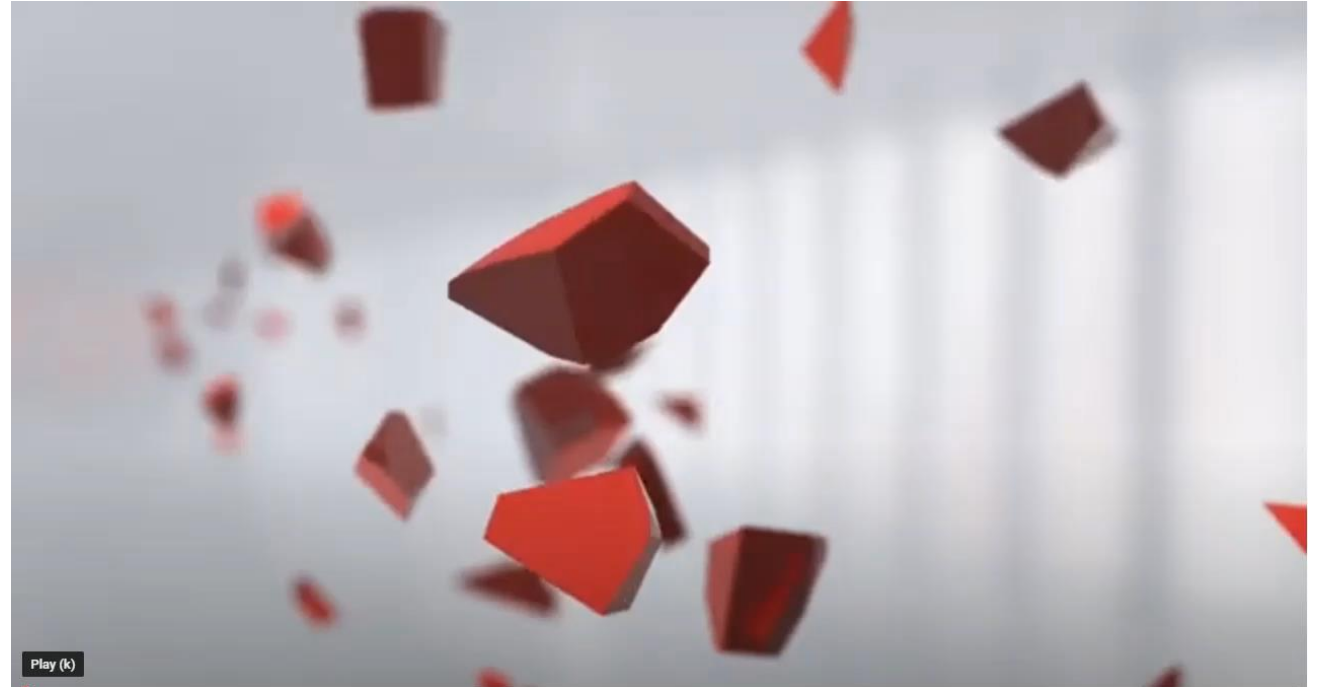
Electrostatic precipitators, ESP

- Electrostatic precipitator is a physical process by which particles suspended in gas stream are discharged electrically and, under the influence of the electrical field, separated from the gas stream. A typical wire and pipe precipitator is shown in Figure beside
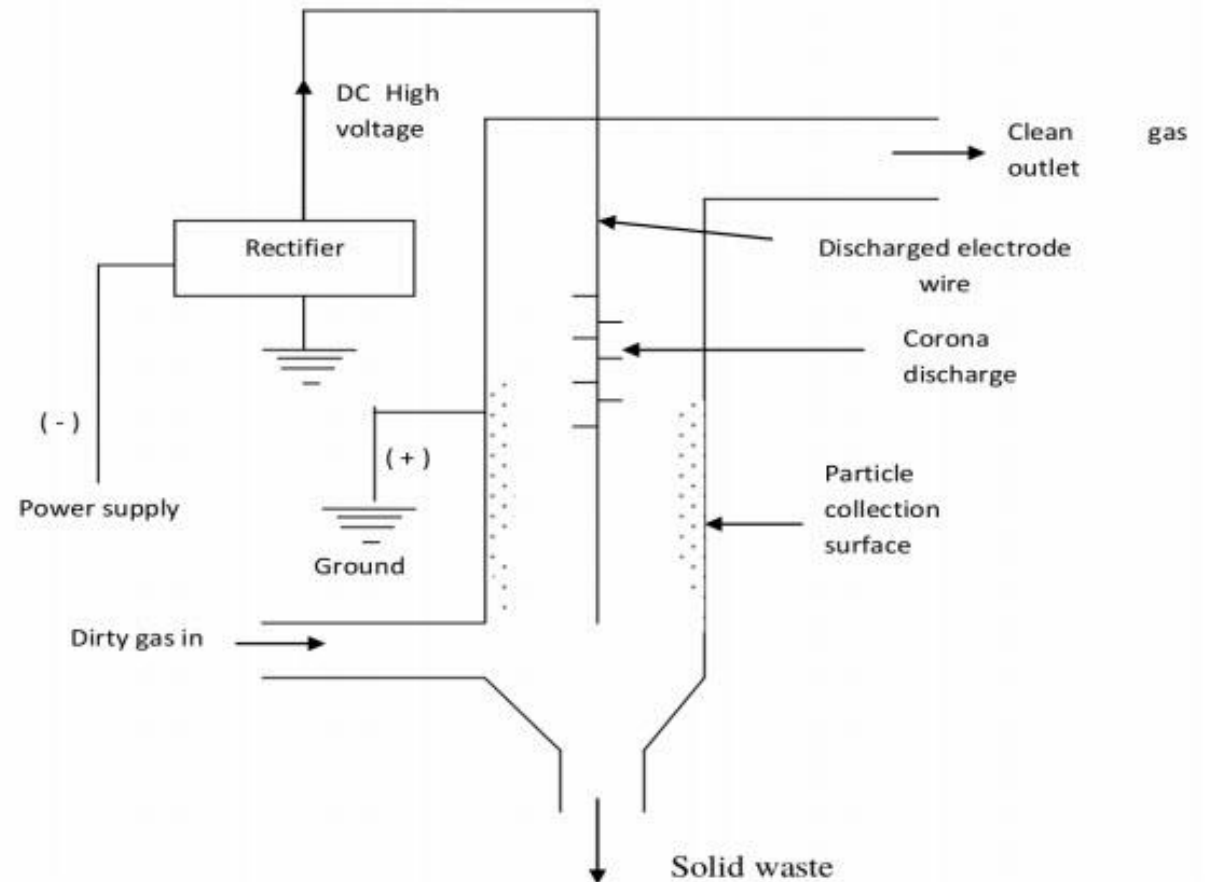
ESP How it works ….

The ESP system consists of a positively charged (grounded) collecting surface and a high-voltage discharge electrode wire (negative electrode) suspended axially in the tube. At every DC a corona discharge occurs close to the negative electrode, setting up an electric field between the wire electrodes and the collecting surface electrode.

Electrons are released at the wire electrode in a corona discharge. As the particle laden gas enters near the bottom and flows upward, these electrons attach themselves to particles to charge them. The charge particles are derived by the electric field toward the grounded surface of tube; on the surface the particles lose their charge and collection occur.

Advantages of electrostatic precipitators:

1- Pressure drop and hence power requirement is small compare to that of other devices.

2- High collection efficiencies very small particles can be collected wet and dry.

3- Can handle both gas and mists for high volume flows

4- Low energy consumption.

5- Ability to operate with relatively high temperature gases.

Disadvantages of electrostatic precipitators:

1- Relatively high initial cost and large space requirement

2- It is necessary to safeguard operating person from high voltage.

3- Collection efficiency can deteriorate gradually.

Wet scrubbers

- Wet scrubber is one of the particulate control equipment in which water is used to capture particulate dust.

- The resulting the solids are removed from the gas stream by water as slurry. The principal mechanism involved impact (impingement) of the dust particles and water droplet in order to achieve good contact time.

Advantage of Wet Scrubbers:

Simultaneously removal of gases and particulate.

Can effectively remove fine particulate, both liquid and solid, ranging from 0.1- 20 μm from gas stream.

Equipment occupies only a moderate amount of space compared to dry collectors such as bag house.

The disadvantages of wet scrubbers:

1 Relatively high energy costs.

2 Problem of wet sludge disposal.

3 Corrosion problems

4 The wet sludge causes water pollution and there is need to treatment method to remove particles from the water.

5 Very small particles (sub-micron sizes) may not capture.
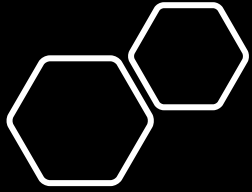
Major Types of wet scrubbers

# Types of Wet Scrubbers are:

**Spray scrubbers**

Centrifugal scrubbers

Venture scrubbers

Spray Scrubbers

- The simplest type of wet scrubbers is a spray tower (Fig.18) in which the polluted gas flows upward and water droplet is sprayed downward by means of spray nozzles located across the flow passage.

