Control of Air Pollution

The air pollutants in atmosphere are controlled by natural processes as well as by engineered systems wherever necessary.

Natural self cleaning properties of the Environment:

→ The various natural processes which act as the pollution removal mechanisms in the atmosphere such as dispersion, settling, washout, rainout and adsorption.

→ Although dispersion is not really a removal mechanism, it reduces concentration of pollutants at one place.

→ Settling means gravitational settling which removes relatively large particles of diameter greater than 20 micrometer.

→ Washout is the natural absorption process where particulates or gaseous pollutants are collected in rain (or) mist and settle down with that moisture.

- This process, however does not help in removing particles smaller than 1 um in size.

→ Rainout is the process involving precipitation above the cloud level, where submicron particles present in the atmosphere serve as condensation nuclei, around which drops of water may form and fallout as rain drop.

Types of Collection Equipment:

A list of common types of collection equipment for aerosols (particulates) as follows:

1) Settling Chambers
2) Inertial Seperators
3) Cyclones
4) Filters
5) Electrostatic precipitators
6) Scrubbers (or) Wet collectors

1) Settling Chambers:-

→ It is the simplest type of equipment used f the collection of solid particulates.

→ It consists of a chamber in which the car gas velocity is reduced so as to allow the particulates to settle out of the moving st under the action of gravity.

→ The most common form is a long box like with an inlet at one end and an outlet at other, set horizontally, often on the ground.

→ It can be constructed from brick and concrete.

→ The solid particles having the higher density the surrounding gas, settle under the influe of gravity on the base of the chamber, from where they are removed through hoppers.

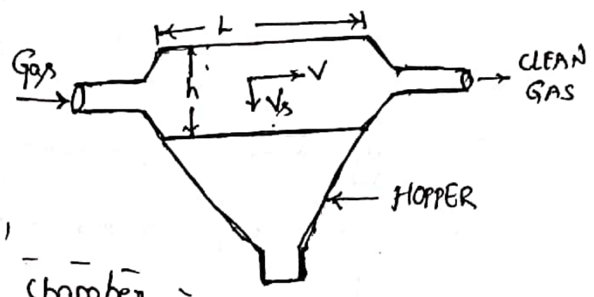
→ Gravity settling chamber assumes that the solids move along the chamber with the velocity of gas and also settle with Stoke's velocity.

→ If the settling time is same (or less than) the time the gas ~~taken~~ takes to pass through the chamber.

Thus,

$$\frac{V_s}{V} = \frac{h}{L}$$

$$\Rightarrow V_s = \frac{Vh}{L}$$



Where L = length of the chamber

V_s = settling velocity of particulates

V = horizontal velocity of carrier gas

h = height through which the particulates travel before settling down.

By Stoke's Law

$$V_s = \frac{gD^2(G_s - 1)}{18\nu}$$

Advantages:

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

Disadvantages:

1) Large space requirements

2) Only comparitively large particles can be collected.

Applications:

→ These are used widely for the removal of large solid particulates from natural draft furnaces, kilns etc.

→ They are also, sometimes used in the process industries, particularly the food and metallurgical industries, as a first step in dust control.

2. Inertial Seperators: It includes all collectors which utilise the relatively greater inertia of the dispersoid to effect the particulate - gas seperation.

→ Two types of equipment utilise this fundamental principle. They are

i) Inertial or Impact Seperators

ii) Cyclonic Seperators.

i) Inertial Seperators: They employ incremental changes of direction of the carrier gas stream to exert the greater inertial effects of the dispersoid.

There are 3 fundamental types

1) Baffle type Separator

2) Louvre type "

3) Dust traps

Baffle type Separator:

→ This is the simplest type of impingement separator.

→ Here the gas stream is made to follow a tortuous flow path, which is obtained by the insertion of staggered plates into the path of the gas stream.

→ This device is suitable for removing particles larger than 20 μ diameter.

→ It is simple to operate. It has no moving parts.

→ It is slightly more expensive to construct than a simple open settling chamber, because of the interior work involved in fabricating and installing the baffles.

