FUNDAMENTALS OF AIR POLLUTION CONTROL

Air pollution control methods & equipment

- The industrial growth had made our life more comfortable
- The world has became smaller because of rapid transportation
- The growth of industries has another side of coin i.e. pollution
- We have to use same control methods to minimize the pollution

Dilution

- Accomplished by the use of tall stack
- It's Short term control & may cause highly considerable effects.
- For effective dilution

  $H = 74\ Q^{0.27}$

  H = Stack height

  Q = Particulate emission rate
- $H_{SO2} = 14\ Q^{1/3}$

  H = Stack height, m

  Q = SO_2 rate, kg/hr

Gravity settling

Absorption

- Natural Absorption process
  - Particulate or Gaseous
- Below cloud level
- Falling rain drops absorbs pollutants called as Washout or scavenging
- Does not remove particles less than 1µm in size.
- Gaseous pollutants removed in dissolved state with moisture with or without chemical changes.

Rain

Adsorption

- Prevention is Better than cure…..
- Try to minimize the WASTE at SOURCE
- It can be done by
  - Investigation of various approaches at early stage of process design & Development
  - Selection of method which do not contribute pollution
  - This methods are called as source correction methods….
  - Application of this methods are difficult in the existing plant, but still could be applied without severely upsetting the economy of the operation

Control of pollution at SOURCE

- Raw material changes
- Operational changes
- Modification or replacement of process equipment
- By more effective operation of existing equipment

Raw material changes

- If raw material is responsible for causing air pollution
  - Use of a purer grade of raw material
    - Reduce undesirable impurities & by-product
    - Eliminate treatment of effluent gas
  - Use of low sulfur fuel in place of higher ones
    - Limited availability of low sulfur fuel for wholesale use
    - Fuel desulfurization is an attractive alternative
  - Ore handling operation usually result in emission of large quantities of dust into atmosphere.

- In steel industries replacement of raw ore with pelleted ore has gradually reduced dust emission

Process change

- It involves new or modified techniques to lowering atmospheric pollutant emissions
- Radical changes in chemical & petroleum refining had minimized the material emission to atmosphere.
  - The volatile substance are recovered by condensation & the non-condensable gases are recycled for additional reaction

- Rotary kiln are major source of dust generation in cement plant.
- Some dust is controlled by adjusting operating conditions such as
  - reduction of gas velocities
  - modification of the rate
  - location of feed introduction

- Smelting & paper industries are major source of emission of sulphourous material
- It can be reduced by major process changes such as
  - hydro-metallurgical separation of ore
  - Avoiding use of sulphide in paper making

- Formation of nitric oxide in combustion chamber reduce by low excess air combustion by flue gas recirculation & water injection
- The fly ash emission from coal pulverization reduce by washing of coal before pulverization

Equipment modification or replacement

- In petroleum industries hydrocarbon vapors are released into atmosphere from storage tanks due to temperature changes, direct evaporation and displacement during filling.
- These can be minimized by designing tank with floating roof covers or by pressurizing the tanks.

- Replacement of open hearth furnace with oxygen furnace in steel industries
- Use of alternative power source for automobiles in place of internal combustion Engine.
- In addition to above three methods, air pollutant emission can be reduced by
  - proper equipment maintenance
  - housekeeping
  - changes in the design of local exhaust hood & proper installation

- Chemical plants have excessive leakage around ducts, piping, valves & pumps. Checking the seals routinely can prevent such leaks
- Floor, storage bins, loading areas & material transmitter conveyors must be kept clean to reduce dust pollution.

Selection of Air pollution control equipment

- Quantity of gases to be treated
- Pollution load
- Temperature & pressure
- Corrosive effect
- Desire quality of treated effluent

Objectives of using Control Equipment

- Prevention of nuisance
- Prevention of Physical damage to property
- Elimination of health hazard to plant personnel & general population
- Recovery of the valuable product and material
- Minimization of economic losses
- Reduction of plant Maintenance
- Improvement of Product Quality

Separation Mechanism used in pollution control equipments

1. **Gravitational Settling**
2. **Centrifugal Impaction**
3. **Direct interception**
4. **Diffusion**
5. **Electrostatic precipitation**

Gravitational Settling

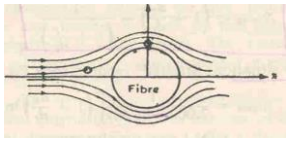
- Particulates Settles under the influence of Gravitational Force when sufficient resident time is provided in Equipment.
- e.g. Settling Chambers

Centrifugal Impaction

- Centrifugal Force is created by motion gas in the equipments because of which Particulates (Particles) are thrown at the wall and decreases bottom and relatively particulate free gas makes central care which rises up and leaves at top.
- e.g. Cyclone separator

Direct interception

- Interceptive plates in the path intercept particle from gas stream by some means like the direction of gases streams is changed.
- eg. Fabric filter system



Diffusion

- Basically mass transfer operations and equipments used to separate / eliminate gaseous / odors contaminants by contacting with suitable phase.
- Eg. Scrubbing, Absorption, Adsorption, etc.

