3.4 CENTRIFUGAL SEPARATORS

Working Principle / Operational Considerations:

A cyclone separator consists of a cylindrical shell, conical base, dust hopper and an inlet where the dust-laden gas enters tangentially. Under the influence of the centrifugal force generated by the spinning gas, the solid particles are thrown to the wall of the cyclone as the gas spirals upward at the inside of the cone. The particles slide down the walls of the cone and into the hopper. The operating efficiency of a cyclone depends on the magnitude of the centrifugal force exerted on the particles. The greater the centrifugal force, the greater the spreading efficiency. The magnitude of the centrifugal force generated depends on particle mass, gas velocity within the cyclone, and cyclone diameter.

$$Fc = Mp\frac{vi^2}{R}$$

Where,

Fc= Centrifugal force, N

Mp=Particulate mass, Kg

Vi=Equals particle velocity

R= Equals radius of the cyclone, m/s.

From this equation ,it can be seen that the centrifugal force on the particles, and thus the collection efficiency of the cyclone collector can be increased by decreased R. Large-diameter cyclone have good collection efficiencies for particles 40 to 50µm in diameter.

Mechanism of Action

The dust laden gas enters tangentially, receives a rotating motion and generates a centrifugal force due to which the particulates are thrown to the cyclone walls as the gas spirals upwards inside the cone. The particulates slide down the walls of the cone and are discharged from the out let.

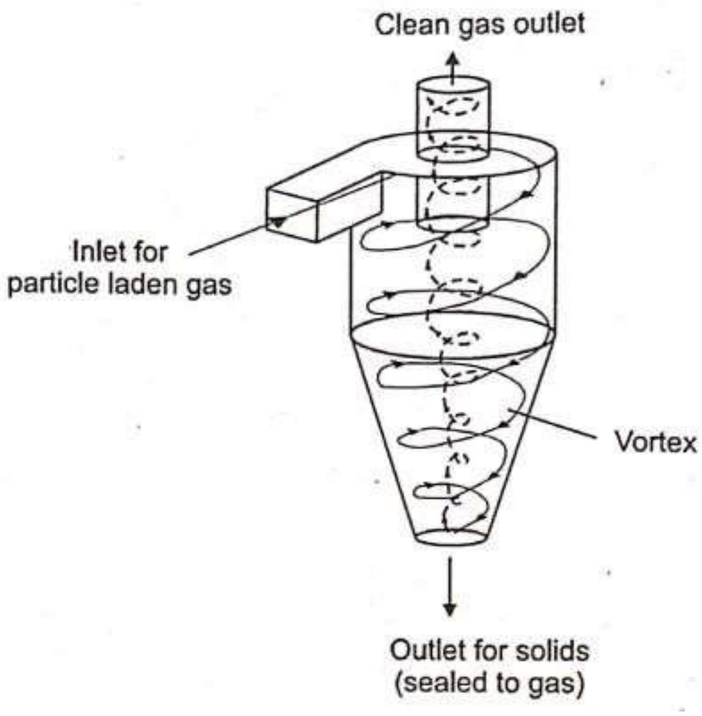

Figure 3.4.1 Cyclone Separator

[Source:https://www.degruyter.com/document/doi/10.1515/psr-2016-0122/asset/graphic/j_psr-2016-0122_figure7.jpg]

- Centrifugal force is utilized to separate the particulate matter.
- It can remove 10 to 50µm particle size.
- Used mostly in industries.

Advantages:

- Low initial cost.
- Require less floor area.
- Simple construction and maintenance.
- Can handle large volume of gas at high temperature.

Disadvantages:

- Requires large head room.
- Less efficiency for smaller particles (<10µm).
- Sensitive to variable dust load and flow rate.

3.6 PARTICULATE SCRUBBERS

Combustion is sometimes cause of harmful exhausts, but, in many cases, combustion may also be used for exhaust gas cleaning if the temperature is high enough oxygen is available.