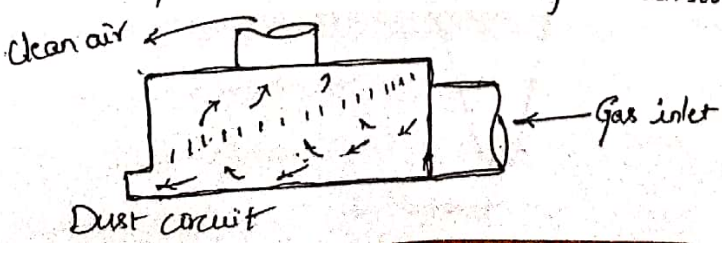
→ These devices are widely used for particulate removal in power plants and rotary kilns.

Louvre Type Separator:

→ Here there is a series of louvres (or) impingement elements set at an angle to the carrier gas stream so as to cause a rapid reversal of the gas flow direction and thereby cause the particulates to impinge on the louvres.

→ This is suitable for removing particles larger than 30μ in diameter.

→ This is simple and low cost of construction.



Dust Trap: In this, the dust laden gas is introduced into a central pipe, and is made to undergo a change in direction by 180°.

→ This is useful when the loading is high and quantity of gas to be handled is low.

→ The collection efficiency for particles greater than 50 μ is about 70%.

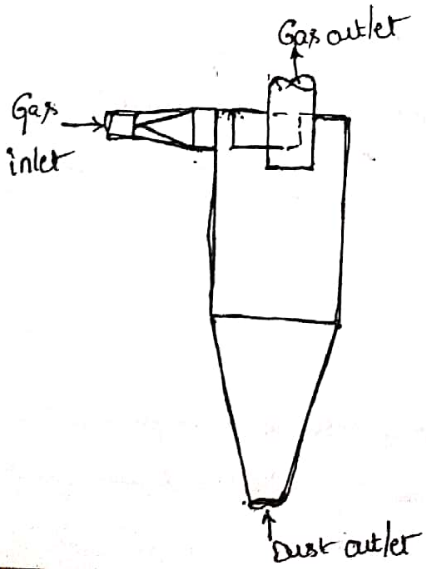
Cyclones:- They produce a continuous centrifugal force as a means of exerting the greater inertial effect of the dispersoid.

→ It is an important and popular type of dust removal equipment.

→ It consists of a vertically placed cylinder which has an inverted cone attached to its base.

The particulate - laden gas stream enters tangentially at the inlet point into the cylinder.

→ The outlet pipe for the purified gas is a central cylindrical opening at the top. The dust particles are collected at the bottom in a storage hopper.



- The gas path generally follows a double - Vortex
- The minimum diameter of a particle which can theoretically be completely seperated from the gas stream is

$$D_p(\text{min}) = \left[\frac{9 \mu B}{\pi V N_t (\rho_p - \rho)}\right]^{1/2}$$

Where,

μ = Viscosity of the fluid (poise)

B = Width of cyclone inlet duct (cm)

V = avg inlet velocity (cm/s)

N_t = number of turns made by gas stream in cyclone.

ρ_p = density of the particle (g/cc)

ρ = density of fluid (g/cc)

- For a given pressure drop, smaller the diameter, higher is the efficiency, because centrifugal action increases with decreasing radius of rotation.
- Cyclone efficiencies are greater than 90% for particles with diameter of the order of 10 μ. For particles with diameter higher than 20 μ, efficiency is about 95%.
- They can be operated at temperatures as high as 1000°c and pressures 500 atmospheres.
- An important precaution to be taken in operating a cyclone is to prevent gas leakage.
- A 15% gas leakage can bring down the efficiency to virtually zero.

Operating Problems: There are 3 important operating problems i) erosion ii) Corrosion & iii) material build-up

i) Erosion: Heavy, hard, sharp-edged particles, in a hi[gh] concentration, moving at high velocity in the cyclo[ne] continuously scrape against the wall and can erode the metallic surface unless suitable materi[als] are used.

ii) Corrosion: It is a problem if the cyclone is operating below the condensation point when reactive gases are present in the effluent stream.

iii) Build-up: Build-up of dust cake on the cyclone walls, especially around the Vortex finder, at the en[d] of any internal vanes, and opposite the entry can become a severe problem.

→ It occurs most frequently with hygroscopic d[ust]

Advantages of Cyclones:

1) Low initial cost
2) Simple construction & operation
3) Low pressure drop
4) Low maintenance requirements
5) It has no moving parts
6) Continuous disposal of solid particles
7) They can be constructed of any material which will meet the temperature and pressure requirements and corrosion potential of the carrier gas stream.