Electrostatic precipitation

- by passing negatively charged gas through positively charged Cylinder, the particulate matter is collected on wall of positively charged cylinder.
- E.g Electrostatic precipitator

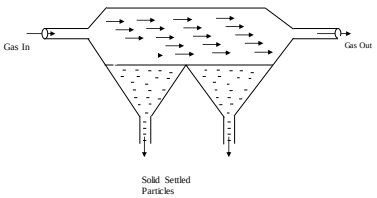
There are generally five equipments

1. Gravitational settling chamber
2. Cyclone Separators
3. Fabric filters
4. Electrostatics Precipitators
5. Wet collector

Gravitational settling chamber

- It is simplest type of equipment
- Used for separation of solid particulates(>50µm) from gas stream
- **Principle:** Particulates Settles under the influence of Gravitational Force when sufficient resident time is provided in Equipment.

Gravity Settling Chamber



- **Construction and working:**
  - It consist of a chamber in which carrier gas velocity is reduced so as to allow the particulate to settle out of moving stream under the action of gravity.
  - The most common form is a long box with inlet at one end and outlet at other end, placed horizontally on ground.

- Air enters at one end & leaves on the other end, the air (carrier gas) velocity is reduced for allowing the particulates to settle out of the moving stream under the influence of gravity
- The entering particles in the upper part of the chamber are collected at the bottom & then in hoppers, if the settling time is same are or less then time the gas takes to pass through the chamber
- The efficiency of settling chamber can be improved by using the horizontal trays in the chambers so height to be traveled by particle is less

Advantages

- low initial cost
- simple construction
- low maintenance cost
- low pressure dope
- Dry & continues can be used
- Temp & pressure limitation can by material of construction

Disadvantages

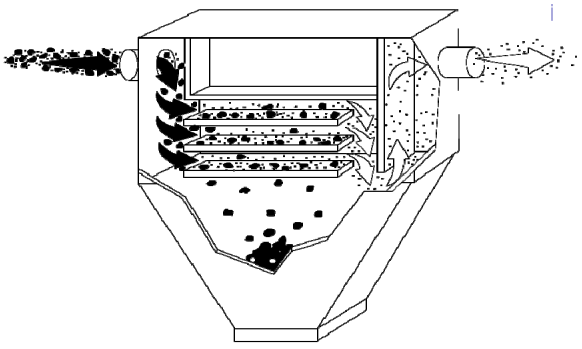
- large space required
- It is used for particle less then 50 µm .
- Efficiency is low.

Application of settling chamber

- Industrial applications of this equipment are less.
- Settling chamber is used to removes the particles of diameter greater than 50 micron.
- Removes carbon black from metallurgical fumes

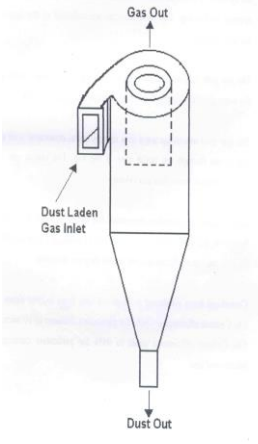
- Removal of large particles from natural draft furnaces kilns
- It is used as a primary dust control equipment in food industries

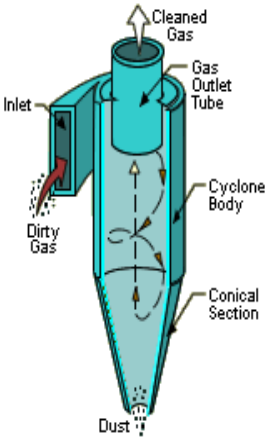
Howard Settling Chamber



Cyclone Separator

- **Principle:** centrifugal force is generated by using high gas velocity and this force is used to remove solid particles from gas





Construction and working

- It is the structure without moving parts in which the Velocity of an inlet gas stream is transferred in to a confined vortex from which centrifugal Forces tend to drive the particles to the wall of the Cyclone Body.
- It consists of a vertically placed Cylinder which has an inverted cone attached to its base.

- The particulate laden gas streams enter tangentially at the inlet point in to the cylinder.
- The outlet pipe for the particulate free gas is central Cylinder opening at the top.
- The gas receives a rotating motion. The vortex so formed develops centrifugal forces
- The gas path follows a double vortex.
- First the gas spirals down ward at the outer periphery of the cylindrical portion and reaches the Bottom.

- The gas then moves up ward in a narrow spiral concentric with the first and leaves through the outlet pipe at the top.
- The carrier gas velocity exceeds several times inlet gas velocity.
- Due to such rapid spiraling movement the disperses solid (Particulate) are thrown at the wall of the cyclone by the Centrifugal Force and than they drop by the gravity to the bottom where they are collected.