1. Wet Scrubber

Wet scrubbers to solve air pollution control problems for over 40 years. The five principal designs customizable to meet your requirements:

- Scrubber with no moving parts
- Dynamic scrubber with integral fan
- High efficiency venturi scrubber
- Multi-venturi scrubber
- Packed towers for gas absorption

Working Principle/Operational Consideration:

- Scrubbing liquid is introduced into the scrubber as a spray directed down over a circular “scrubbing vane” arrangement.
- As the liquid drains through the vanes, it creates curtains of scrubbing liquid.
- Dust laden gas enters the scrubber tangentially and collides with the curtains initiating particle agglomeration.
- The coarse particles produced are washed down to the slurry outlet.
- A restriction disc located in the scrubbing vane assembly accelerates the spin velocity of the gas.
- This action combined with the flood of atomized liquid from the spray causes the formation of fine liquid droplets which encapsulate the fine particulates, again enhancing agglomeration.
- The cyclonic action of the saturated gas stream as it spins upward forces the agglomerated particles to fall out of suspension.
- The coarser droplets impinge on the mist eliminator vanes and the finer droplets are

forced to drop out of suspension by gravitational and centrifugal forces acting on the gas stream as it exits through the top.

Design and Performance Equations:

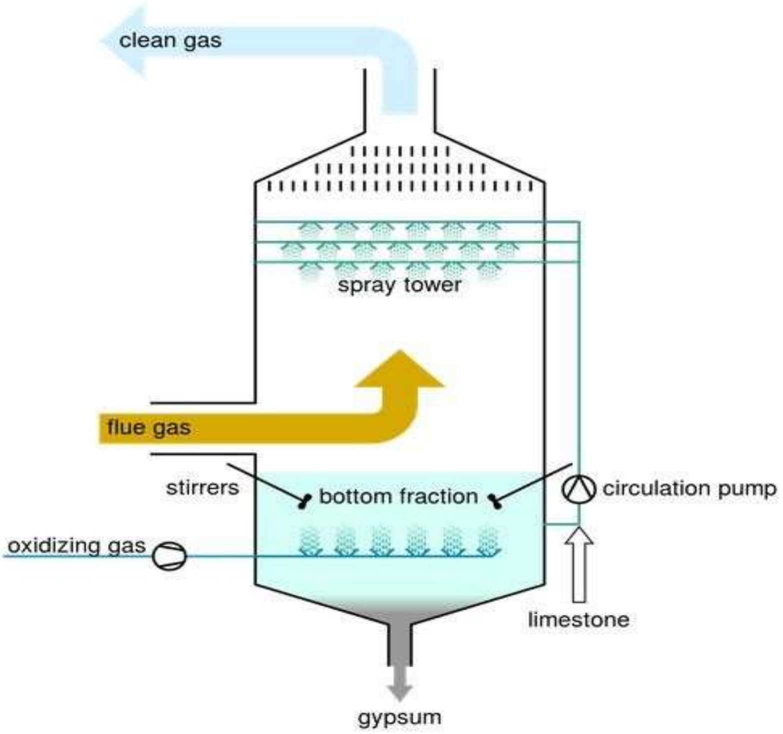

Figure 3.6.1 Wet scrubbers

[Source:https://energyeducation.ca/wiki/images/thumb/e/eb/Wetscrubber.png/360px-Wetscrubber.png]

- The design of wet scrubbers or any air pollution control device depends on the industrial process conditions and the nature of the air pollutants involved.
- Inlet gas characteristics and dust properties (if particles are present) are of primary importance.
- Scrubbers can be designed to collect particulate matter and/or gaseous pollutants.
- The versatility of wet scrubbers allow them to be built in numerous configurations, all designed to provide good contact between the liquid and polluted gas stream.

- Wet scrubbers remove dust particles by capturing them in liquid droplets.
- The droplets are then collected, the liquid dissolving or absorbing the pollutant gases.
- Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream by means of another device referred to as a mist eliminator or entrainment separator (these terms are interchangeable).
- The resultant scrubbing liquid must be treated prior to any ultimate discharge or being reused in the plant.
- A wet scrubber's ability to collect small particles is often directly proportional to the power input into the scrubber.
- Low energy devices such as spray towers are used to collect particles larger than 5 micrometers.
- To obtain high efficiency removal of 1 micrometer (or less) particles generally requires high-energy devices such as venturi scrubbers or augmented devices such as condensation scrubbers.
- A properly designed and operated entrainment separator or mist eliminator is important to achieve high removal efficiencies.
- The greater the number of liquid droplets that are not captured by the mist eliminator, the higher the potential emission levels.
- Wet scrubbers that remove gaseous pollutants are referred to as absorbers.
- Good gas-to-liquid contact is essential to obtain high removal efficiencies in absorbers.
- Various wet-scrubber designs are used to remove gaseous pollutants, with the packed tower and the plate tower being the most common.
- If the gas stream contains both particulate matter and gases, wet scrubbers are generally the only single air pollution control device that can remove both pollutants.