- The particle from the polluted gas is colliding with water droplet and the water droplet contaminated with this particle. If the gas flow rate is relatively slow, the contaminated water droplets will settle by gravity to the bottom of the tower as slurry.
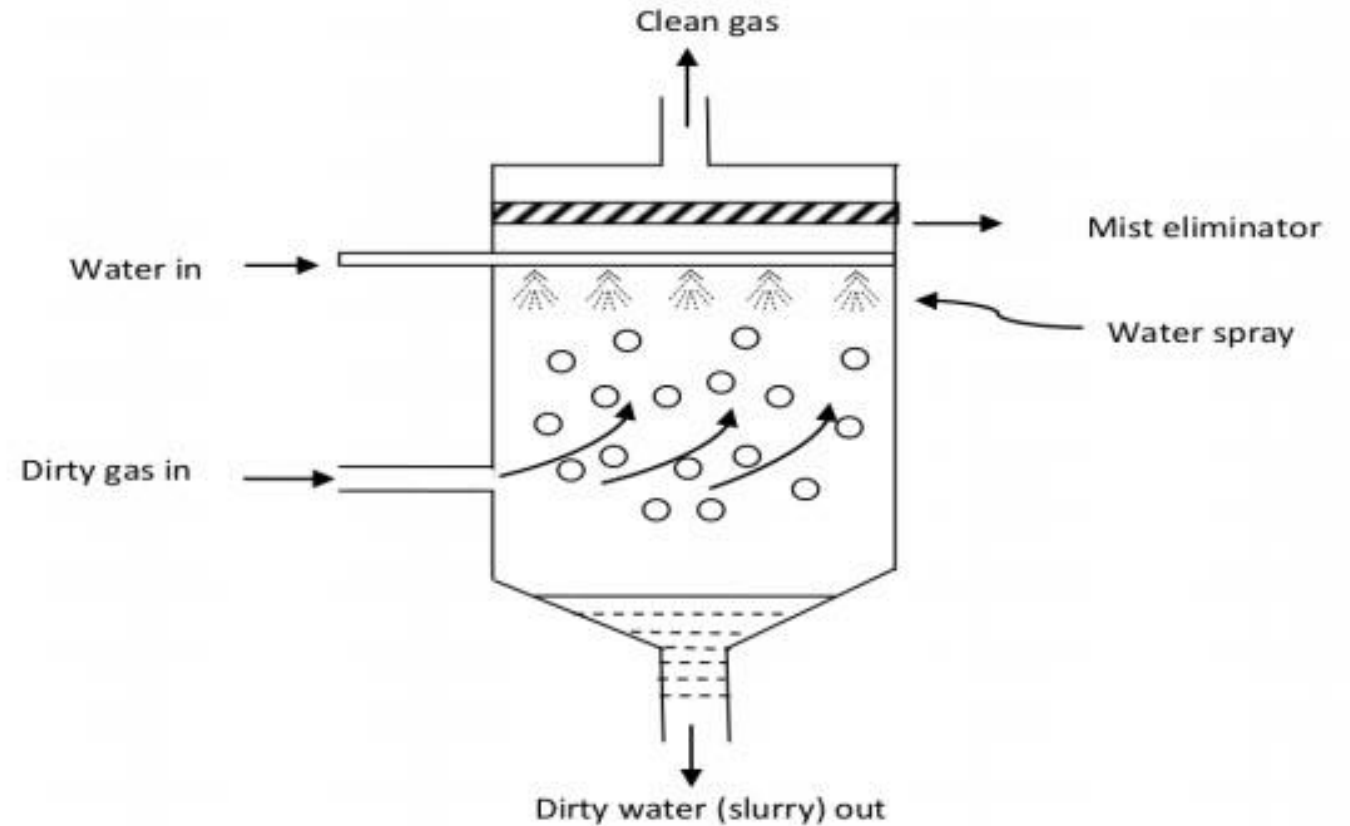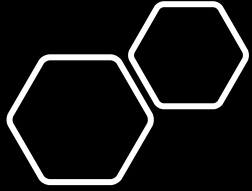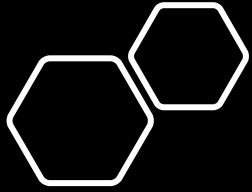
Wet Scrubbers

- The particle from the polluted gas is colliding with water droplet and the water droplet contaminated with this particle. If the gas flow rate is relatively slow, the contaminated water droplets will settle by gravity to the bottom of the tower as slurry.

- A mist eliminator is usually placed at the top of the tower to remove both exes clean water droplet and dirty droplets which are very small that cannot be settled and thus carried upward by the gas flow. High pressure spray produces small droplet with more surface area per mass of water used. The effectiveness spray towers ranges from 95% for 5 µm particles 99% for 25µm particles

Centrifugal scrubbers

- The polluted gas introduced tangentially into the lower portion of the vertical cylinder. Water drops are injected from multiple nozzles, which throw the water radially outward across the flow gas stream.

- The collection efficiency for the particles smaller than those recovered in spray towers can be increased through the use of centrifugal scrubbers. Commercial scrubbers have operating efficiency of 97% or better for particles larger than 1 μm.
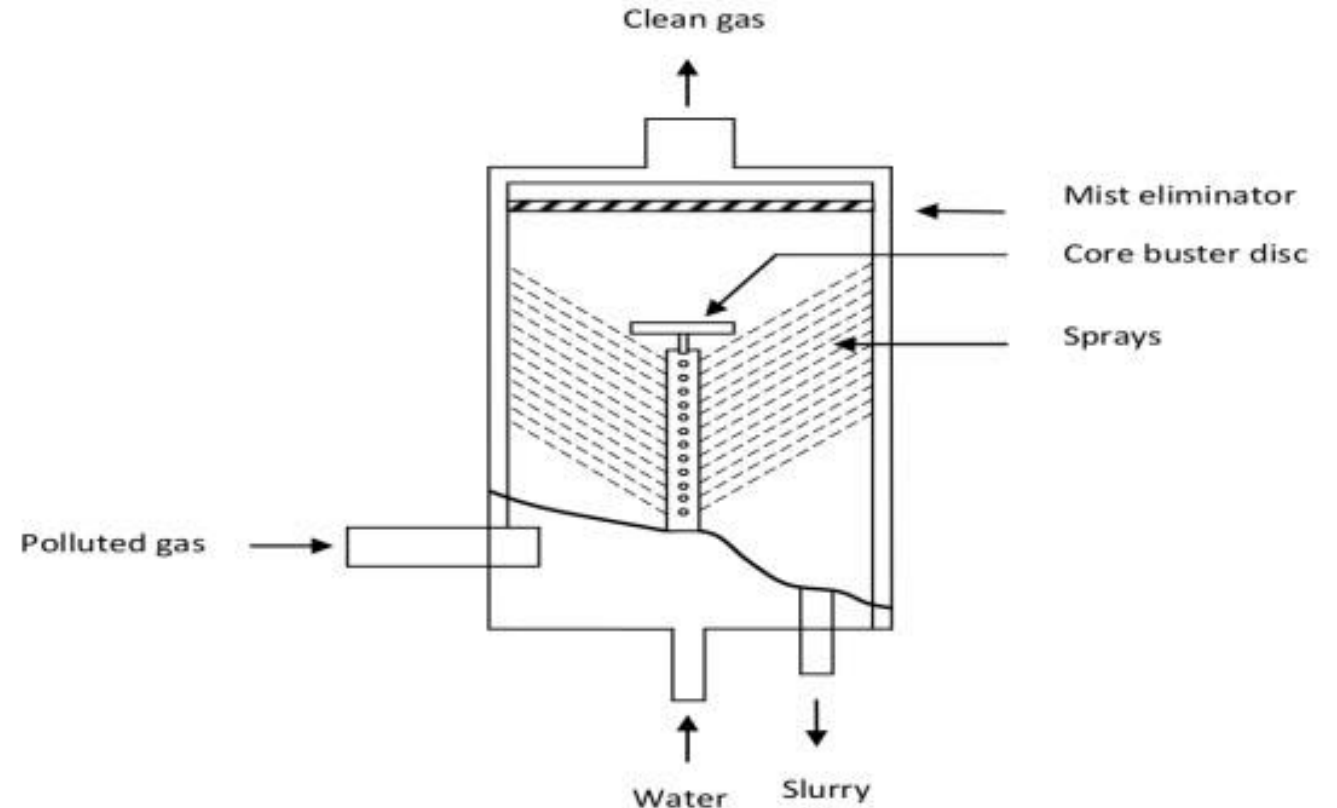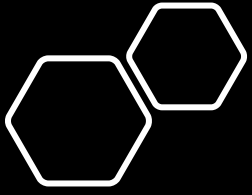
How C.WS works...

