CH1203 Industrial Pollution Prevention and Control

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Topics Covered

1. Sustainability
2. Environmental Regulations
3. Pollution
4. Air pollution control methods
5. Principles of water treatment

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Air Pollution Control Methods

Broad Classification of pollution control devices

Typically, air pollution control devices are divided into two classes:

1. those that are used to control particulates and
2. those that are intended for control of gaseous pollutants.

Note: Some processes may be capable of removing both types of contaminants.

Air Pollution Control Methods

Particulate matter

Settling Chamber

Cyclone

Baghouse filter

Scrubber

Electrostatic Precipitator

Gas Removal

Absorption

Wet Scrubbing

Adsorption

Incineration

Air Pollution Control Methods – Particulate matter

Particulate matter control devices - *Settling chamber/ gravity settlers*

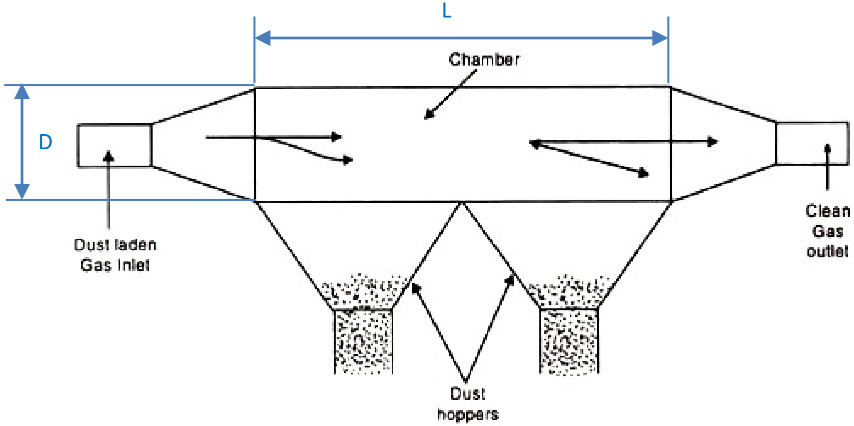


Fig. 6.4. Horizontal Flow Settling Chamber.

L – Length of the chamber
D – Diameter of the chamber

- Several devices are available for control of particulate matter.
- The simplest is a settling chamber, which relies simply on gravitational settling of large particulates.
- The chamber consists of an increase in the size of the exhaust flue cross sectional dimensions so that the air flow velocity is reduced, allowing larger particles to settle.

Air Pollution Control Methods – Particulate matter

Particulate matter control devices - Settling chamber/ gravity settlers

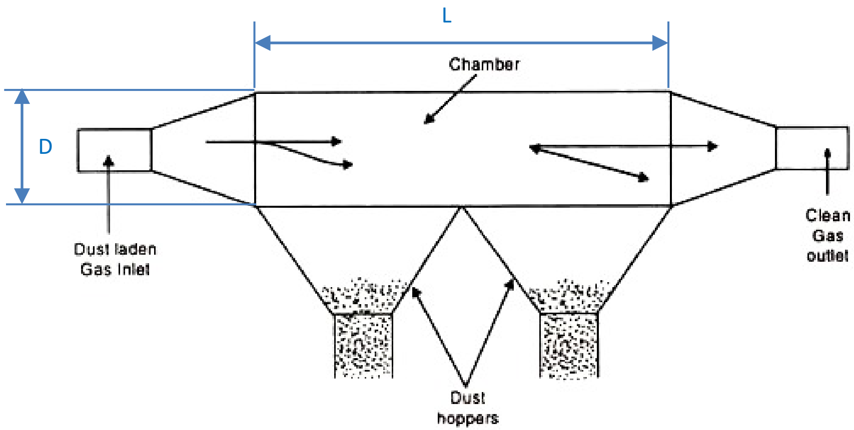


Fig. 6.4. Horizontal Flow Settling Chamber.

L – Length of the chamber
D – Diameter of the chamber

- Stokes' law can be used to determine the settling velocity of a particle as given in next slide.