- Wet scrubbers can achieve high removal efficiencies for either particles or gases and, in some instances, can achieve a high removal efficiency for both pollutants in the same system.
- In many cases, the best operating conditions for particles collection are the poorest for gas removal.
- In general, obtaining high simultaneous gas and particulate removal efficiencies requires that one of them be easily collected (i.e., that the gases are very soluble in the liquid or that the particles are large and readily captured), or by the use of a scrubbing reagent such as lime or sodium hydroxide.

2.Dynamic Scrubber

Working Principle/Operational Considerations

- Dust laden gas enters the lower chamber of the scrubber tangentially, imparting a cyclonic action to the stream.
- Coarse particles are removed by a combination of centrifugal and gravitational forces.
- The stream encounters slurry, created in a later stage, coming down from the upper chamber and becomes partially wetted, initiating agglomeration.
- As the stream spins through a series of scrubber vanes, intermediate sized particles impinge on the wetted surfaces of the vanes. These particles are then washed down.
- The gas stream containing the remaining fine dust is drawn into an adjacent chamber containing a wet- ted fan.
- Atomized scrubbing liquid is sprayed into the eye of the fan, further reducing droplet size.
- These droplets encapsulate the fine dust particles, thus enhancing agglomeration.
- The gas stream then flows into the upper chamber tangentially at high velocity.
- The wet agglomerated particles are forced by cyclonic action against the chamber walls and drain down to the internal discharge cone.

- The gas stream, free of liquid droplets, spins out through an outlet atop the scrubber.

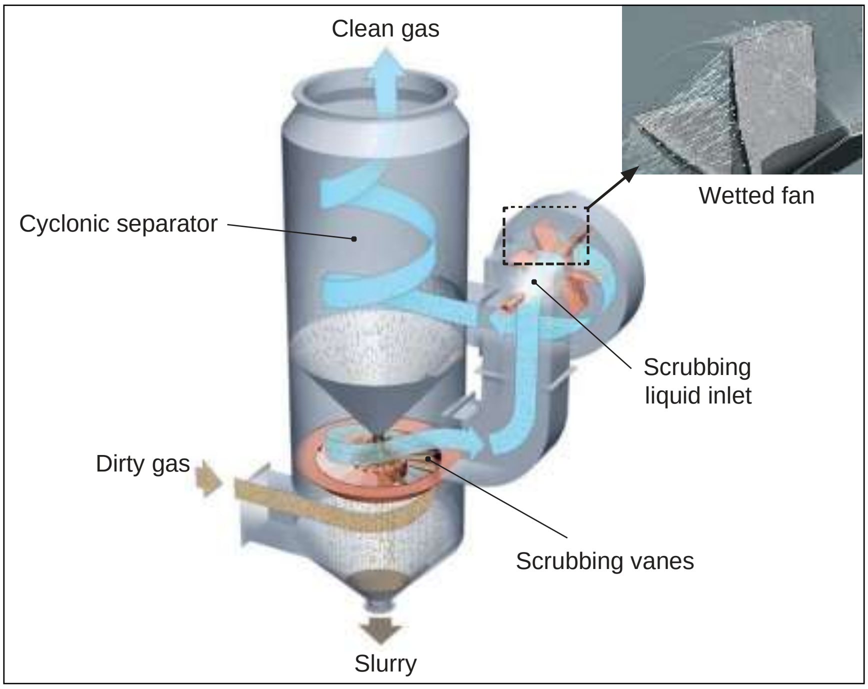

Figure 3.6.2 Dynamic Scrubber

[Source: https://www.nedermanmikropul.com/en]

3.Venturi Scrubber:

- The design of the MikroPul Venturi Scrubber consists of a “wet ap- proach” venturi followed by a liquid entrainment separator.
- Dust laden gases enter the venturi and instantly make contact with the tangentially introduced scrubbing liquid swirling down the venturi’s converging walls.
- At the venturi throat, the gas and liquid streams collide and the liquid breaks down into droplets which trap dust particles.
- This gas/liquid mixture passes through a flooded elbow, and then enters the entrainment separator through a tangential inlet.
- Centrifugal action removes the heavy wetted particles from the gas stream. As an alternate, when very large diameter separators are required, the liquid is separated by passing the stream through a chevron-type mist eliminator baffle.
- The dust/liquid mixture is discharged from the separator bottom drain and the cleaned gas leaves through the top of the separator.