- Centrifugal force employed in Cyclones varies from 5-2500 times gravity.
- The Cyclone efficiencies < 90% for particulate diameter of 10 micron.
- The Cyclone efficiencies equal to 95% for particulate diameter of 20 micron and less

Efficiency increases with increase in:

- Dust Particle Size
- Dust Particle Density
- Gas Inlet Velocity
- Inlet Dust loading
- Cyclone Body Length (Number of Gas Revolutions)
- Ratio of Body Diameter to Gas Outlet Tube Diameter.

Efficiency Decreases with

Increase in

- Gas Outlet Diameter
- Cyclone Diameter
- Gas Viscosity / Density
- Inlet width and Inlet Area.
- Mixing of Dirty gas with clean gas at top

To Increase Efficiency a smaller diameter long taper Cyclone should be used.

Operating Problems:

There are three problems:

- **Erosion:** Heavy, hard, sharp, edged particles in high concentration moving at high velocity scrap against wall and erode the metallic surface.
- **Corrosion:** Occurs when Cyclone operates at a temperature below condensation point. Stainless Alloy is a better choice.
- **Build-Up:** Dust cake builds at the wall especially when it is Hygroscopic. The cheapest way is to use flange connection between dust collecting hopper and body cake can be periodically scraped.

Cyclone

(Multi-clones for high gas volumes)

Primary collection mechanism:

Centrifugal force carries particle to wall

Efficiency:

<50% for <1 um diameter

>95% for >5 um diameter

Advantages

- Low Initial Cost
- Low pressure drop
- Simple Construction and Operation
- No Moving Parts
- Continuous Disposal of Solid Particles
- Low maintenance requirement
- higher collection efficiency for particles less than 200 micron and grater than 10 micron.

Disadvantages

- Low Efficiency for particles below 5 micron diameter.
- Severe Abrasive Deterioration

Applications

- It is widely used for control of gas-born particles in cement manufacturing.
- It is widely used in mineral processing, paper industries and textile industries.
- It is also used to separate dust in rock crushing and in ore handling.
- It is also used in the recovery of catalyst dust in petroleum industry
- It is used in the reduction of fly ash emission.

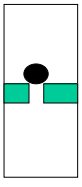
Multi Cyclones

- Also known as multiclones
- consist of a number of small diameter cyclones,
- operating in parallel and having a common gas inlet and outlet.
- Multi clones operate on the same principle as cyclones creating a main downward vortex and an ascending inner vortex.
- Multiclones are more efficient than single cyclones because they are longer and smaller in diameter.

- The longer length provides longer residence time while the smaller diameter creates greater centrifugal force.
- These two factors result in better separation of dust particulates.
- The pressure drop of multiclone collectors is higher than that of single cyclone separators.

Fabric filters

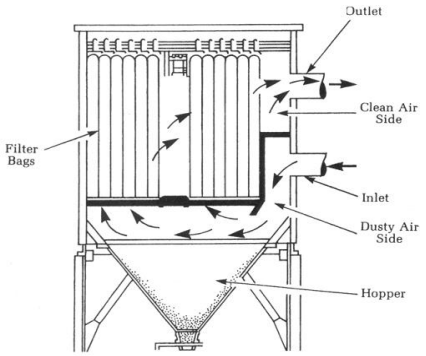
Bag House
Particle Collection Mechanisms