• Water drops are injected from multiple nozzles, which throw the water radially outward across the flow gas stream. These droplets are caught in the spinning gas stream and are thrown upward towards the wall by centrifugal force. During their motion the, the droplets collide with particles and capture them. The scrubbing liquid along with the particles flows down the wall to the bottom of the scrubber and exits as slurry. The cleaned gas exists through a demister and is processed for the removal of any entrained water droplets.
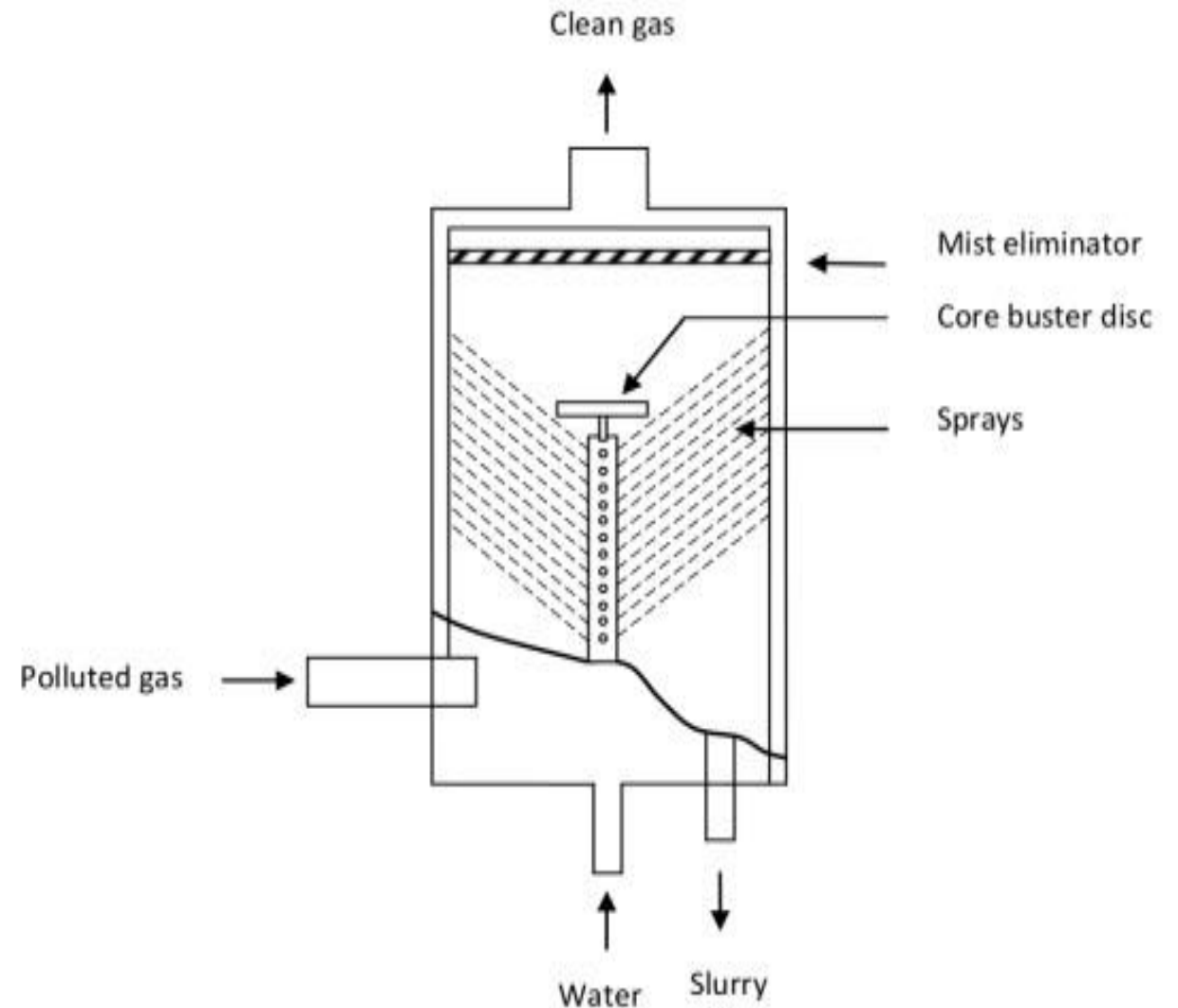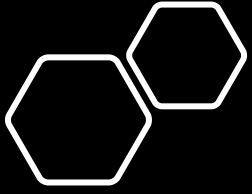
Venturi scrubbers

- A venturi is a rectangular or circular flow channel which converges to a narrow throat section and diverges back to its original cross section area. The narrow throat causes acceleration of the velocity of the gas to a high level in the venturi section. Figure on the side shows a vertical downward venturi with throat injection.

Dirty gas

Water inlet

Water + dust outlet to cyclonic separator
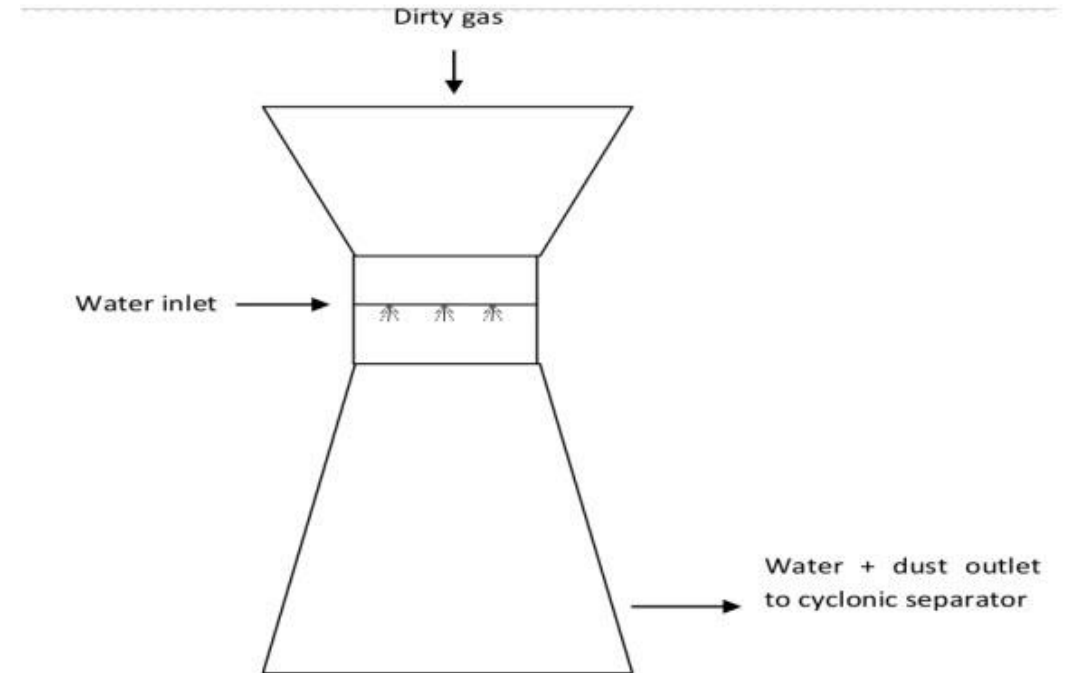
How venturi works ?

- A bank of nozzles on either side of throat injects water into high velocity gas stream. The high velocity gas assist in atomizing the liquid injected into the gas. The drops collide with dust particles in the gas to form dust-water agglomerates. The gas-liquid mixture is then directed to a separation device such as cyclone separator where the droplets carrying the particulates are separated from the gas stream. Venturi scrubbers offer high performance collection of fine particles usually smaller than 2 to 3 μm. They are suitable when the particulate matter is sticky, flammable or highly corrosive.

Air pollution equipment design

Dr.Omar

Collection efficiency

- The collection efficiency measures the system performance. This expressed as a percentage:

$$\eta_T = \frac{\text{Weight of material collected}}{\text{Total amount enter in collector}} \times 100$$

  - The collection efficiency in each size range can be computed by the Equation below:

$$\eta_i = \frac{\text{Fraction in range i collected}}{m_i} \times 100$$

where m_i is the amount in range i entering the collector.

Overall collection efficiency

- The overall collection efficiency η_T can be calculated over n number of size fractions a :

$$\eta_T = \frac{\sum_i^n m_i \cdot \eta_i}{M} \times 100$$

- where n is the number of size fractions and M is the total amount entering the collectors
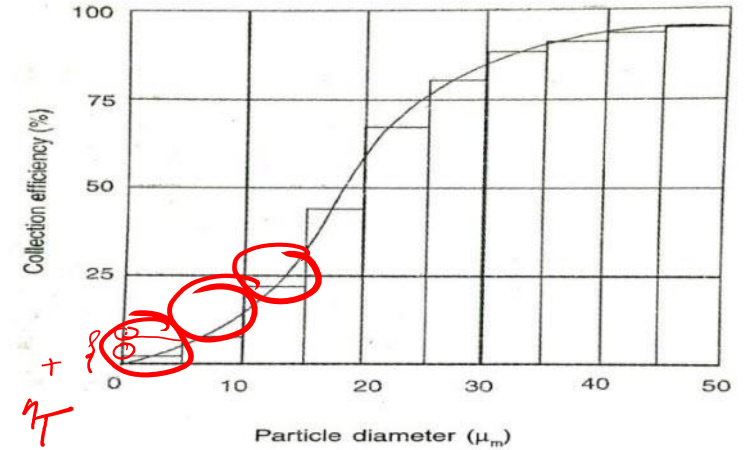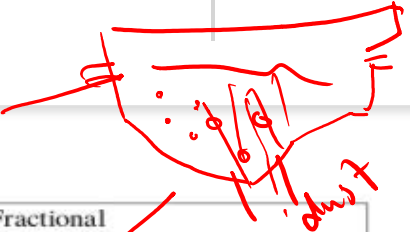
Example

- The following table shows the size distribution of dust sample and the fraction efficiency of removal in a gas cleaning equipment. Calculate the overall collection efficiency.

Dust size	Weight per 100 g of dust (g)	Fractional efficiency η_i (%)
< 5	2	1
5-10	2	7
10-15	4	16
15-20	7	44
20-25	10	67
25-30	8	81
30-35	7	88
35-40	10	92
40-50	15	93
50-60	20	95
60-70	10	98
>70	5	100

Solution

- On the same table we can add another column to estimate the fractional efficiency, and then we can the overall efficiency of the quipment.