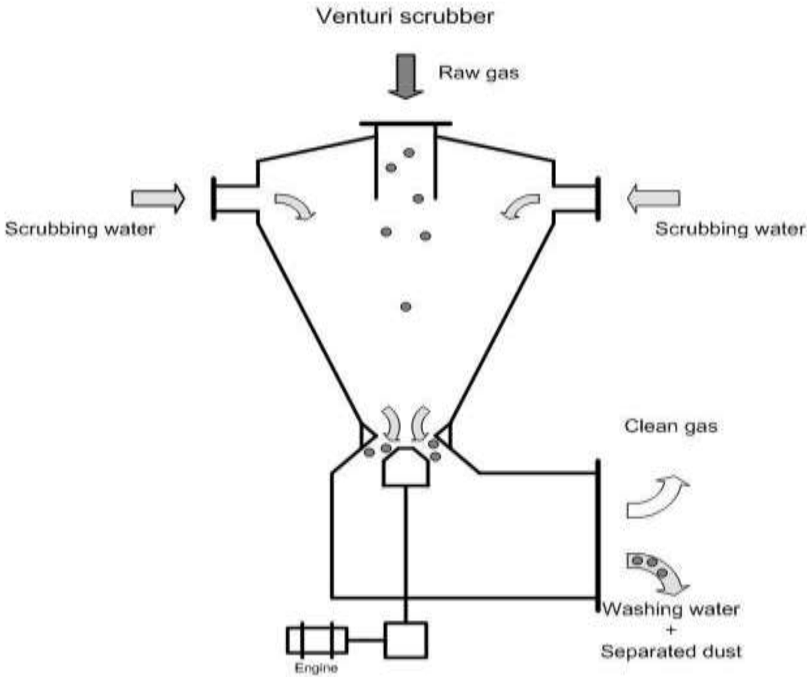

Figure 3.6.3 Venturi Scrubber

[Source:https://emis.vito.be/sites/emis/files/data_sheets/migrated/venturi_scrubber_luss_2.PNG]

4. Multi-venturi scrubber:

Working Principle/Operational Considerations

The dirty gases are directed through a venturi-rod deck where atomized scrub water is introduced cocurrently with the gas stream. The scrub water is sprayed through a series of low pressure, large orifice nozzles, dis- tributing it evenly across the deck.

The gas rapidly accelerates as it passes through the venturi-rods. This action creates smaller droplets, caus- ing encapsulation of the particles and increasing the collection efficiency of submicron particles.

As the gases exit the venturi-rod area, velocity slows causing the larger particulate laden droplets to fall out of the stream. The scrubbed gasses are then directed toward a two-stage demisting zone by distribution baffles or turning vanes. Primary demisting and gas distribution occurs in the pre- demist area, which removes 90% of the water. The remaining free water droplets are removed by impingement on the final stage demist vanes.

The scrub water collected prior to the demist section flows down the scrubber floor to the drain trough. The de- watered scrubbed gases are exhausted via the scrubber outlet.

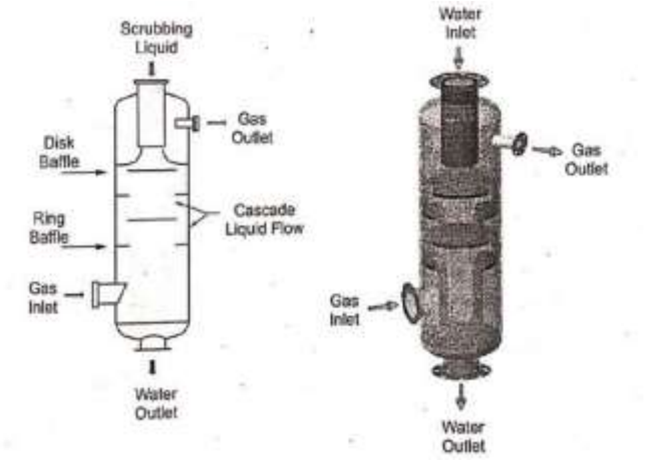

Figure 3.6.4 Multi-Venturi Scrubber

[Source:https://emis.vito.be/sites/emis/files/data_sheets/migrated/venturi_scrubber_luss_2.PNG]

Advantages:

- Can handle flammable and explosive dusts with little risk
- Can handle mists
- Relatively low maintenance
- Simple in design and easy to install
- Collection efficiency can be varied
- Provides cooling for hot gases; and
- Corrosive gases and dusts can be neutralized

Disadvantages:

- Effluent liquid can create water pollution problems
- Waste product collected wet
- High potential for corrosion problems
- Protection against freezing required
- Off gas may require reheating to avoid visible plume

- Collected PM may be contaminated, and may not be recyclable; and
- Disposal of waste sludge may be very expensive.