Screening

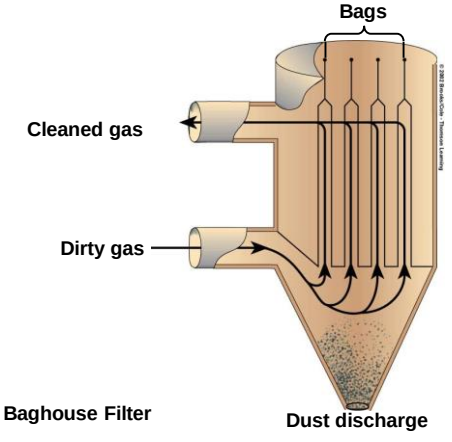
Impaction

Electrostatic

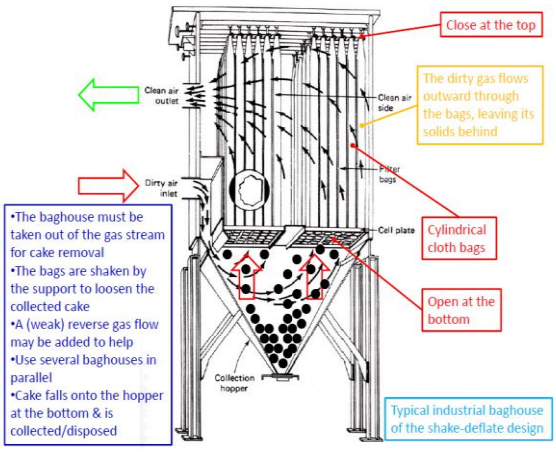


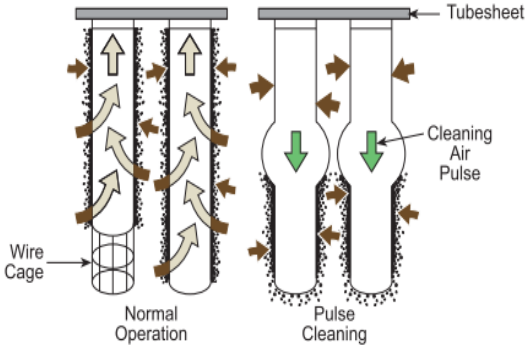
Bag House

- Fabrics Filters system generally consist of a tubular bags or an envelop, suspended or mounted in such a manner that collected particles fall into hopper.
- The structure in which the bag hangs is known as bag house.
- The particle-laden gas enters into bag at bottom & passes through fabric while the particles are deposited inside of bag.
- The bags are constructed at fixed time interval by shaking.
- Large bag house are constructed with several department



Baghouse Filter





Operating Problems

- Cleaning: Removal of Clogging / cake
- Rapture of Cloth: By shakers / by Solid Particles.
- Temperature: Temperature fluctuation should be with stand
- Bleeding: Fine particles passes through filter bag pores and leave along with gas. Thick Woven Fabric / Double Layer material should be used.

- Humidity: The problem is severe for Hygroscopic Materials.
- Chemical Attack: Especially Corrosive Chemicals when present e.g. SO_2 gas.

Bag House

Efficiency:

>99.5% for <1 um diameter

>99.8% for >5 um diameter

Fabric filter materials:

1. Natural fibers (cotton & wool)
   Temperature limit: 80 °C
2. Synthetics (acetates, acrylics, etc.)
   Temperature limit: 90 °C
3. Fiberglass
   Temperature limit: 260 °C

Selection of Filter Medium

- Characteristic and properties of carrier gas should be considered.
- Carrier Gas Temperature
- Carrier Gas Composition
- Carrier Gas Flow Rate.
- Size and shape of Dust particles.

Variety of Fabric: Cotton, Wool, Nylon, Terelene, Poly Propylene, Fiber Glass etc.

Bag House

Bag dimensions:

15 to 30 cm diameter

~10 m in length

Pressure drop: 10-15 cm of H_2O

Cleaning:

1. Shaker
2. Reverse air
3. Pulse jet

Bag House

Design basis:

Gas to cloth ratio (G/C)

$$\frac{G}{C} = \frac{\text{m}^3/\text{min of gas}}{\text{m}^2 \text{ of fabric}} = \text{m/min}$$

Woven G/C range: 0.5 to 0.9

Felt G/C range: 1.5 to 3.5

Advantages

- Higher Collection Efficiency for all particles even >10 micron
- Simple Construction
- Nominal Power Consumption
- Dry Disposal of Collected Material

Disadvantages

- High maintains and Fabric replacement Cost.
- Large Size Equipment.
- Dust Handling: Corrode / Blind the Bag.

Applications

- Metallurgical Industries
- Foundries
- Cement
- Chalk and Lime Plants
- Brick Works
- Ceramics
- Flour Mills
- Dye Stuffs.

Electrostatic precipitator

- These are Particulates Collection devices that use Electrical Energy to assist removal of Particulate matter.
- Particulates as small as tenth of a micron (1 / 10) can be removed.
- A gas containing aerosols is passed between two electrodes that are electrically insulated from each other and between them,

- There is considerable difference in electric potential one which is at high potential is discharge electrode and the other which is at low potential is collecting electrode at which particles are collected.

Principle of Electrostatic Precipitators (ESP)

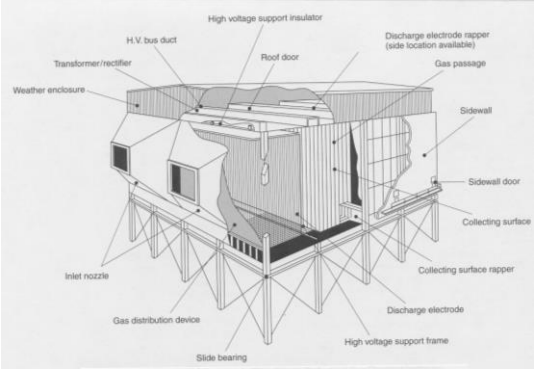
- Electrostatic Precipitators is a physical process by which particles suspended in gas stream are charged electrically and under the influence of the electric field, separated from the gas stream.

Major Components of Electrostatic Precipitators are:

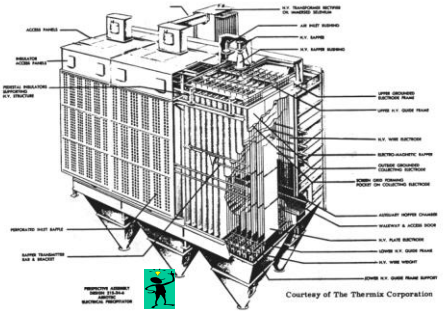
- Source of High Voltage
- Discharge and Collecting Electrodes
- Gas inlet and Outlet
- Hopper for Disposal of the collected Material
- Electronic Cleaning System
- Outer Casing to form an enclosure around the electrodes (Precipitator Shell).
- It may be rectangular or cylindrical.