Disadvantages:

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

2) Equipment is subject to severe abrasive deterioration

3) Multiple Cyclones:

For high efficiency at reasonable capacity, a battery of smaller cyclones operating in parallel is used in preference to a large single unit. This battery of smaller cyclones is known as "multiple cyclones".

→ Multiple cyclones consist of rows of parallel tubes, about 25 cms in diameter, with a common inlet chamber, a common outlet plenum, and a common dust collection system.

→ Multiple cyclones have good abrasion resistance.

→ They have low pressure drops and are highly efficient in collecting heavy particles.

→ These are used as collectors for cement clinkers, steel mill sinter and stone dust in quarry & asphalt operations.

Cyclones in Series: The efficiency of two cyclone dust collectors operating in series is

$$\boxed{\eta = \eta_p + \eta_s (100 - \eta_p)}$$

Where:
η = efficiency of the combination of both cyclones
η_p = efficiency of the primary cyclone
η_s = " " " secondary "

→ The second cyclone serves to remove particles which were not collected in the first cyclone.

→ The efficiency of the second cyclone will be less than that of the first cyclone.

Advantages:

1) Cyclones in series may be used to maintain a large degree of dust collection even if the du outlet of the primary cyclone plugs. In such a condition, the secondary cyclone acts as a prim cyclone as far as collection efficiency is conc

2) A primary large diameter cyclone may be used collect coarse material which would otherwise the smaller passages of more efficient small diameter secondary cyclones.

Filters: It is one of the most reliable, efficient and economic methods by which particulate - matter can be removed from gases.

→ They can be broadly divided into

1. Fabric or cloth filters
2. Fibrous or deep - bed filters

1. Fabric filters: In this, the filter is in the form of a fabric bag arrangement - tubular bags or as cloth envelopes, and is suitable for a dust loading of the order of 1 g/cu m.

→ The most common type is the tubular type, consisting of tubular bags.

→ A bag filter consists of numerous vertical bags of 1200 - 400 mm dia and 2 - 10 m long.

→ They are suspended with open ends attached to a manifold.

→ The hopper at the bottom serves as a collector for the dust.

→ The gas entering through the inlet pipe strikes a baffle plate, which causes the larger particles to fall into a hopper due to gravity.

- The carrier gas then flows upward into the tubes and then outward through the fabric leaving the particulate matter as a 'cake' on the inside of the bags.

→ Efficiency during pre-coat formation is low, but increases as the pre-coat is formed, until a final efficiency of over 99% is obtain[ed]

→ They can be cleaned by rapping, shaking or vibratio[n] (or) by reverse air flow, causing the filter cake to be loosened and fall into the hopper below.

→ The normal velocities at which the gas is passed through the bags is 0.4 - 1 m/min.

Factors Affecting Efficiency: The efficiency may decrease due to

1> Excessive filter ratios – 'Filter ratio' is defined as the ratio of the carrier gas volume to gross filter area, per minute flow of the gas.

– Excessive filter ratio's lower particulate remo[val] efficiency and result in increased bag wear.

2> Improper selection of filter media:

While selecting filter media, properties like temperature resistance, resistance to chemical attack and abrasion resistance should be tak[en] into consideration.

Operating Problems :-

1) Cleaning: important operation problem is the periodic cleaning of the bags.

→ At intervals they get so clogged up with a covering of dust particles that the gas can no longer pass through them.

→ Then the bags have to be cleaned by rapping, shaking (or) by reverse air flow.

2) Rupture of the cloth: It results from shaking.

→ It is often difficult to locate ruptures, and when they are found the replacement time is often considerable.

3) Temperature: Upper temperature limit is about 260 - 290 °c.

→ They will not perform properly if a gross temperature overload occurs.

4) Bleeding: is penetration of the fabric by the fine particles, which we come across occassionally in fabric filtration.

→ The solution is to use a double layer material (or) a thick woven fabric.

5) Humidity: Humidity control is a common and important problem, especially if a hygroscopic dust is involved.

6) Chemical attack: There is a possibility of chemical attack due to corrosive chemicals present in the process effluent.

Advantages :

1. High collection efficiencies for all particle sizes, especially for particles smaller than 10 μ in dia
2. Simple Construction & Operation
3. Nominal power consumption
4. Dry disposal of collected material.