5.Two-stage scrubbers:

- The most commonly used is a Mikropul Venturi Scrubber with a Packed Bed section.
- It is used to remove particulate as well as gaseous contaminants from the gas stream.
- The principles of operation are as described for the Venturi scrubber and Packed Tower designs.
- The designs are optimized by using pH control, liquid circuit separation, and mist eliminators to enhance removal efficiencies for specific contaminants.

Another common 2-stage design is a Multi-venturi inlet with a Dynamic or Mikrovane Scrubber. It utilizes the Multi-Venturi rod deck technology as a pre-cleaner to the Dynamic Scrubber or as a retrofit component to enhance performance of an existing Dynamic or Mikrovane Scrubber.

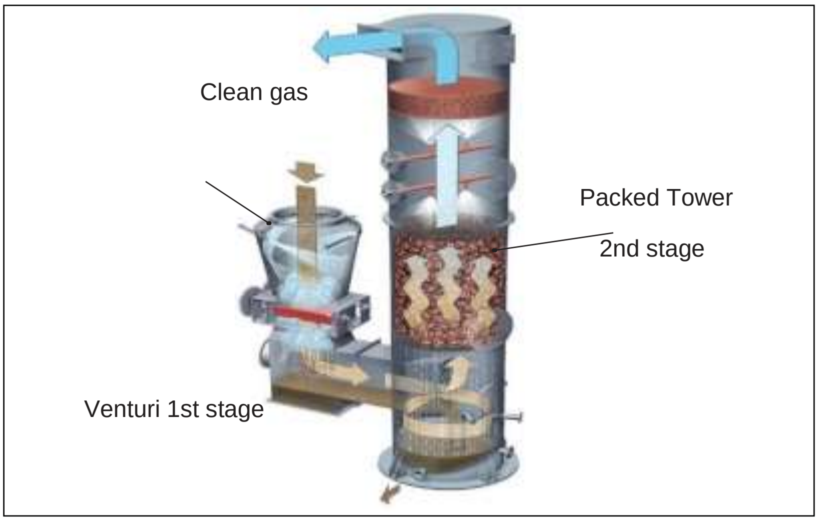

Figure 3.6.5 Two-stage scrubbers

[Source :https://www.nedermanmikropul.com/en]

3.5 FABRIC FILTERS

- Flue gas is allowed to pass through a woven fabric, which filters out particulate matter.
- Small particles are retained on the fabric.
- Consists of numerous vertical bags 120-400 mm dia and 2-10 m long.
- Remove particles up to 1 µm.
- Its efficiency up to 99%.

Working Principle/Operational Considerations:

Most baghouses use long, cylindrical bags (or tubes) made of woven or felted fabric as a filter medium. For applications where there is relatively low dust loading and gas temperatures are 250 °F (121 °C) or less, pleated, nonwoven cartridges are sometimes used as filtering media instead of bags.

- Dust-laden gas or air enters the baghouse through hoppers and is directed into the baghouse compartment.
- The gas is drawn through the bags, either on the inside or the outside depending on cleaning method, and a layer of dust accumulates on the filter media surface until air can no longer move through it.
- When a sufficient pressure drop (ΔP) occurs, the cleaning process begins.
    - ➢ Cleaning can take place while the baghouse is online (filtering) or is offline (in isolation).
    - ➢ When the compartment is clean, normal filtering resumes.
- Baghouses are very efficient particulate collectors because of the dust cake formed on the surface of the bags.
- The fabric provides a surface on which dust collects through the following four mechanisms:

1. Inertial collection

Dust particles strike the fibers placed perpendicular to the gas-flow direction instead of changing direction with the gas stream.