Particulate matter control devices - Settling chamber/ gravity settlers

Stokes' law

$$v = \sqrt{\frac{4}{3} \cdot g \cdot \frac{\rho_p D}{C_d \rho_a}}$$

where v = terminal settling velocity
g = gravitational acceleration
C_d = drag coefficient
ρ_p = density of the particulate
ρ_a = density of air
D = particulate diameter

Air Pollution Control Methods - Particulate matter

Particulate matter control devices - Settling chamber/ gravity settlers

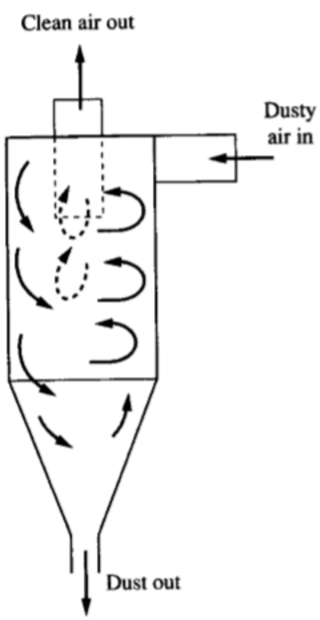
If we set L equal to the chamber length, W to the width, and Q to the air flow rate, v is equal to Q/WL. Substituting this into the equation above, we can solve for the particulate size that will be completely removed in the settling chamber:

$$D = \frac{0.75 C_d Q^2 \rho_a}{g L^2 W^2 \rho_p}$$

- Particles of smaller diameter will also be removed, in proportion to the ratio of their settling velocity to that of the terminal settling velocity of the particle defined above.
- The practical lower particle size limit for settling chambers is only about 50-100 µm, about the diameter of a human hair. For smaller particles, other devices are needed.

Air Pollution Control Methods - Particulate matter

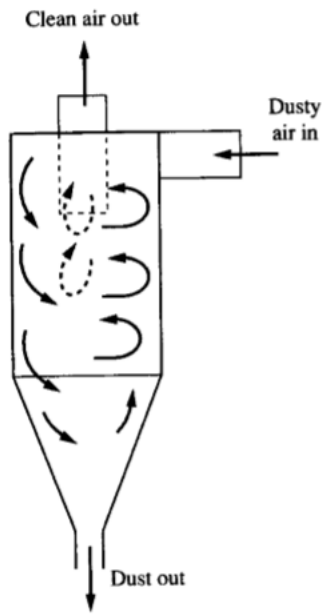
Particulate matter control devices - Cyclone separator



- For particle diameters down to about 10 µm, the collection device of choice is usually a cyclone or cyclone separator.
- This is a simple, economical unit with no moving parts, that relies on inertial effects for particulate removal.
- Particulate-laden air is sent into a conical cylinder, where it is forced into a spiral flow path and accelerates (see figure).

Air Pollution Control Methods – Particulate matter

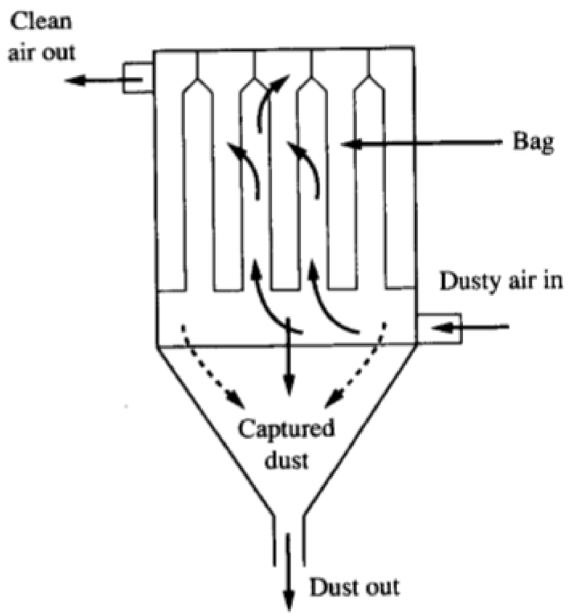
Particulate matter control devices - Cyclone separator



- The centrifugal force imparted on the particulates forces them to move to the wall of the chamber, where they then slide down to the bottom of the cone and are removed.
- The clean air exits up through the center of the cyclone.