Auxiliary Components:

- **Access Doors (Provisions):** Access Doors (Provisions) can be either a door or a plate which are closed and bolted under normal operating conditions. They are opened for inspection and maintenance.
- **Dampers:** Dampers are provided to control the gas flow rate. These are a device which opens and closes to adjust the gas flow.
- **Safety Devices:** Mainly they are earthling devices and electrical insulation.

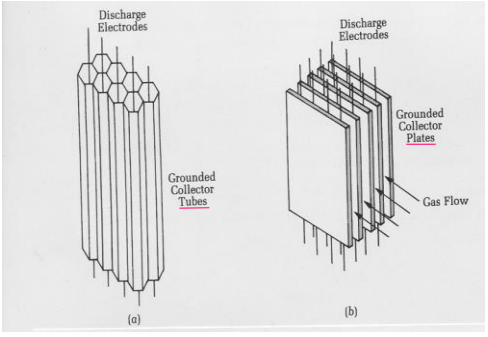


Electrostatic Precipitator (ESP)

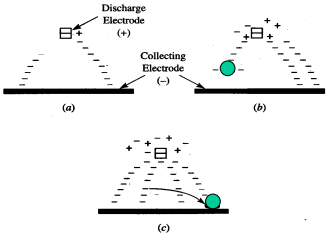


Electrostatic Precipitator (ESP)

- **Collecting System:** These are collecting surfaces where particulate matter is deposited.
- **Rectifiers and Transformers:** They provide high voltage direct current source of energy. Transformers are require to step up the Voltage as High as 50 kV- 100 kV. Rectifiers convert the AC current to DC current.



ESP Tube (a) and Plate (b) collectors



ESP Collection Mechanism

Working

- The particulates bearing gas enters the ESP at a pre decided rate (eg. 10000 m^3/hrs.) between two electrodes.
- One is at high voltage (negative electrode) and connected to power supply it is known as Discharge electrode.
- The other is at low voltage positive electrode (Grounded) known as collecting electrode.

- Because of high potential difference as high has 100kV (usually 40-60 kV) powerful ionizing field is formed.
- As a result ionization of gas molecules close to negative electrode occurs developing active blow zone (i.e. . blue electric discharge) called ***Corona.***
- As the particulates in the gas pass through this zone, they got negatively charged and migrate towards collecting electrode (surfaces).

- The particles once deposited on the surface lose their charge and removed periodically by rapping or vibrating the collector to dislodge the particles.
- The dislodge particles drop below the electrical treatment zone and are collected for ultimate disposal.
- Usually large number of such two electrodes systems are place in parallel in a single housing.

Thus there are four steps in ESP Process:

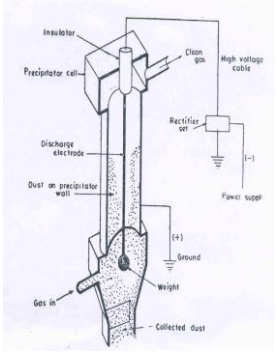
- Place the charge on particles to be collected.
- Migrate the particles to the collector.
- Neutralize the charge at the collector
- Remove the collected particles.

Types:

- Wire and Pipe Precipitator
- Parallel Plate Precipitator

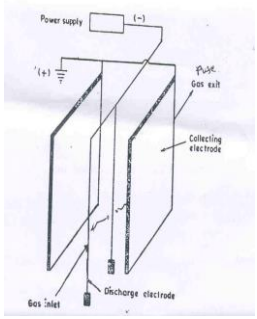
Wire and Pipe Precipitator

- electrodes are nest of parallel pipes which may be round, square or octagonal generally 30 cm or less in diameter
- Height 2-5 meters
- Spacing: 8-15 cm



Parallel Plate Precipitator

- Parallel plates they are 1-2 m wide and 3-6 m high
- spacing 15-35 cm
- material of construction like Tungsten, steel alloys and Copper
- Normal gas velocity ranges between 0.5-0.6 m /s.



Electrostatic Precipitator (ESP)

Efficiency:

>95% for >1 um diameter

>99.5% for > 5 um diameter

Pressure drop: 0.5 to 1.5 cm of H_2O

Voltage: 20 to 100 kV dc

Plate spacing: 30 cm

Plate dimensions: 10-12 m high x 8-10 m long

Gas velocity: 1 to 1.5 m/s

Cleaning: rapping plates

Classification of Precipitators

- **Dry Precipitators:** If the particulates collocated on the collecting surfaces are removed by rapping or vibrating only, it is known as Dry Precipitator.
- **Wet Precipitators:** If the water is used for removal of collected particles it is known as wet precipitator.
- Wet precipitator are though more efficient.
- Dry process Precipitates are predominantly used.