Dust size	Weight per 100 g of dust (g)	Weight fraction w_i	Fractional efficiency η_i (%)	$w_i \times \eta_i$
<5	2	0.02	1	(0.02 x1)
5-10	2	0.02	7	(0.02x7)
10-15	4	0.04	16	(0.04x16)
15-20	7	0.07	44	(0.07x44)
20-25	10	0.1	67	(0.1x67)
25-30	8	0.08	81	(0.08x81)
30-35	7	0.07	88	(0.07x88)
35-40	10	0.1	92	(0.1x92)
40-50	15	0.15	93	(0.15x93)
50-60	20	0.2	95	(0.2x95)
60-70	10	0.1	98	(0.1x98)
>70	5	0.05	100	(0.05x100)
				$\eta_T = 80.17$

$$\eta_T = \frac{\sum_i^n m_i \cdot \eta_i}{M} \times 100$$

$$\eta_T = \sum_{i=1}^{n} w_i \eta_i$$

Settling chamber design

$$F_g = F_D + F_B$$

$$\boxed{F_g = F_b + F_d} \Rightarrow \text{To derive settling velocity.}$$

A gravity settler is simply a long chamber through which the contaminated gas passes slowly, allowing time for particles to settle by gravity to the bottom. The important parameter is the terminal or settling velocity of the particle, Vt the terminal velocity is defined as the constant downward speed that a particle attains in a direction parallel to the Earth's gravity field. If the particle is settling in a fluid at its terminal velocity, three forces acting on it: drag, buoyancy, gravity force, as shown in Figure aside . The terminal settling velocity of the particles is found from forces balance as:

$\dfrac{V}{t}$

$F_D \qquad F_B$

F_g
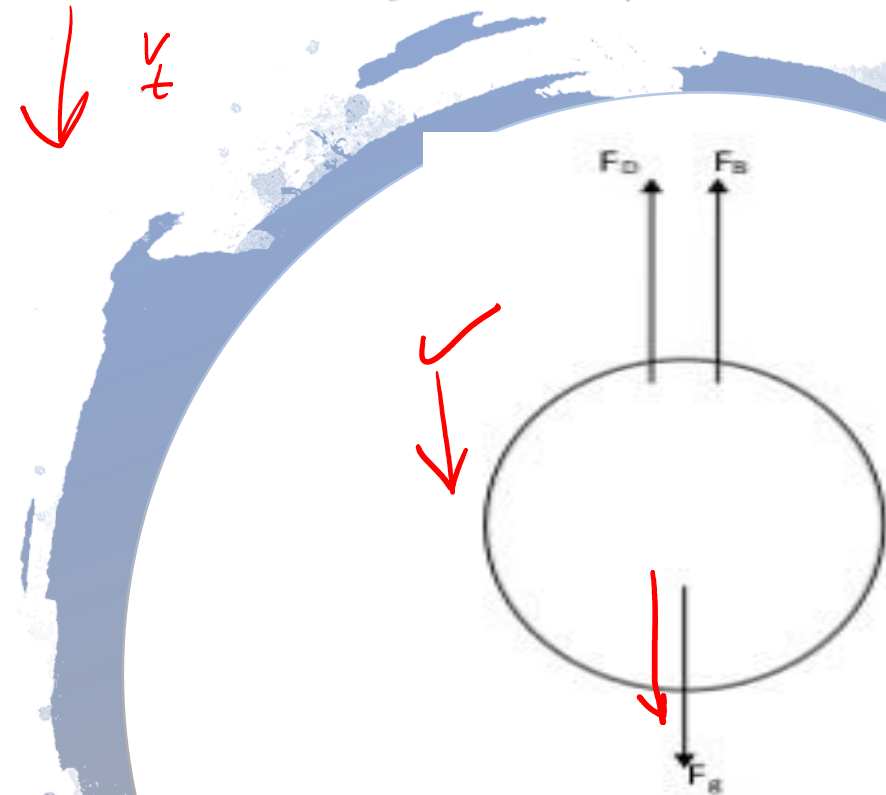
The forces acting on a particle in a fluid

F_d = drag Force = $\dfrac{\rho_g V_t^2 A C_D}{2}$

F_B = Buoyancy force = $m_p * \dfrac{g}{\rho_p} * \rho$

m_p = Mass of particle = $\rho_p * V_p$

ρ_g = Density of gas kg/m³

ρ_p = Density of particle kg/m³

C_D = Drag Coefficient

v_t = terminal settling velocity

A = Frontal cross Sectional area.

V_p = Volume of particle.
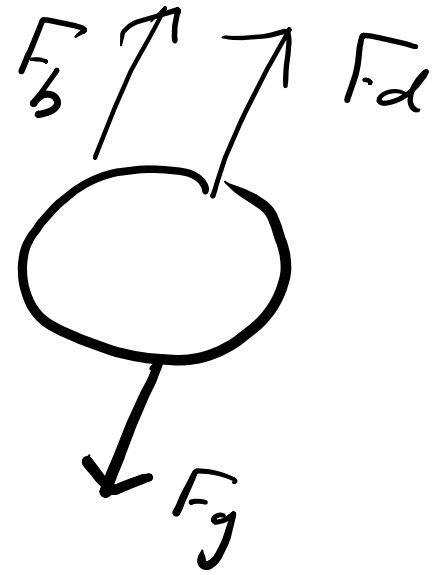
$F_g = F_D + F_b$

$m_p g = \dfrac{\rho_g V_t^2 A \times C_D}{2} + m_p \dfrac{\rho_g}{\rho_g}$

$$V_t = \sqrt{\frac{2 m_p \cdot j \left(\rho_p - \rho_g\right)}{\rho_p \rho_g A C_D}}$$

* $\frac{\rho_p}{} =$ Derive the settling velocity Formula for particles in settling chamber

For spherical particle:-

$$V_p = \frac{\pi}{6} \times d_p^3$$

$$A = \frac{\pi}{4} \times d_p^2$$

$$m_p = \rho_p \times V_p$$

$$V_t = \sqrt{\frac{4 g d_p \left(\rho_p \rho_g\right)}{3 C_D \rho_g}}$$

According to Re

3 Regions

Laminar :

Transition :

Turbulent :

$$Re = \frac{\rho \, d_p \, \boxed{V_t}}{\mu g} \Rightarrow 1?$$

$$V_t = \sqrt{\frac{4g \, d_p \left(\rho_p - \rho_g\right)}{3 \, C_D \, \rho_g}}$$

For Laminar Flow $\Rightarrow C_D = \dfrac{24}{Re_p}$

For Transition Region $\Rightarrow C_D = \dfrac{18.5}{Re_p^{0.6}}$

For Turbulent Region $\Rightarrow C_D = 0.45$ its Constant

Region   Condition

$Re \Rightarrow$

For laminar Region:-

$$V_t = \frac{g\, d_p^2\, (\rho_p - \rho_g)}{18\, \mu}$$

settling velocity?

Re^2

$Re.$

For Transition Region:-

$$V_t = \frac{1.53\ g^{0.71}\ d_p^{1.14}\,(\rho_p - \rho_g)^{0.71}}{\rho_g^{0.29}\ \mu^{0.43}}$$

For turbulent Region :/ $V_t = 1.73 \left[\dfrac{g\, d_p\, (\rho_p - \rho_g)}{\rho_g} \right]^{0.5}$

- It is difficult to estimate Reynolds number and then to estimate which C_D correlation used to calculate terminal velocity, Vt , because Vt is presented in Reynolds number and C_D equations. Therefore, the following equation is used to provide a convenient correlation using K, as follows:

$$K = d_P [\frac{g(\rho_P - \rho_g)\rho_g}{\mu_g^2}]^{1/3}$$

Laminar   *Region?*

- If K < 3.3 then Stokes's region applied to estimate Vt , Use Laminar Region

- If 3.3 ≤ K ≤ 43.6 then transition region applied to estimate Vt use Transition Region

- If K value > 43.6 then turbulent region applied to estimate Vt , use turbulent region

V_t for tansition Region

Sett

, V_t ?   *⟹ Re ?*

Regions

Substituting the drag coefficient for each region, the general settling velocity can be estimated according to the following:

$$Reynolds = \frac{\rho_g d_P V_t}{\mu_g}$$

The general equation for the terminal settling velocity:

$$V_t = \frac{g d_p^2 (\rho_P - \rho_g)}{18\mu}$$

1- Laminar Region

$$C_D = 24/Re_P \qquad V_t = \frac{g d_p^2 (\rho_P - \rho_g)}{18\mu}$$

Transition Region

$$C_D = 18.5/Re_P^{0.6} \qquad V_t = 1.53 \times \frac{g^{0.71} d_p^{1.14} (\rho_P - \rho_g)^{0.71}}{\rho_g^{0.29} \mu^{0.43}}$$

Turbulent Region

$$C_D = 0.45$$

Example:

Three different fly ash particles settled through air, their sizes are 0.4, 40, 400 μm. Calculate the terminal settling velocity for each particle assume the particle are spherical. Data required given below: T_{air} = 114.5 °C, Pair = 1 atm, µair = 0.021 cp, sp.gr. of fly ash = 2.31:

Note: Use K-value as a guide for the region

$$K = d_p \left[\frac{g(\rho - \rho_g)\rho_g}{\mu_g^2} \right]^{1/3}$$

ρ_g = air at 114.5 °C

$$PV = nRT$$

$$\rho_g = \frac{P \cdot MWt}{RT}$$

$$n = \frac{mass}{M.wt}$$

$$R = 0.082 \ \frac{atm \cdot m^3}{kg \, mol \cdot K}$$

P atm

$$T = 114.5 + 273.15 = 387.5 \, K$$

$$\rho = \frac{(1)(29)}{(0.082)(387.5)}$$

$$= 0.9126 \ kg/m^3$$

Viscosity of air : 0.021 Cp

$$= 0.021 + 10^{-3} \ \frac{kg}{m \cdot s}$$

Density of particle = sp.gr. × ρ_{H2O}

$$= 2.31 \times 1000 = 2310 \ kg/m^3$$

$$k = \boxed{dp} \left[\frac{9.81 \, (2310 - 0.9126)(0.9126)}{(0.21 + 10^3)^2} \right]^{1/3}$$
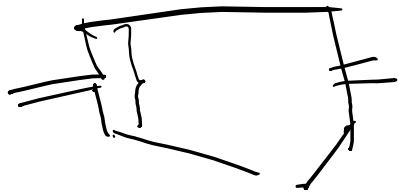
$$k = 36056 \, \underline{\boxed{dp}} \implies$$

v_t for stockes

v_t for Transition

$dp(mm)$	$dp(m)$	k	Region	$v_t(m/s)$
0.4	$0.4 + 10^{-6}$	0.014	stockes	9.58×6
40	$40 + 10^{-6}$	1.442	Stockes	0.0958
400	$400 + 10^{-6}$	14.423	Transition	26.92
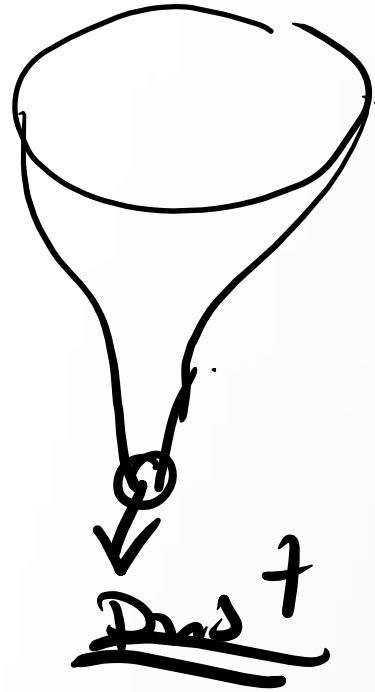
Retention Time
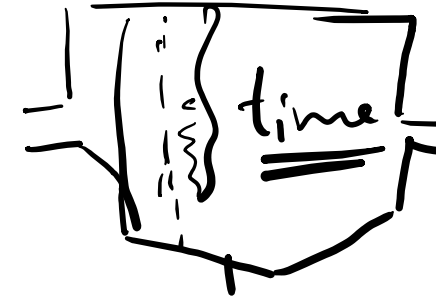
- Additional parameter in design of settling chamber hydrodynamic is retention time, τ, where can be estimated as follows:

$$\tau = \frac{V}{Q} = \frac{LWH}{WHu} = \frac{L}{u}$$

where:

V = The volume of settling chamber (m^3)

Q = Volumetric flow rate of gas stream $(m^3 \cdot s^{-1})$

u = Linear gas velocity $(m \cdot s^{-1})$

L,W,H = Length, width, and height of chamber

$$\tau = \frac{V}{Q} = \frac{LWH}{WH \times u} = \frac{L}{u}$$

Chamber efficiency (η):

The chamber efficiency can be estimated as follows:

$$\eta = \frac{V_t L}{Hw} = \frac{v_t w L}{Q}$$

$$\eta = \frac{V_t L}{Hu} = \frac{V_t W L}{Q}$$

For most air pollution

laminar?

For most air pollution, Stocks law settling velocity can be substituted to get the efficiency as follows:

100%

$$\eta = \frac{d_p^2 g(\rho_p - \rho_g)L}{18\mu_g Hu}$$

$$\eta = \frac{d_p^2 \, g(\rho_p - \rho_0)L}{}$$

Heat exchange

excosion
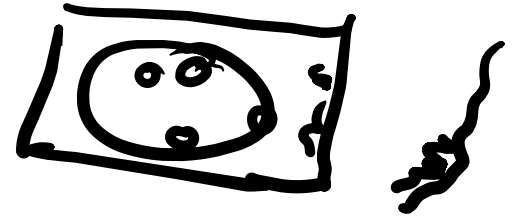
With 100% efficiency (η = 1), the Equation above becomes:

min particle.

$$d_{P,min} = \sqrt{\frac{18\mu_g Hu}{g(\rho_p - \rho_g)L}} \qquad d_{P,min} = \sqrt{\frac{18\mu_g Q}{g(\rho_P - \rho_g)WL}}$$

- A hydraulic acid mist in air at 25 °C is to be collected in a gravity settling chamber. Calculate the smallest mist droplet that will be collected by the chamber, applying stock's law. The operating data and dimension of settler are given below:

Wide (W) = 30 ft, Height (H) = 20 ft, Length (L) = 50 ft, Q_{gas} = 50 ft³/s, ρ_g = 0.076 lb/ft³, μg = 1.24 x 10^{-5} lb/ft.s, sp.gr of acid mist = 1.6

calculate the smallest acid mist:-

$$\eta = \frac{V_t \ L}{H \ u}$$

$\xrightarrow{\hspace{2cm}}$ speed of particle.

$\longrightarrow$ Speed of gas

I will assume $\eta = 100\%$

which means d_p in the equation , will be the mini.

$$\frac{\eta}{100\%} = \frac{d_p^2 \ g \ (\rho_p - \rho_0) \ L}{18 \ \mu_g \ H \ u}$$

$$Q \text{ for gas} = 50 \text{ ft}^3/s$$

$$u = \frac{Q}{A} = \frac{Q}{H \, W} = \frac{50}{(20)(30)} = 0.083 \text{ ft/s}$$

$$\rho_p = s_{p\text{-}gr.} \cdot \rho_{H_2O} = 1.6 \cdot 62.4 = 99.84 \text{ lb/ft}^3$$

$$d_{p,min} = \sqrt{\frac{18 \, \mu_g \, Q}{g \, (\rho_p - \rho_g) \, WL}}$$

$$= \sqrt{\frac{18 \, \mu_g \, u \, W \, H}{g \, (\rho_g - \rho_g) \, WL}} = \sqrt{\frac{18 \, \mu_g \, u \, H}{g \, (\rho_p - \rho_g) \, L}}$$

$$d_{p,min} = \sqrt{\frac{18(1.24 \times 10^{-5})(20 \times 0.083)}{32.2(99 - 0.076)(50)}}$$

$$= 4.81 \times 10^{-5} \, ft \left(\frac{0.3048 \, m}{1 \, ft}\right)\left(\frac{10^6 \, \mu m}{1 \, m}\right)$$

$$\boxed{= 14.7 \, \mu m.}$$

smallest mist particle.

Design of settling chamber

Equations are needed to design ....

Why the minimum height should be 1 meter in the design of settling champer?

$$WL = \frac{18\mu_g Q}{g\rho_P d_p^2}$$

$$A_c = WH = \frac{Q}{u}$$

where:

A_c = cross sectional area of the settling tank

Q volumetric flow rate of the gas stream

W = width of settling chamber

H = height of settling chamber

L = length of settling chamber

u = linear gas velocity, as a design rule of thumb must be below 10 ft/s (30 m/s).

Problem

- Design a gravity settler to remove all the iron particles from a dust laden stream. The particles diameter dp = 35 μm. Use the following data: Gas is air at ambient condition with charac teristics:

$$Q_g = 70 \ ft^3/s, \ u = 10 \ ft/s. \ \rho_g = 0.0775 \ lb/ft^3 \ , \ \mu_g = 1.23 \times 10^{-5} \ lb/ft.s, \ \rho_p = 475.7 \ lb/ft^3$$

- Note: use K-value to estimate type of region

$$k = d_p \left[\frac{g(\rho_p - \rho_g)\rho_g}{\mu_g^2} \right]^{1/3}$$

$\Rightarrow \quad d_p = \quad 35\,\mu m$

$\underline{\underline{16\,lft}}$

$k = \searrow$

$d_p = \quad 35\,\mu m \left[\frac{1}{10^6} \right]^m \left[\frac{1m}{0.3048} \right]^{ft}$

$= 11.48 \times 10^{-5}\,ft$

$Q:$

u

ρ_g

$\mu_g :$

$\rho_p :$

$g = 32.174 \text{ not } 9.81$

$\underset{\underset{\text{unit}}{\text{British}}}{\downarrow} \qquad \underset{SI}{\downarrow}$

$L = \begin{cases} \\ \end{cases}$ for settling chamber

This is the required for Design.

$\rho_p >> \rho_g \cancel{\times}$

$g = $ in British unit

$$k = 11.48 \times 10^{-5} \left[\frac{\boxed{\boxed{32.174}} (475.7)(0.0775)}{(1.23 \times 10^{-3})^2} \right]^{1/3}$$

$k = 0.1056 \; < 3.3$

Then Stockes law can be applied.

$$WL = \frac{18\,\mu_g\,Q}{g\,\rho_p\,d_p^2} = \frac{18(1.23 \times 10^{-5})(130)}{32.174\,(475.71)\,(11.48 \times 10^{-5})^2} = 142.5\,ft^2$$

$Q = u \ast \text{frontal Area}$

$HW = \dfrac{Q}{u} = \dfrac{130}{10} = 13\,ft^2$

$H\,min = 1m = 3.3\,ft$

$W = \dfrac{13}{3.3} = 3.94\,ft.$

$LW = 142.5\,ft^2$

$L = \dfrac{142.5}{3.94} = 36.2\,ft$

$LWH = 3.94\,(3.3)(36.2) = 470.7\,ft^3$

Design multi -tray settling chamber:

- A more elaborate settling chamber is the Howard type whose simplified diagram is shown in Figure beside.