Air Pollution Control Methods – Particulate matter

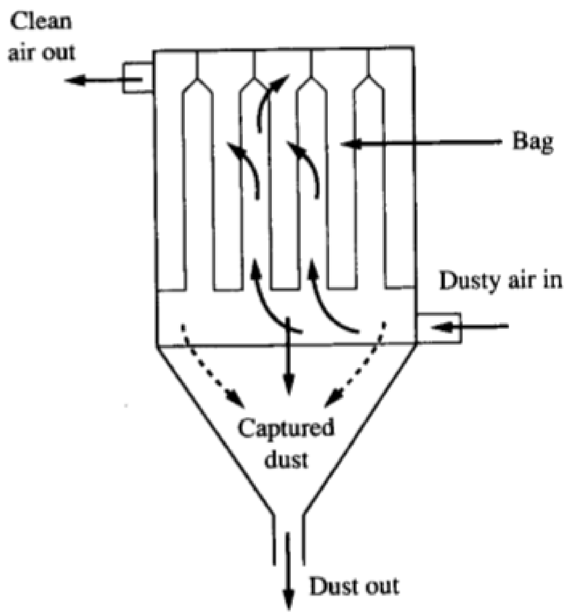
Particulate matter control devices - Bag house filter



- When particles are smaller than 10 μm or a higher collection efficiency is required, a baghouse filter can be used.
- These are widely used in industry. A baghouse filter is similar to a conventional home vacuum cleaner.
- It consists of a chamber housing natural or synthetic cloth bags through which the dirty air is pumped (See Figure).

Air Pollution Control Methods – Particulate matter

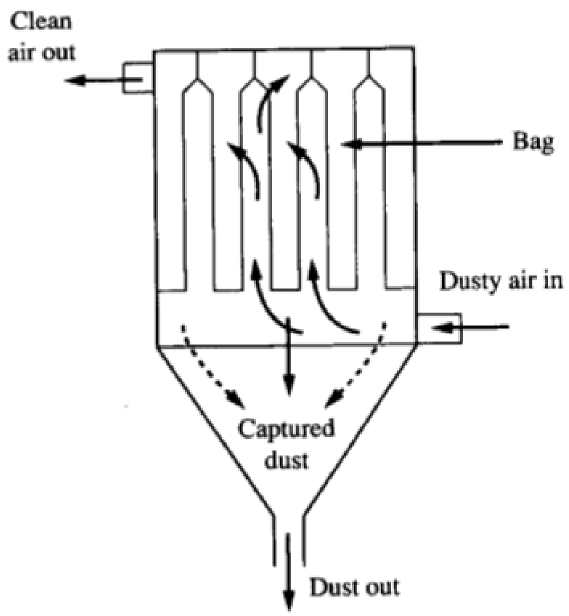
Particulate matter control devices - Bag house filter



- Particulates larger than the openings between the fibers are filtered out; smaller particles are removed by interception on the fibers themselves and by electrostatic attraction between the particles and the fibers.
- Once particles begin to accumulate, the openings become smaller and the importance of sieving increases.
- The cleaned air passes through the bag fabric and exits through an opening in the baghouse chamber.
- Particulates collect on the inside surfaces of the bags.

Air Pollution Control Methods – Particulate matter

Particulate matter control devices - Bag house filter



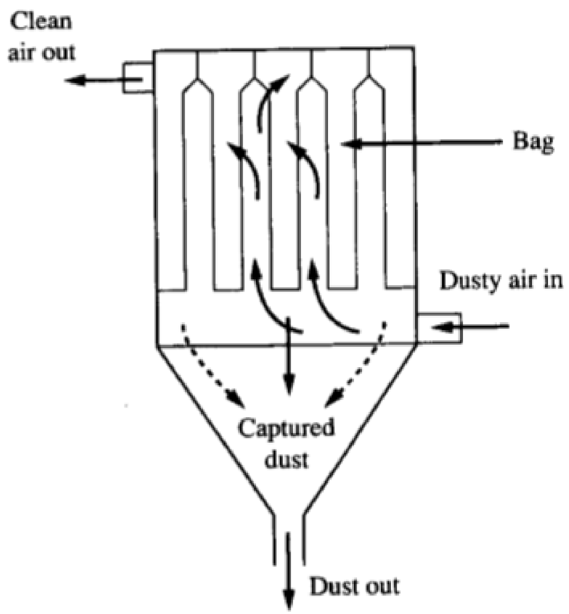
- Eventually, the head loss through the fabric will become excessive, necessitating removal of the particulates.