Disadvantages :-

1. Operating limits are imposed by high carrier gas temperatures, high humidity etc.
2. High maintenance and fabric replacement costs
3. Large size of replacement
4. Problems in handling dusts which may abrade, corrode, or blind the cloths.

Applications :-

- Metallurgical industry
- Foundries
- Cement industry
- Chalk and lime plants
- Brick works
- Ceramic industry
- Flour Mills

Fibrous or Deep-bed Filters:

A fibrous medium like mats of wool, cellulose, etc. acts as a separator and the collection takes place in the interstices of bed, and is suitable for light dust loads of the order of 1 mg/cu.m.

→ The filters can be classified as either viscous or dry.

→ In the viscous type, the filter is coated with a sticky material or 'adhesive' to help in catching the particles and prevent re-entrainment.

→ The adhesive is usually an oil (or) grease of high flash point and low volatility, and it should be a good wetting agent.

→ Dry filters for air conditioning are supplied in units similar in size to the viscous type except that the depth of the dry cell is usually greater.

→ The filter materials may be paper, glass fibres, or cotton batting.

→ ~~They are generally~~ An advantage of deep bed filters is that they are generally very good for service in a corrosive atmosphere because of their "throw-away" nature.

Electrostatic Precipitators: These are particulate coll... devices that utilise electrical energy direct... to assist in the removal of the particul... matter.

→ They have been successfully used for removal of fine dusts from all kinds of waste gases with very high efficiency.

→ Particles as small as a tenth of a micron can be removed.

→ Principle: When a gas containing aerosols is passed between two electrodes that are electrically insulated from each other and betw... which there is a considerable difference in electric potential, aerosol particles precipitate on the l... potential electrode.

→ They are mainly used for industries. They ca... also be used for air cleaning in public buildi... theaters, railways etc.

→ It consist of six major components

1. A source of high voltage
2. Discharge electrodes and collecting electrodes
3. Inlet and Outlet for the gas
4. A means for disposal of the collected material
5. An electronic cleaning system
6. An outer casing to form an enclosure arou... the electrodes

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Steps in the process

1. Place the charge on the particle to be collected
2. Migrate the particle to the collector
3. Neutralise the charge at the collector
4. Remove the collected particle.

Single-stage and Two-stage Precipitators

→ In a single stage precipitator, gas ionisation and particulate collection are combined in a single ~~stage~~ step.

- Whereas in the case of a two-stage precipitator, particles are ionised in the first chamber and collected in the second chamber.

→ Almost all industrial precipitators are of the single-state design.

→ Usually, two stage is used for lightly loaded gases and the single stage, for more heavily loaded industrial gas streams.

→ **Pipe type and Plate type Precipitators:-**

These are two basic designs of the single-stage precipitator.

i) Pipe-type: In this, the collecting electrodes are formed by a nest of parallel pipes which may be round, square (or) octagonal.

→ Generally, the pipe is about 30 cm in dia or less.

→ Pipe electrodes may be 2-5 m high. Spacing between the discharge electrode and collecting electrode ranges from 8-15 cm or even 20 cm.

ii) **Plate-type:** In this, the collecting electrodes consist of parallel plates.

→ The discharge electrodes are similar to those used in pipe-type precipitators, i.e., they are wires with a small curvature.

→ Plates may be 1-2 m wide and 3-6 m high.

→ The collection of the aerosols takes place on the inner sides of the parallel plates.

→ The dust material collected can be removed by rapping either periodically (or) continuously.

→ **Dry & Wet type Precipitators:**

Precipitators can also be classified as dry and wet precipitators, depending upon whether the mode of operation is a dry process or a wet one.

→ If particulate matter is removed from the collecting electrodes, by rapping (or) vibration only, it is known as a dry precipitator.

→ If water (or) other fluid is used for removal of solid particulate matter, it is known as a wet precipitator.

→ In general, wet precipitators are more efficient collec[tors.] However, it is the dry process type precipitators which are predominantly used.

Advantages:

High collection efficiency

Particles as small as 0.1 μm can be removed.

Low maintenance and operating costs.

Low pressure drop (0.25 - 1.25 cm of water)

Satisfactory handling of a large volume of high temperature gas.

Treatment time is negligible.

Cleaning is easy by removing units of the precipitator from operation.

There is no limit to solid, liquid (or) corrosive chemical usage.