- For settling chamber having the dimensions L x W x H and n number of trays including the bottom surface (Figure 5.12), the hydraulic diameter for flow passage between the trays is given by:

$$D_h = \frac{2W\Delta H}{W + \Delta H}.$$

$$Re = \frac{vD_h\rho_g}{\mu_g}$$
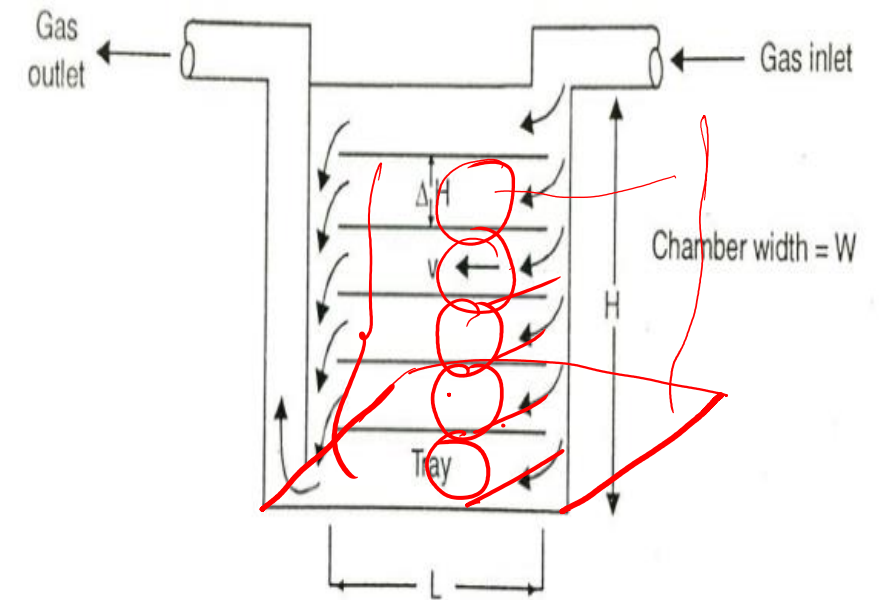
where v is the linear velocity and can be estimated according to the following:

$$v = \frac{Q}{nW\Delta H}$$ Total cross sectional area.

where Q is the volumetric flow rate.

Design multi -tray settling chamber:

- Now, substituting for v and D_h in the Equation of Reynold No.:

$$Re = \frac{2Q\rho_g}{n\mu_g(W + \Delta H)}$$

- The spacing between the trays is, ΔH is given by:

$$\Delta H = \frac{H}{n}$$

- Substituting for H in the Equation :

$$Re = \frac{2Q\rho_g}{\mu_g(nW + H)}$$

- The efficiency of collecting is given as follows:

$$\eta = \frac{V_t nWL}{Q}$$

The minimum particle size ,which is removed at assumption of 100% efficiency, can be estimated as follows:

$$d_{p,min} = \sqrt{\frac{18\mu_g Q}{nW Lg(\rho_p - \rho_g)}}$$

All previous equations for laminar flow condition.

Problem

n =

A multi-tray settling chamber having 8 trays. Including the bottom → n 14
surface, handles 6 m³/s of air at 20 °C. The trays are spaced 0.25 m a
part and the chamber is to be 1 m wide and 4 m long.
$= w$ $= L$

- 1. What is the minimum particle size of density 2000 kg/m³ that can
  be collected with 100% efficiency? $n = 100\%$

- 2. What will be the efficiency of the settling chamber if 50 μm
  particles are to be removed? $d_p = 50 \ \mu m$

- Assume Laminar flow condition within the chamber. μ_g at 20 °C =
  1.81x10⁻⁵ kg/m.s, ρ_p = 2000 kg/m³ . $= \mu_g$
                                                 vis

$=$ Particles.

$$d_{p(min)} = \sqrt{\dfrac{18 M_g Q}{n W L g (\rho_p - \rho_g)}}$$

$$\therefore \quad \underline{\rho_p \gg \rho_g} \quad \text{It can be neglected.}$$

$$① \quad \underline{d_{p(min)}} = \sqrt{\dfrac{18(1.8 \times 10^{-5}) 6}{\underline{18}(1)(4)(9.81)(2000)}} = 5.6 \times 10^{-5} m = 56 \mu m$$

$$W L$$
$$A_c = \text{cross sectional area}$$
$$A_f = \text{Frontal area}$$
$$A_f = W L$$

$$\dfrac{h_?}{h_{100}} = \dfrac{g d_p^2 (\rho_p - \rho_g) n W L}{\cancel{18 M_g Q}}$$
$$\dfrac{g d_{pmin}^2 (\rho_p - \rho_g) n W L}{\cancel{18 M_g Q}}$$

$$② \quad \boxed{\eta = \dfrac{V_t n W L}{Q} = \dfrac{g d_p^2 (\rho_p - \rho_g) n W L}{18 M_g Q}}$$

$$\dfrac{d_{p \text{ re } q u i r e}}{}$$

$$\eta = ? \quad \text{if the } d_p = 50 \mu m$$

$$\dfrac{\eta}{\eta_{100}} = \left(\dfrac{d_p}{d_{p min}}\right)^2 = \dfrac{\eta}{1} = \left(\dfrac{50}{56}\right)^2 = 80\%$$

$$\dfrac{\eta}{\eta_{100}} = \dfrac{50^2}{56^2} =$$

$$\dfrac{\eta}{100} = 0.79 \%$$
$$\eta \simeq 80\%$$

Turbulent Flow model (well-mixed settling)

This model is often referred as the well-mixed settling model. Assume that the gas flow is totally mixed in y-direction and not in x-direction.

$$cAu = (c + dc)Au + cu_tW\,dx$$

where c is the mass concentration, and $A = W\Delta H$

$$\int_{in}^{out} \frac{dc}{c} = \frac{u_tW}{Au}\int_0^L dx$$

$$ln\frac{c_{out}}{c_{in}} = \frac{u_tWL}{Au}$$
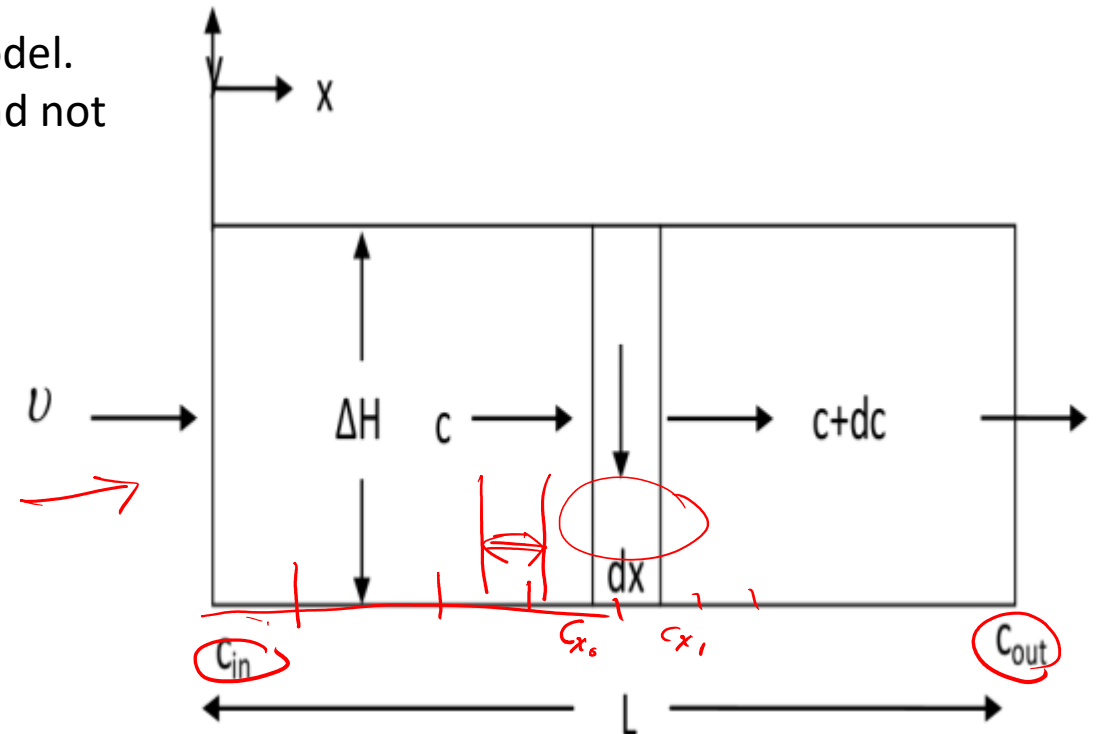
Mass concentration of particles entering the elemental volum $(A\,dx)$	$=$	Mass concentration of particles leaving the elemental volum $(A\,dx)$	$+$	Mass concentration of particles leaving the elemental volum $(A\,dx)$

The efficiency can be estimated as follows:

ℓ

$$\eta = 1 - \frac{C_{out}}{C_{in}}$$

what will

the η if the condition

is Turbulent.

If we substitute, the η will be estimated according to the following equation:

$$\eta = 1 - \frac{C_{out}}{C_{in}} = 1 - exp\left(-\frac{nWLu_t}{Q}\right)$$

The Equation above can be written in terms of η laminar, as follows:

$$\eta = 1 - \frac{C_{out}}{C_{in}} = 1 - exp\left(-\eta_{laminar}\right)$$

Centrifugal separators (Cyclone separators)design:

- Two standard designs for gas-solid cyclones; (a) high-efficiency cyclone, Figure (a) below and (b) high gas flow rate cyclone, Figure below (b). The performance curves for the high efficiency cyclone and high gas rate cyclone are shown in Figure below (a) and (b). These curves can be transformed to other cyclone sizes and operating conditions by use the following scaling equation for a given separating efficiency:

$$d_2 = d_1 \left[\left(\frac{D_{c2}}{D_{c1}} \right)^3 \left(\frac{Q_1}{Q_2} \right) \left(\frac{\Delta \rho_1}{\Delta \rho_2} \right) \left(\frac{\mu_2}{\mu_1} \right) \right]$$

d_1= mean diameter of particle separated at standard condition, at chosen separation efficiency.

d_2= mean diameter of particle separated in proposed design, at the same separation efficiency.