- The bags are periodically shaken to remove the accumulated dust, or the bag is isolated and air is blown into the bag from outside to dislodge particles. The released dust falls into a hopper below.

- Baghouse filters are very efficient and can remove even submicrometer size particles.

Air Pollution Control Methods – Particulate matter

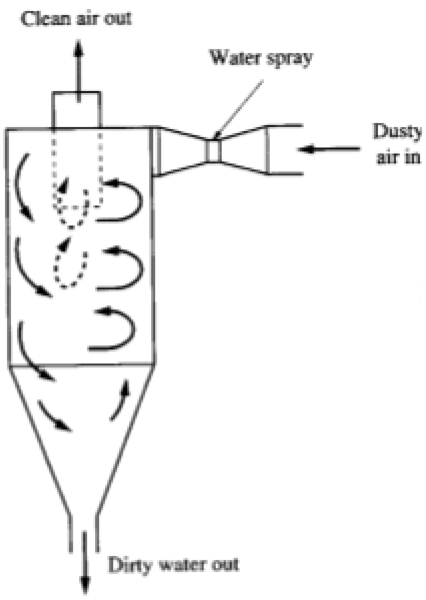
Particulate matter control devices - Bag house filter



- However, they cannot be used for wet air streams, because the particulates may cake on the filter surface, or the gases may be corrosive to the filter fabric.
- They also cannot be used for treatment of high-temperature gas streams (> 90-l00°C for cotton or wool bags or> 260°C for glass fiber bags) because damage to the filter material will result.

Air Pollution Control Methods – Particulate matter

Particulate matter control devices - Scrubber



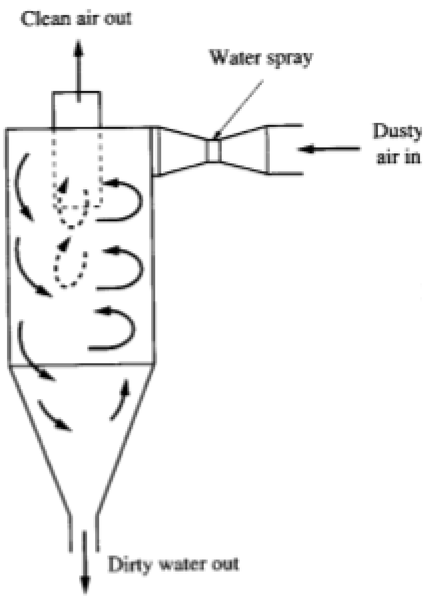
- A scrubber is another device that can be used to remove particulates from air. Scrubbers are of particular value where the contaminated air is wet, corrosive, or hot, applications where bag-houses cannot be used.

- Simple spray chambers can be used for removal of larger particle sizes. Dirty air flows through a chamber into which atomized water droplets are sprayed.

- The water droplets accumulate on the particulates in the air, increase their size and weight, and cause them to settle more rapidly and efficiently than in a settling chamber.

Air Pollution Control Methods – Particulate matter

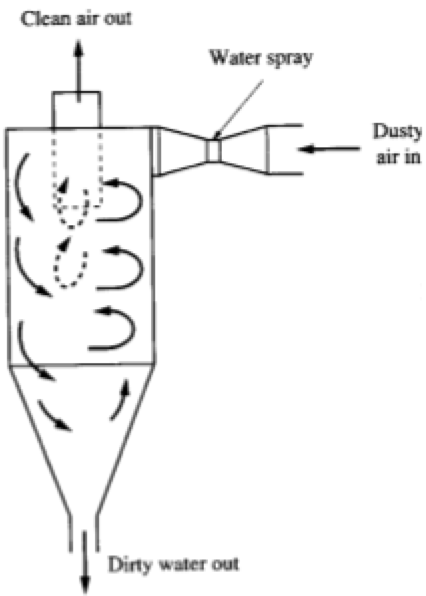
Particulate matter control devices - Scrubber



- The removed particulates in the collected spray water at the bottom of the spray chamber are drawn off to a settling basin, where the particulates are settled.
- The clarified water is usually recycled back to the scrubber.
- For high-efficiency removal of fine particles, a combination venturi scrubber and cyclone can be used (see Figure).
- A fine mist is sprayed into the dirty air as it flows through the venturi. The air then enters a cyclone, where the now large and heavy.