Disadvantages:

1. High initial cost
2. Space requirement is more because of the large size of the ~~requirement~~ equipment.
3. Possible explosion hazards during collection of combustible gases (or) particulates.
4. Precautions are necessary to maintain saftey during operation.
5. The poisonous gas, ozone is produced by the negatively charged discharge electrodes during gas ionization.

Applications of Industrial Precipitators

1) Cement factories
   - Cleaning the flue gas from cement kilns
   - Recovery of cement dust from kilns
2) Pulp and Paper mills
3) Steel Plants
   - Cleaning blast furnace gas to use it as a fuel
   - Removing tars from coke oven gases
4) Non-ferrous metals industry
5) Chemical industry
6) Petroleum industry
7) Carbon black industry
8) Electric power industry
   - collecting fly ash from coal-fired boilers.

Scrubbers (or) Wet Collectors:

These are devices which utilise a liquid to assist in the removal of particulates from the carrier gas stream.

- Generally, water is used as the scrubbing liquid.

→ Four major steps are involved in collecting particles by wet scrubbing.

- The first of these is transport. The particles must be moved to the vicinity of the water droplets which are usually 10 to 1000 times larger.

→ The second step is Collision. The particle must collide with the droplet.

→ The 3rd step is adhesion. Adhesion is promoted directly by the property surface tension.

→ The 4th step is precipitation, (or) removal of the droplet containing the dust particle from the gas phase.

Types of Scrubbers:

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

1. Spray towers: It is the simplest type of gas scrubber. It can be either round (or) rectangular.

→ The principal Collection mechanisms are impingement and interception.

→ These are used only for removing coarse dusts (> 1-2 μ) where high efficiency is not required.

→ These are used as coolers and as primary cleaners in treating blast furnace gas and for fly ash and cinder removal.

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Venturi Scrubbers: It is a high energy wet scrubber with a good efficiency.

→ In this the particulate laden stream is directed through a venturi tube at throat velocity of 60 to 100 m/s.

→ Inertial impact is the primary collection mechan… the faster the gas passes through the venturi, … higher the efficiency.

→ These are used for removing mists and dusts from gases from Kraft mill furnaces, various metallurgy furnaces.

Cyclone Scrubbers: This is a modification of the d… cyclone by the addition of a liquid phase.

→ Impingement and inertial seperation are the primary collection mechanisms.

→ Wet cyclone has higher efficiency than the dry cyclone.

→ However, sludge removal is more difficult … dry particulate removal.

Packed Scrubbers: It uses fibre glass (or) other …

→ Impingement is the primary collection mechanism

→ These can also be of co-current type (or) cross-… type design depending on the direction of liquid flow with respect to the direction of gas …

Mechanical Scrubbers: It is a mechanically aided unit which has an internal rotating mechanical part.

→ These are high energy scrubbers.

→ Liquid - dispersoid contact is achieved by the simultaneous introduction of the liquid medium and the gas stream on to the rotating discs, blades (or) perforated plates.

→ These scrubbers have a high initial cost, high - operating cost, and require considerable maintenance.

→ The water use rate is also high.

Advantages:

1. Low initial cost
2. Moderately high collection efficiency for small particles
3. Applicable for high temperature installations
4. They can simultaneously remove particulates and gases.
5. There is no particle re-entrainment

Disadvantages:

1. High power consumption for higher efficiency
2. Moderate to high maintenance costs owing to corrosion and abrasion
3. Wet disposal of the collected material.

Choice of Equipment:

While selecting a particulate collector from various equipment available, the following factors must be taken into consideration.

1. Particulate size, shape and density
2. Particulate loading (mg/m3)
3. Efficiency required
4. Properties of the carrier gas

   a) Composition b) Temperature c) Pressure d) Viscosity e) Density f) Humidity g) Combustibility h) Reactivity i) Toxicity j) Electrical and Sonic properties.

5. Flow characteristics of the carrier gas

   a) Flow rate b) Variations in flow rate

6. Specific properties of the contaminant

   a) Composition b) Contaminant phase c) Solubility d) Combustibility e) Reactivity f) Toxicity g) Hygroscopicity h) Agglomerating characteristics i) Electrical and Sonic properties j) Catalyst poisoning

7. Allowable pressure drop
8. Contaminate disposal
9. Capital and Operating costs of the equipment
10. Ease of maintenance and reliability.