D_{c1}= diameter of standard cyclone = 8 inches (203 mm).

   -for high efficiency design = 223m³/h.

   -for high throughput design = 669m³/h

D_{c2}= diameter proposed cyclone, mm
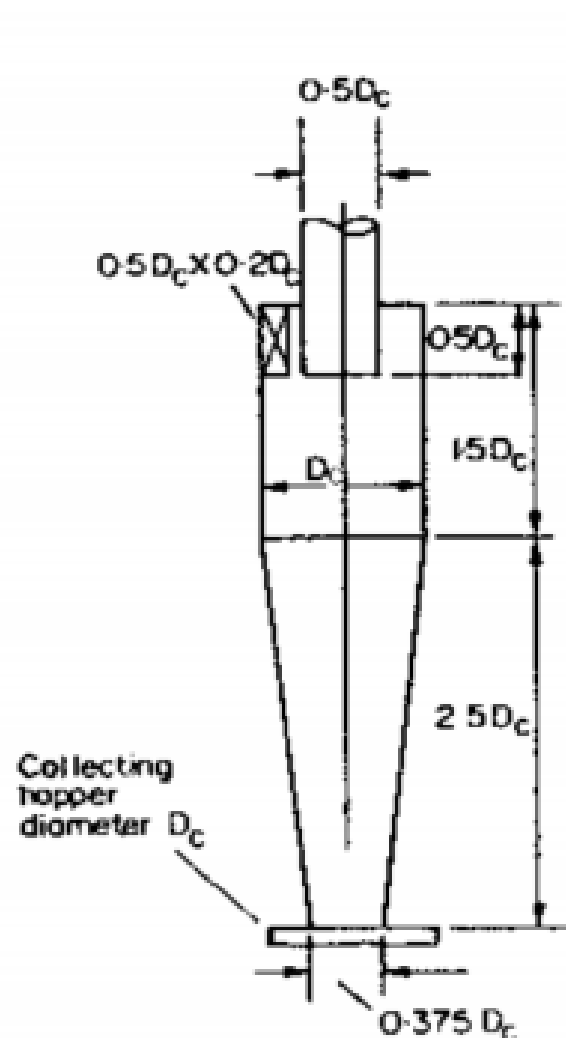
Q_1= proposed flow rate,m³/h.

Q_2= proposed flow rate,m³/h.

$\Delta\rho_1$= solid-fluid density difference in standard condition = 2000 kg/m³ .
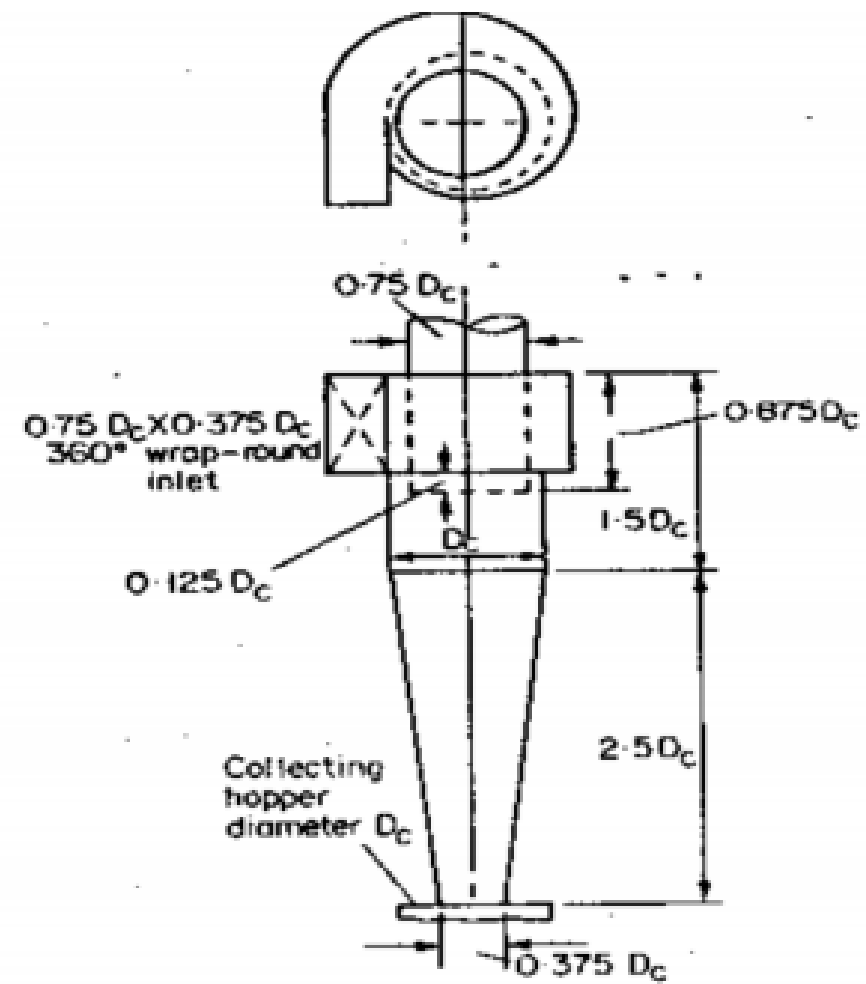
$\Delta\rho_2$= solid-fluid density difference, proposed design.

μ_1= fluid viscosity (air at 1 atm, 20 °C = 0.018mNs/m2).

μ_2= fluid viscosity, proposed design.

(a) High efficiency cyclone

(b) High gas rate cyclone

Cyclone pressure drop

- The pressure drop in cyclone will be due to the entry and exit losses, and friction and kinetic energy losses in the cyclone. The empirical equation can be used to estimate the pressure drop:

$$\Delta P = \frac{\rho_g}{203}\left(u_1^2\left[1 + 2\phi^2\left(\frac{2r_t}{r_e} - 1\right) + 2u_2^2\right]\right)$$

where:
ΔP= Cyclone pressure drop (millibars)
ρ_g= gas density (kg/m³)
u_1= inlet duct velocity (m/s).
u_2= exit duct velocity (m/s)
r_t= radius of circle to which the center line of the inlet is tangential(m)
r_e= radius of exit pipe (m)

ϕ= Factor estimated from Figure below
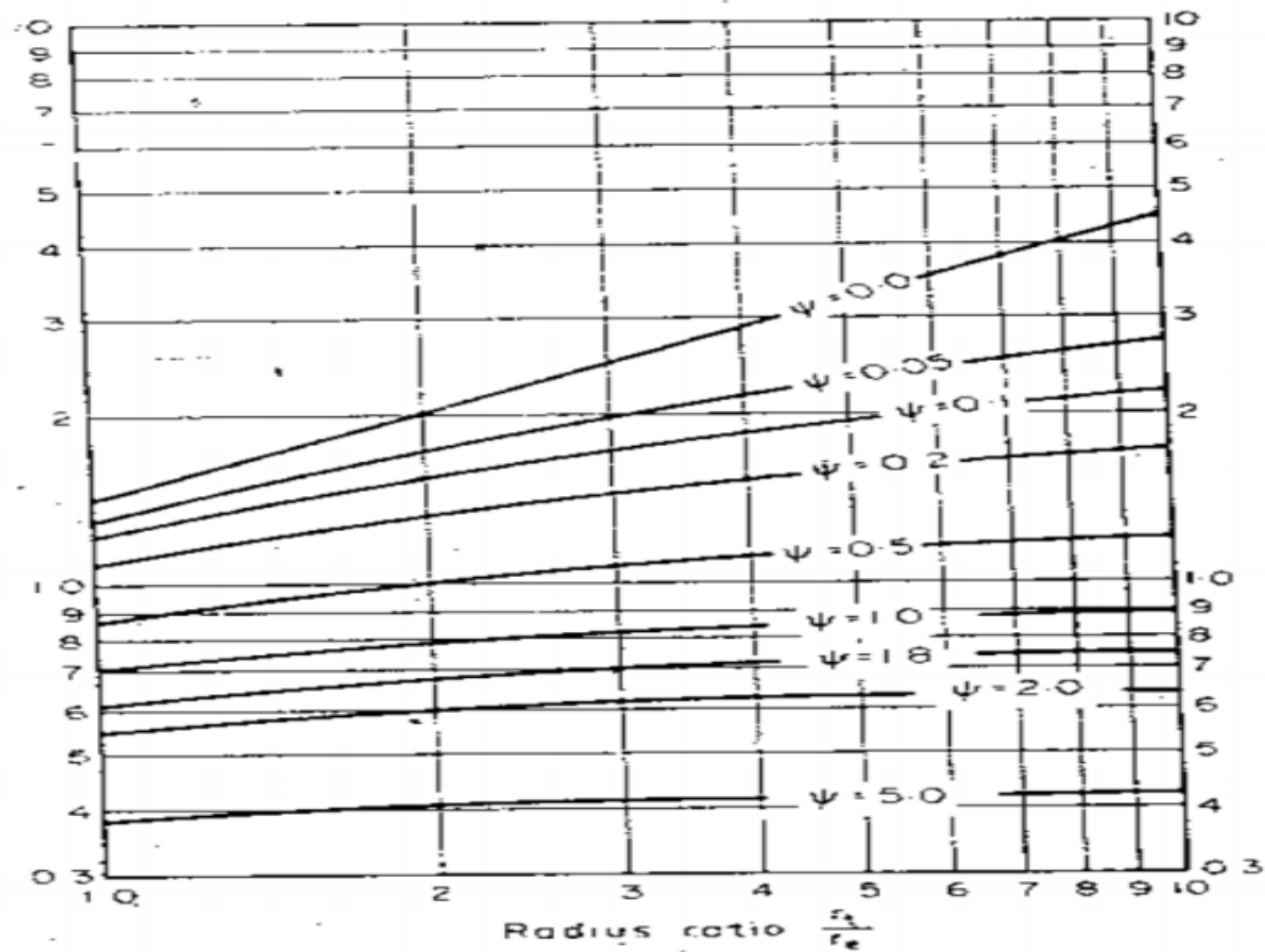ψ= $f_s A_c/A_1$ parameter used to detect (ϕ) from Figure
f_s= friction factor taken as 0.005 for gas
A_s= surface area of cyclone expose to the spinning fluid (m²)
A_1= area of inlet duct (m²)