Air Pollution Control Methods – Particulate matter

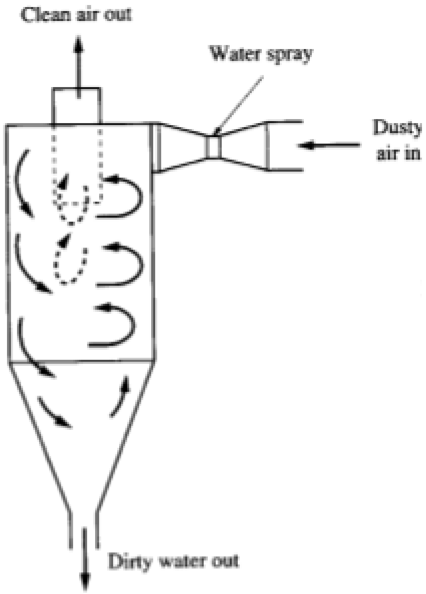
Particulate matter control devices - Scrubber



- A fine mist is sprayed into the dirty air as it flows through the venturi.
- The air then enters a cyclone, where the now large and heavy water-laden particulates are removed by cyclonic action.
- Particulate removal efficiencies can be as high as 99 percent with a well-designed scrubber system.
- However, the air exiting the scrubber is saturated with water vapor and the stack plume may be very visible, creating an aesthetic problem.

Air Pollution Control Methods – Particulate matter

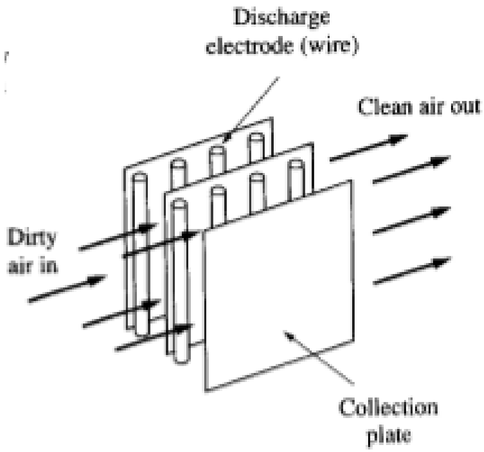
Particulate matter control devices - Scrubber



- In addition, the waste is still present, but now it is in liquid form, requiring further treatment, rather than in a solid form as it is from one of the previously described particulate removal processes.

Air Pollution Control Methods – Particulate matter

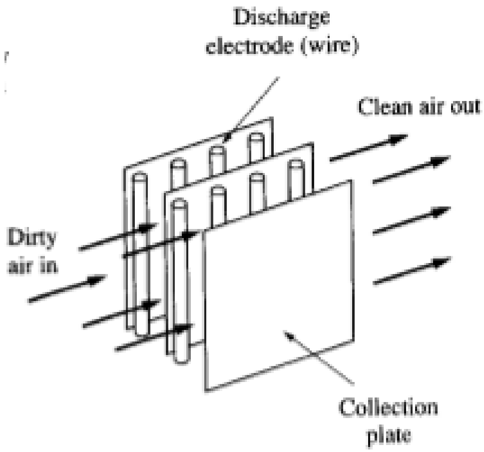
Particulate matter control devices - Electrostatic Precipitator



- A fourth type of particulate control device is the electrostatic precipitator (ESP). The ESP is a high-efficiency dry collector of particulates from air.
- The particulate matter is removed by applying a high electrical direct current potential (36-75 kV) between alternating plates and wires (see Figure).
- A full-scale ESP may have hundreds of parallel plates, with very large surface areas.

Air Pollution Control Methods – Particulate matter

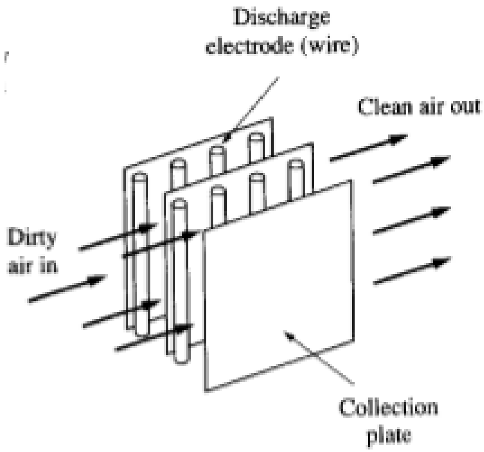
Particulate matter control devices - Electrostatic Precipitator



- As the particle-laden gas stream passes through this ion field, ions attach to the particulates, giving them a net negative charge.
- The particulates then migrate to the positively charged plates, were they are neutralized and stick.
- They are periodically removed from the ESP plate surfaces by rapping the plates.
- Efficiencies can be very high, even for small particulates.