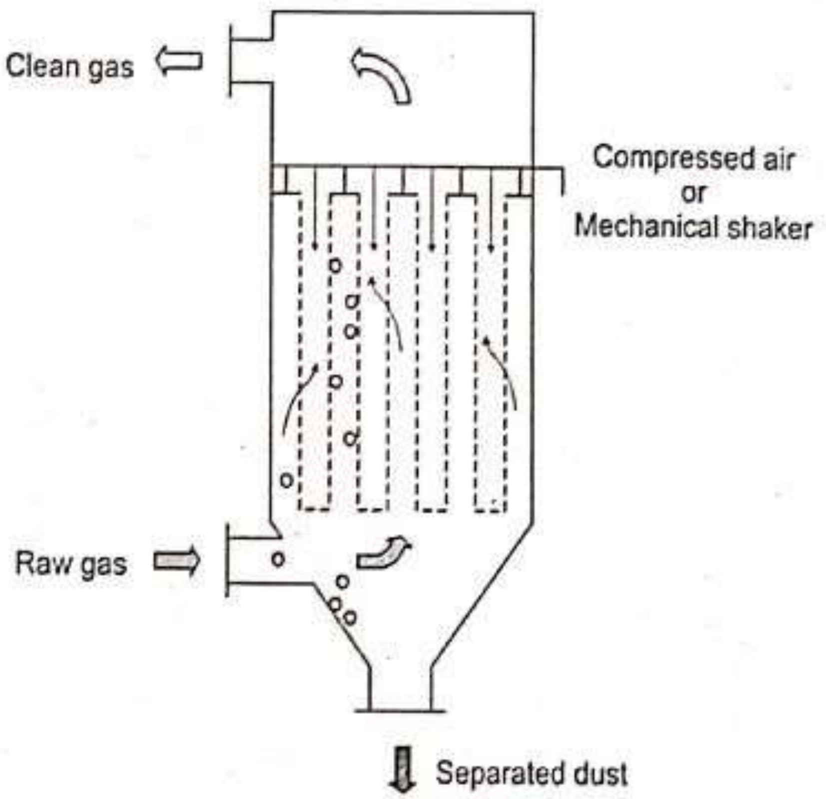

Figure 3.5.1 Fabric Filter

[Source:https://emis.vito.be/sites/emis/files/data_sheets/migrated/fabric_filter_luss_2.PNG]

2. Interception

Particles that do not cross the fluid streamline come in contact with fibers because of the fiber size.

3.Brownian movement

Submicrometre particles are diffused, increasing the probability of contact between the particles and collecting surfaces.

4.Electrostatic forces

The presence of an electrostatic charge on the particles and the filter can increase dust capture.

A combination of these mechanisms results in formation of the dust cake on the filter, which eventually increases the resistance to gas flow. The filter must be cleaned periodically.

- Filter bags usually tubular or envelope –shaped are capable of removing most particles as small as 0.5mm and will remove substantial quantities of particles as small as 0.1mm.
- Filter bags ranging from 1.8 to9m long ,can be utilized in a bag house filter arrangement shown in figure 3.5.2

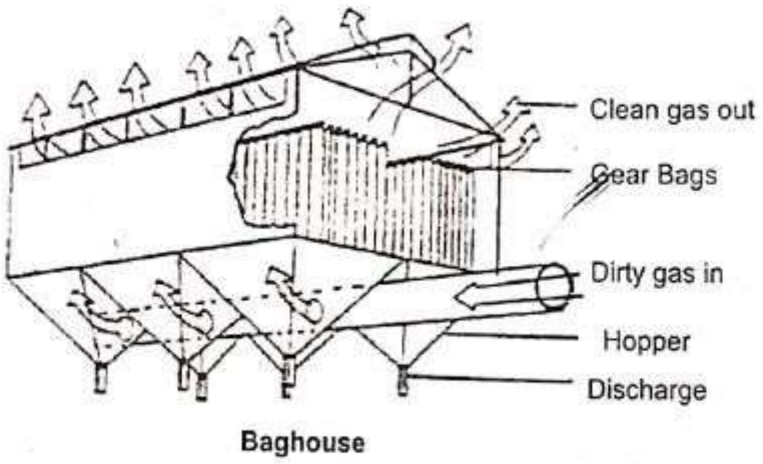

Figure 3.5.2 Baghouse

[Source:https://ars.els-cdn.com/content/image/3-s2.0-B9780750672948500208-f20-07-9780750672948.gif]

- As particulates build up on the inside surface of the bags, the pressure drop increases.
- Before the pressure drop becomes too severe, the bag must be relieved of some of particulate layer .Fabric filter can be cleaned intermittently, periodically, or continuously.

Design and performance equations:

- Pressure drop, filter drag, air-to-cloth ratio, and collection efficiency are essential factors in the design of a baghouse.
- Pressure drop is the resistance to air flow across the baghouse. A high pressure drop corresponds with a higher resistance to airflow.

- Pressure drop is calculated by determining the difference in total pressure at two points, typically the inlet and outlet.
- Filter drag is the resistance across the fabric-dust layer.
- The air-to-cloth ratio (ft/min or cm/s) is defined as the amount of gas entering the baghouse divided by the surface area of the filter cloth.
- Commonly baghouses are designed with 99.9% collection efficiency. Often cleaned air is recirculated back into the plant for heating.