- **Efficiency:** In most cases approach 100%. 98-99% efficiency is obtained very frequently (like removal of Acid Mists and recovery of Catalyst).
- Low efficiency as low as 35% for carbon black because they have Agglomerating tendency.

Advantages

- High collection efficiency.
- Particles as small as 0.1 micron 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 (0.1-10 s).
- Cleaning is easy by removing units of the precipitator from operation.
- There is no limit to solid, liquid or corrosive chemical usage.

Disadvantages

- High initial cost.
- Space requirement is more because of the large size of the equipment.
- Possible explosion hazards during collection of combustible gases or particulates.
- Precautions are necessary to maintain safety during operation.

- Proper gas flow distribution, gas resistively, particulate conductivity, and corona spark over rate must be maintained carefully.
- The Poisonous gas, ozone, is produced by the negatively charged discharge electrodes during gas ionization.

Electrostatic Precipitator (ESP)

Applications (non-explosive):

1. Fly ash
2. Cement dust
3. Iron/steel sinter

Choice of Equipment

- While selecting particulate collector from various equipment available, the following factors must be taken in to consideration

1. Particulate size, shape and density
2. Particulate loading, ($\mu g/ m^3$)
3. Efficiency required

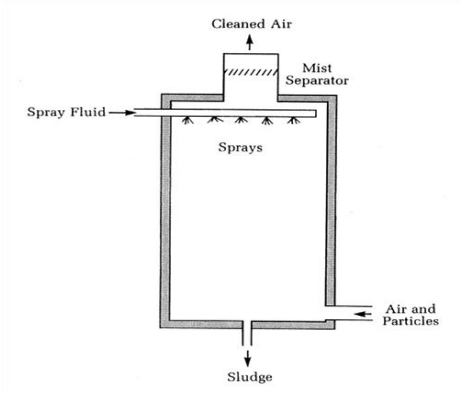
4. properties of the carrier gas
   - Composition
   - Temperature
   - Pressure
   - Viscosity
   - Density
   - Humidity
5. Flow characteristics of the carrier gas
   - Flow rate
   - Variations in flow rate

6. Specific properties of the contaminant
   - Composition
   - Contaminant phase
   - Solubility
   - Combustibility
   - Reactivity
   - Toxicity
   - Hygroscopicity
   - Agglomerating capacity
   - Electrical and sonic properties
   - Catalyst poisoning
7. Allowable pressure drop
8. Contaminate disposal
9. Capital operating cost of the equipment
10. Ease of maintenance and reliability

WET SCRUBBER

WET SCRUBBER

- Spray Towers
- Venturi Scrubber
- Cyclone Scrubber
- Packed bed column
- Tray towers



Spray Towers

Spray Towers

• Simple In Construction
• Round / Rectangular
• Inertial impaction and Interception of particle into water droplet
• Particle Size > 10µm can be removed
• Maximum efficiency occurs if Droplets have Diameter of 0.8 mm
• Efficiency:
  >99% for 25 µm diameter
  >94% for 5 µm diameter

Advantages

- Little Pressure drop
- Handle large volume of gas

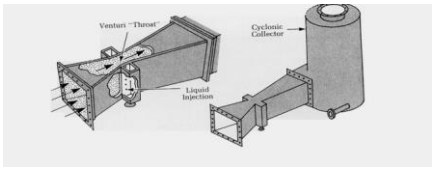
Efficiency will depends on

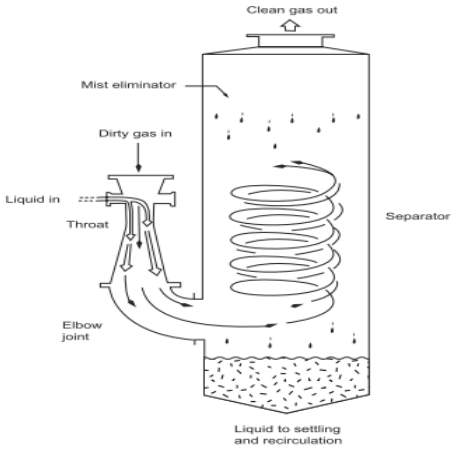
- Droplet Size
- Velocity of the gas
- Velocity of Liquid

Applications:

1. Sticky, wet corrosive or liquid particles
   Examples: chrome plating bath
   paint booth over spray
2. Explosive or combustible particles
3. Simultaneous particle/gas removal

Venturi Scrubbers





Venturi

Primary collection mechanism:

- High Energy wet scrubbers
- High Performance 0.5 – 5 µm particles

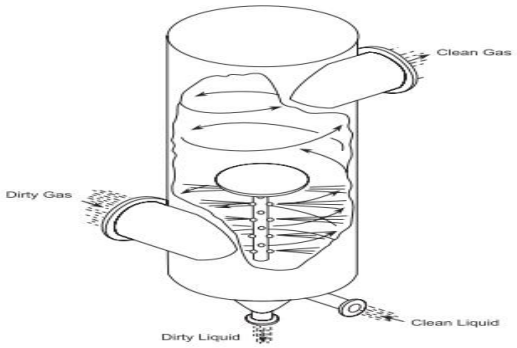
Inertial impaction of particle into water droplet

Water drop and collected particle are removed by cyclone

Applications:

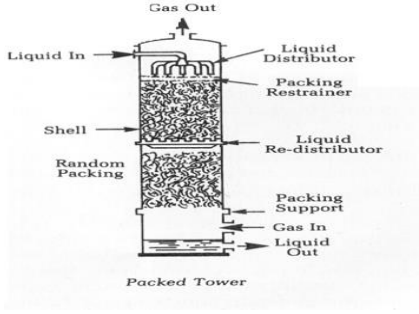
- Phosphoric acid mist
- Kraft Mill Furnaces
- Metallurgical furnaces (Open hearth Furnace)
- Ferro-silicon furnace
- For removal of dust and mist

Cyclone Scrubbers

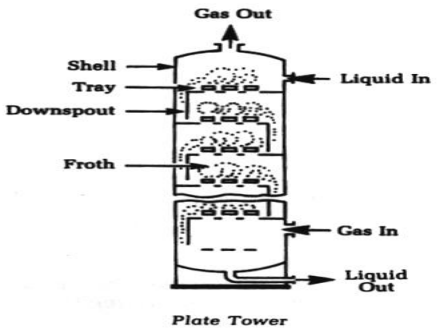


- Modification of Dry cyclone by addition of liquid phase
- Gas is tangentially swirled around and water sprays from the centre
- Efficiency is slightly higher than spray tower as well as Dry Cyclone

Packed Column



Tray Towers



Advantages

- Wet scrubbers have the ability to handle high temperatures and moisture.
- In wet scrubbers, the inlet gases are cooled, resulting in smaller overall size of equipment.
- Wet scrubbers can remove both gases and particulate matter.
- Wet scrubbers can neutralize corrosive gases.

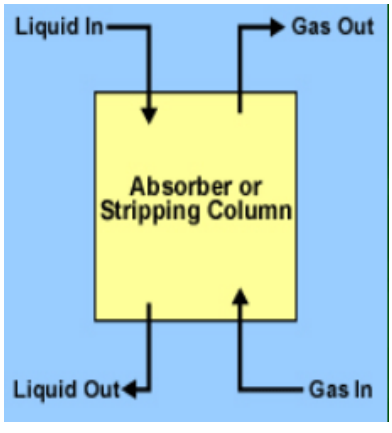
Disadvantages

- High operating Cost
- corrosion,
- the need for entrainment separation or mist removal to obtain high efficiencies
- the need for treatment or reuse of spent liquid.

Control of Gaseous Pollutants

- A**b**sorption
- A**d**sorption
- Condensation
- Combustion

- The removal of one or more selected components from a gas mixture by absorption is probably the most important operation in the control of gaseous pollutant emissions.
- Absorption is a process in which a gaseous pollutant is dissolved in a liquid.
- 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.



- Absorbers are often referred to as scrubbers, and there are various types of absorption equipment.
- The principal types of gas absorption equipment include spray towers, packed columns, spray chambers, and venture scrubbers.
- In general, absorbers can achieve removal efficiencies grater than 95 percent.
- One potential problem with absorption is the generation of wastewater, which converts an air pollution problem to a water pollution problem.

Absorption

Primary application: inorganic gases

Example: SO_2

Mass transfer from gas to liquid

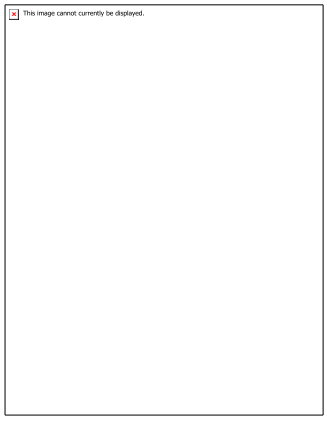
Contaminant is dissolved in liquid

Liquid must be treated

ADSORPTION

- When a gas or vapor is brought into contact with a solid, part of it is taken up by the solid. The molecules that disappear from the gas either enter the inside of the solid, or remain on the outside attached to the surface. The former phenomenon is termed absorption (or dissolution) and the latter adsorption

- The most common industrial adsorbents are activated carbon, silica gel, and alumina, because they have enormous surface areas per unit weight.
- Activated carbon is the universal standard for purification and removal of trace organic contaminants from liquid and vapor streams.



- Carbon adsorption systems are either regenerative or non-regenerative.
  - **Regenerative system** usually contains more than one carbon bed. As one bed actively removes pollutants, another bed is being regenerated for future use.
  - **Non-regenerative systems** have thinner beds of activated carbon. In a non-regenerative adsorber, the spent carbon is disposed of when it becomes saturated with the pollutant.