Radius ratio $\frac{r_s}{r_e}$

Cyclone efficiency

- The efficiency of cyclone can be estimated by using the concept of a cut diameter, cut diameter can be defined as the particle diameter at which 50% of particle are removed by cyclone:

$$d_{p,50} = \left(\frac{9\mu_g b}{2\pi N V_g (\rho_p - \rho_g)}\right)^{\frac{1}{2}}$$

where:
μ_g= gas viscosity (kg/m.s)
b= cyclone inlet width (m)
N= effective number of outer turn in the cyclone (Normally 4)
V_g= inlet gas velocity (m/s)
ρ_p= particle density (kg/m³)
ρ_g= gas density (kg/m³)

Note:- The cut diameter can be used to establish the collection efficiency for any other diameter particle d_p as shown in Figure below
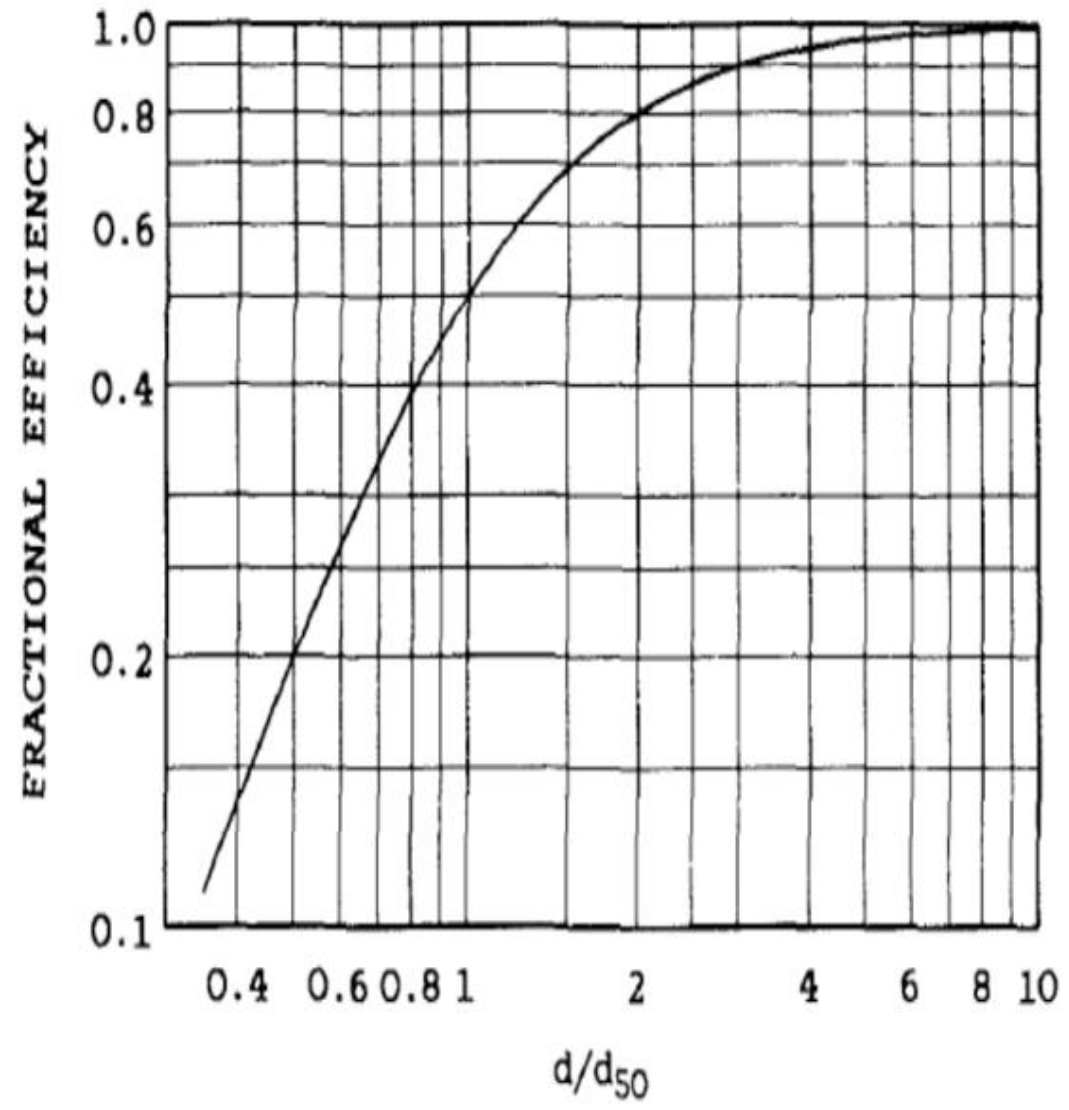
Environmental Engineering

Solid Waste Management

Solid waste

- Solid waste, often called the third pollution, after air and water pollution. Solid waste is that material which arises from various human activities and which is normally discharged as useless or unwanted.

Solid waste consists from:

Highly heterogeneous mass of discharged materials from the urban community

The more homogeneous accumulation of agricultural, industrial and mining waste.

Classification of solid wastes:
Solid wastes may be classified based party on content and party on moisture and heating value. A typical classification is as follows:

Garbage :	• Refers to the putrescible solid waste constituents produced during the preparation or storage of meat, fruit, vegetables etc. These wastes have a moisture content of about 70% and heating value of about 6×10^6 J/kg.
Rubbish:	• Refers to non-putrescible solids waste constituents, either combustible or non-combustible. Combustible wastes would include paper, wood scrap, rubber, leather etc. Non-combustible wastes are metals, glass, ceramics etc. These wastes contain a moisture content of about 25% and heating value of the waste is around 15×10^6 J/kg.
Pathological wastes	• Dead animals, human waste, etc. The moisture content is 85% and there are 5% non-combustible solids. The heating value is around 2.5×10^6 J/kg
Industrial Waste	• Chemicals, paints, sand, metal ore processing, fly ash, sewage treatment sludge etc.
Agricultural Wastes	• Farm animal manure, crop residues

Disposal Methods for solid waste

- An appropriate selection of disposal method of solid waste:

Can save and avoid future problems.

The method should also provide opportunities for recycling of materials if possible

Should not pollute the air, the ground water, the surface water or the land.

Disposal Methods

Open dumping

Sanitary landfill

Incineration

Composting

Open dumping

- Open dumping is practiced in many cities because it is cheap and requires no planning.

- The open dumps cause public health problems by encouraging the breeding of flies, rats, mosquitoes and other pests.

- They also become source of objectionable odors and cause air pollution when the wastes are burned in order to reduce their volume and conserve space.

Sanitary landfill

- Sanitary landfilling is an engineering operation, designed and operated according to acceptable standards. It may be defined as a method of disposing refuse on land without creating nuisances or hazards to public health or safety.

Describe the Sanitary landfill operation?

- In sanitary landfill operation, refuse is spread and compacted in thin layers within a small area. This layered structure is usually referred to as a cell. The cell is then covered with a layer of soil which is spread uniformly and then compacted. To provide an adequate seal the cover should normally be at least 20 cm thick. When a number of cells reach the final desired elevation, a final cover of about one meter of earth is placed and it is again compacted. The final cover is necessary to prevent rodents from burrowing into refuse.

Incineration

- Incineration involves burning of solid wastes at high temperature, leftover ashes, glass, metals and unburned combustible amount to perhaps 25% of the original waste.

- Incineration leads to air pollution unless the plant is designed, equipped and operated to comply with air pollution standards. Typical air pollution from incineration is fly ash, SO2, hydrogen chloride, and organic acid.

- Incineration is an economic method for solid waste disposal because useful material and energy can be recovered from the process. Heat can be recovered by putting a waste heat boiler or some other recovery device on an existing waste incinerator. The solid waste has about one-third the heating value of coal with very low sulfur content.

- The advantages of incineration include wide range ability for handling varying loads and small space requirement for ultimate disposal. However, the method requires fairly high level of maintenance and the operating costs are higher than those for operating of a sanitary landfill.

Composting

Composting of refuse is an aerobic method of decomposing solid waste. Many types of microorganisms already present in the waste stabilize the organic matter in the waste to produce a soil conditioner.

Describe the composting operation?

- Initially, the process starts with the mesophilic bacteria which oxidize the organic matter in the refuse to carbon dioxide and liberate heat. The temperature rise to about 45 °C and at this point the thermophilic bacteria take over and continue to decomposition. During this phase, the temperature further rise to about 60 °C. The refuse is periodically turned over to allow sufficient oxygen to penetrate to all parts of the material to support aerobic life. After about three week, the compost is stabilized. The end point of operation can be measured by noting a drop in temperature. The compost should have an earthy smell and a dark brown color.