Advantages

- Higher collection efficiency for smaller than 10 μm particle size
- Performance decrease becomes visible, giving pre warning.
- Normal power consumption.

Disadvantages

- High temperature gases need to be cooled.
- High maintenance and fabric replacement cost.
- Large size equipment.
- Fabric is liable to chemical attack

3.1 FACTORS AFFECTING SELECTION OF CONTROL EQUIPMENT

There are a number of factors to be considered prior to selecting a particular in air pollution control equipment. In general, they can group into three categories.

- Environmental
- Engineering
- Economic

1. Environmental

Equipment location, availability space, ambient conditions, availability of adequate utilities and ancillary system facilities.

- Maximum available emissions (air pollution regulation)
- Contribution of air pollution control system to waste water and solid waste.
- Contribution of air pollution control system to plant noise levels.

2. Engineering

- Design and performance characteristics of the particular control system (size and weight, pressure drop , reliability and dependability, temperature limitation, maintenance requirement)
- Gas stream characteristics (volume, flow rate, temperature, pressure, humidity, composition, viscosity, density, reactivity, corrosiveness and toxicity)
- Contaminant characteristics (physical and chemical properties, concentration, particulate shape and size distribution in the case of particulates)

3. Economic

- Capital cost (equipment, installation, engineering, etc.)
- Operating cost (utilities, maintenance, etc.)
- Expected equipment lifetime and salvage value.

3.2 GAS PARTICLE INTERACTION

Gas is one of the four fundamental states of matter (the others being solid, liquid and plasma). A pure gas may be made up of individual atoms (e.g. a noble gas like neon), elemental molecules made from one type of atoms (e.g. Oxygen), or compound molecules made from a variety of atoms (e.g. carbon dioxide)

- A gas mixture, such as air, contains a variety of pure gases. What distinguishes a gas from liquids and solids is the vast separation of the individual gas particles.
- This separation usually makes a colorless gas invisible to the human observer.
- The interaction of gas particles in the presence of electric and gravitational fields are considered negligible, as indicated by the constant velocity vectors in the image.
- The gaseous state of matter is found between the liquid and plasma states, the latter of which provides the upper temperature boundary for gases.
- Bounding the lower end of the temperature scale lie degenerative quantum gases, which are gaining increasing attention.

Physical properties/ Macroscopic characteristics:

Most gases are difficult to observe directly, they are described through the use of four physical properties or macroscopic characteristics:

- Pressure
- Volume
- Number of particles
- Temperature

- Gas particles are widely separated from one another, and consequently, have weaker intermolecular bonds than liquids or solids.
- These intermolecular forces result from electrostatic interactions between gas particles.
- Like-charged areas of different gas particles repel, while oppositely charged regions of different gas particles attract one another; Gases that contain permanently charged ions are known as plasmas.

- Gaseous compounds with polar covalent bonds contain permanent charge imbalances and so experience relatively strong intermolecular forces, although the molecule while the compound's net charge remains neutral.
- Transient, randomly induced charges exist across non- polar covalent bonds of molecule and electrostatic interactions caused by them are referred to as Vandar Waals forces.
- The interaction of these intermolecular forces varies within a substance which determines many of the physical properties unique to each gas.
- A comparison of boiling points for compounds formed by ionic and covalent bonds leads as to this conclusion.
- The drifting smoke particles in the image provide some insight into low – pressure gas behavior.
- Compared to the other states of matter, gases have low density and viscosity. Pressure and temperature influence the particles within a certain volume.
- This variation in particle separation and speed is referred to as compressibility. This particle separation and size influences optical properties of gases as can be found in the following list of refractive indices.
- Finally, gas particles spread apart or diffuse in order to homogeneously distribute themselves throughout container.