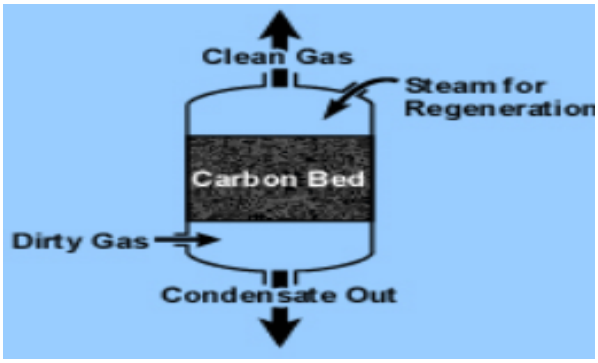
Adsorption

Primary application: organic gases
Example: trichloroethylene

Mass transfer from gas to solid

Contaminant is 'bound' to solid

Adsorbent may be regenerated



Common Adsorbents

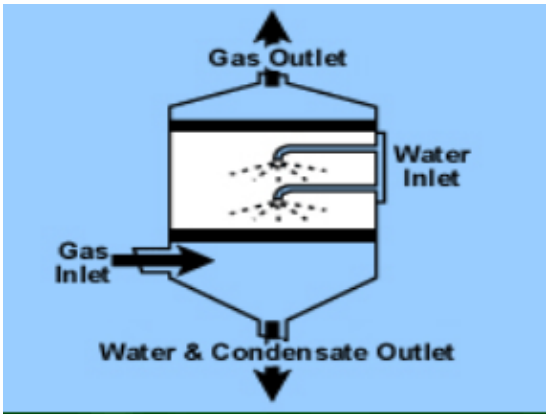
Activated carbon
Silica gel
Activated alumina

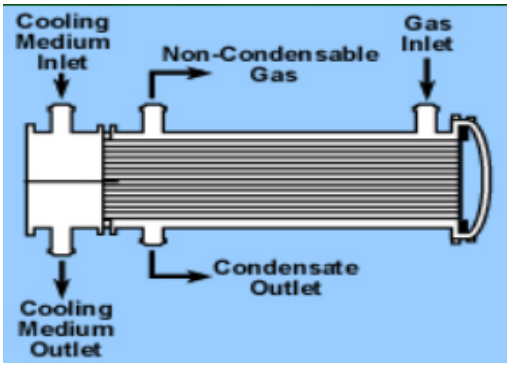
Adsorbent	Major Use
Activated Carbon	Odor, solvent recovery
Alumina	Drying Air, Gases and Liquids
Bauxite	Treating Petroleum fraction, Drying Gases and Liquids
Bone Char	Decolorizing Sugar Solution
Silica gel	Drying and purifying Gases

Condensation

- Condensation is the process of converting a gas or vapor to liquid. Any gas can be reduced to a liquid by lowering its temperature and/or increasing its pressure.
- Condensers are typically used as pretreatment devices. They can be used ahead of absorbers, absorbers, and incinerators to reduce the total gas volume to be treated by more expensive control equipment.

- Condensers used for pollution control are contact condensers and surface condensers.
- In a **contact condenser**, the gas comes into contact with cold liquid.
- In a **surface condenser**, the gas contacts a cooled surface in which cooled liquid or gas is circulated, such as the outside of the tube.
- Removal efficiencies of condensers typically range from 50 percent to more than 95 percent, depending on design and applications.





Combustion

- Combustion, also known as Incineration, is most used to control the emissions of organic compounds from process industries.
- This control technique refers to the rapid oxidation of a substance through the combination of oxygen with a combustible material in the presence of heat.
- When combustion is complete, the gaseous stream is converted to carbon dioxide and water vapor.

- To obtain complete combustion3T's are required
  - Temperature: 375 – 825 ^{0}C
  - Time: 0.2 – 0.6 sec
  - Turbulence: 4 – 8 m/s

- Equipment used to control waste gases by combustion can be divided in three categories:
  - Direct combustion or flaring,
  - Thermal incineration and
  - Catalytic incineration.

Direct Combustion / Flare

- As the name implies, is a method by which the waste gases are burnet directly in a combustor with or without the aid of additional fuel.
- Net heating value : 900 kcal / m^3
- Highly combustible streams with high heating value can be eliminated by direct flaring

- However flaring is not satisfactory solution when the gas stream contains excessive amount of inorganic pollutants like sulfur, chlorine, and fluorine.
- in such cases streams are pretreated before flaring
- Often unsaturated hydrocarbons such as olefins and aromatics with their low hydrogen to carbon ratio produce smoke unless the design is such that it allows them to burn smokeless.

Thermal Incineration

- Most efficient and most flexible technique for destroying Diluted gas stream.
- Temp: 500 ^{0}C – 800 ^{0}C
- Time: 0.3 – 0.7 sec

Catalytic Oxidation