3.3 WORKING PRINCIPLE, DESIGN AND PERFORMANCE EQUATIONS OF GRAVITY SEPARATORS

Working Principle

- They are generally used to remove large, abrasive particles (usually > 50 mm) from gas streams. Since most of the troublesome particles have much smaller size than 50 mm, there devices are usually used as per cleaners prior to passing the gas stream through high efficiency collection device.
- Settling chambers, which rely on gravitational settling as a collection mechanism, are the simplest and oldest mechanical collectors. Settling chambers are generally built in the form of long, horizontal, rectangular chambers with an inlet at one end and an exit at the side or top of the opposite end.
- Flow within the chamber must be uniform and without any macroscopic mixing. Hoppers are used to collect the settled-out material, though drag scrapers and screw conveyers have also been employed.
- The dust removal system must be sealed to prevent air from leaking into the chamber which increases turbulence, causes dust re-entrainment, and prevents dust from being properly discharged from the device.
- There are two primary types of settling chambers: the expansion chamber and the multiple-tray chamber. In the expansion chamber, the velocity of the gas stream is significantly reduced as the gas expands in a large chamber. The reduction in velocity allows larger particles to settle out of the gas stream.
- A multiple-tray settling chamber is an expansion chamber with a number of thin trays closely spaced within the chamber, which causes the gas to flow horizontally between them.
- While the gas velocity is increased slightly in a multiple-tray chamber, when compared to a simple expansion chamber, the collection efficiency generally improves because the particles have a much shorter distance to fall before they are collected. Multiple-tray settling chambers have lower volume requirements than expansion-type settling chambers for the collection of small particles.

- The efficiency of settling chambers increases with residence time of the waste gas in the chamber. Because of this, settling chambers are often operated at the lowest possible gas velocities.
- In reality, the gas velocity must be low enough to prevent dust from becoming re-entrained, but not so low that the chamber becomes unreasonably large. The size of the unit is generally driven by the desired gas velocity within the unit, which should be less than 3 m/s (10 ft/sec), and preferably less than 0.3 m/s (1 ft/sec).

Design and Performance Equations of Gravitational Settling Chamber:

If we assume that Stokes law applies we can derive a formula for calculating the minimum diameter of a particle collected at 100% theoretical efficiency in a chamber of length L.

$$V_{t/H}=V_{h/L}$$

$$v_t = \frac{g(\rho_p - \rho_a)d_p^2}{9\mu_a}$$

Where ,

V_t=terminal settling velocity, m/s

g=gravitational constant m/s^2

ρ_p=density of particle, kg/m^3

ρ_a=density of flue gas, kg/m^3

d_p=diameter of particle, m

μa=viscosity of air, kg/ms

H=height of settling chamber, m

v_h=horizontal flow velocity, m/s

L=length of settling chamber, m.

Solving for d_p gives an equation that predicts the largest-size particle that can be removed with 100% efficiency from a settling chamber of given dimension.

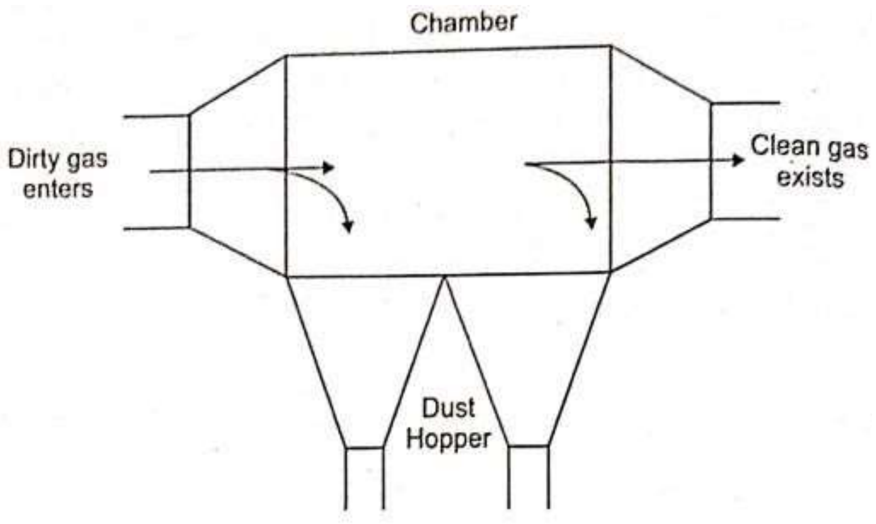

Figure3.3.1 Gravity settling chamber

[Source:https://www.degruyter.com/document/doi/10.1515/psr-2016-0122/asset/graphic/j_psr-2016-0122_figure6.jpg]

Advantages of Settling Chambers:

1. Low capital cost

2. Very low energy cost

3. No moving parts, therefore, few maintenance requirements and low operating costs

4. Excellent reliability

5. Low pressure drop through device

6. Device not subject to abrasion due to low gas velocity

7. Provide incidental cooling of gas stream

8. Temperature and pressure limitations are only dependent on the materials of construction

9. Dry collection and disposal.

Disadvantages of Settling Chambers:

1. Relatively low particulate matter collection efficiencies, particularly for particulate matter less than 50 µm in size.

2. Unable to handle sticky or tacky materials.

3. Large physical size; and

4. Trays in multiple-tray settling chamber may warp during high-temperature operations.