Air Pollution Control Methods – Particulate matter

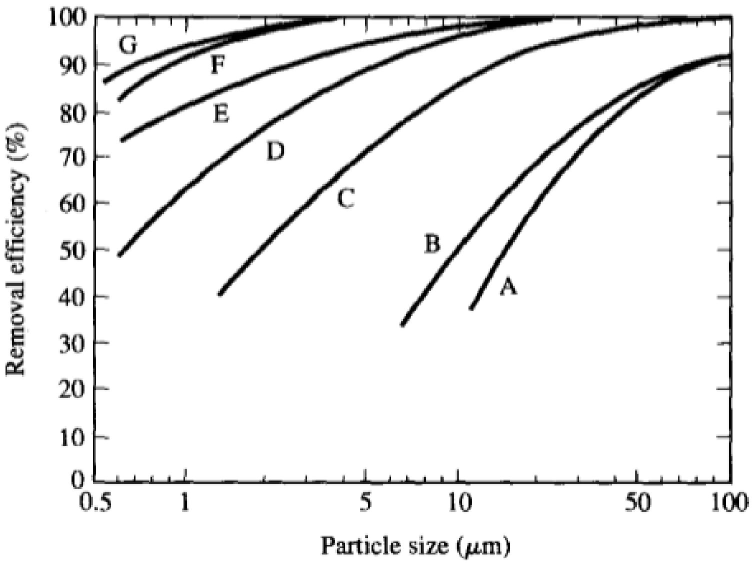
Particulate matter control devices - Electrostatic Precipitator



- Electrostatic precipitators are commonly used in electric power plants.
- They are also used to control air pollution from blast furnaces, cement kilns, metal roasters, and acid production facilities.

Air Pollution Control Methods – Particulate matter

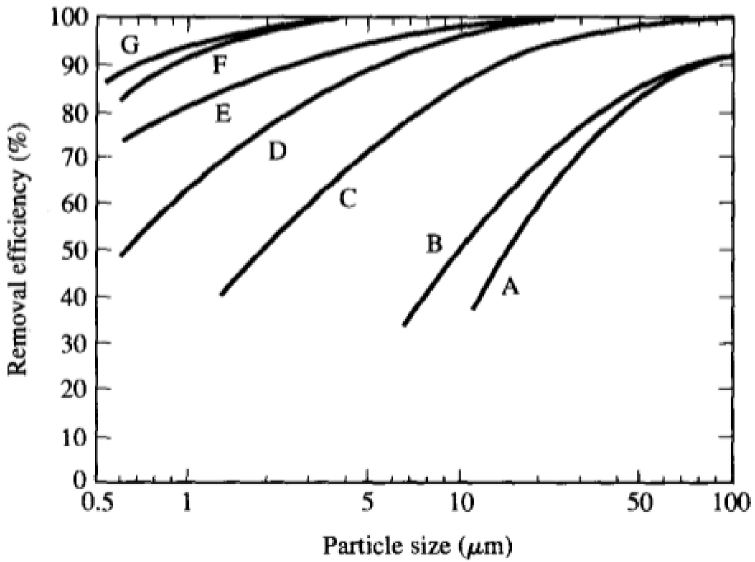
Particulate matter control devices - Electrostatic Precipitator



- In general, the efficiencies of various particulate control devices depend on the size and composition of the particles.
- Figure shows the plots approximate collection efficiencies, as a function of particle size, for several control devices.
- Figure also presents the range of particle sizes over which various control devices are effective.
- As can be seen, bag filters are the most efficient devices available, followed closely by scrubbers.

Air Pollution Control Methods

Particulate matter control devices - Electrostatic Precipitator



Comparison of approximate removal efficiencies of several air particulate control devices.

A = settling chamber
B = simple cyclone
C = high-efficiency cyclone
D = electrostatic precipitator
E = spray tower wet scrubber
F = venturi scrubber
G = bag filter

Air Pollution Control Methods

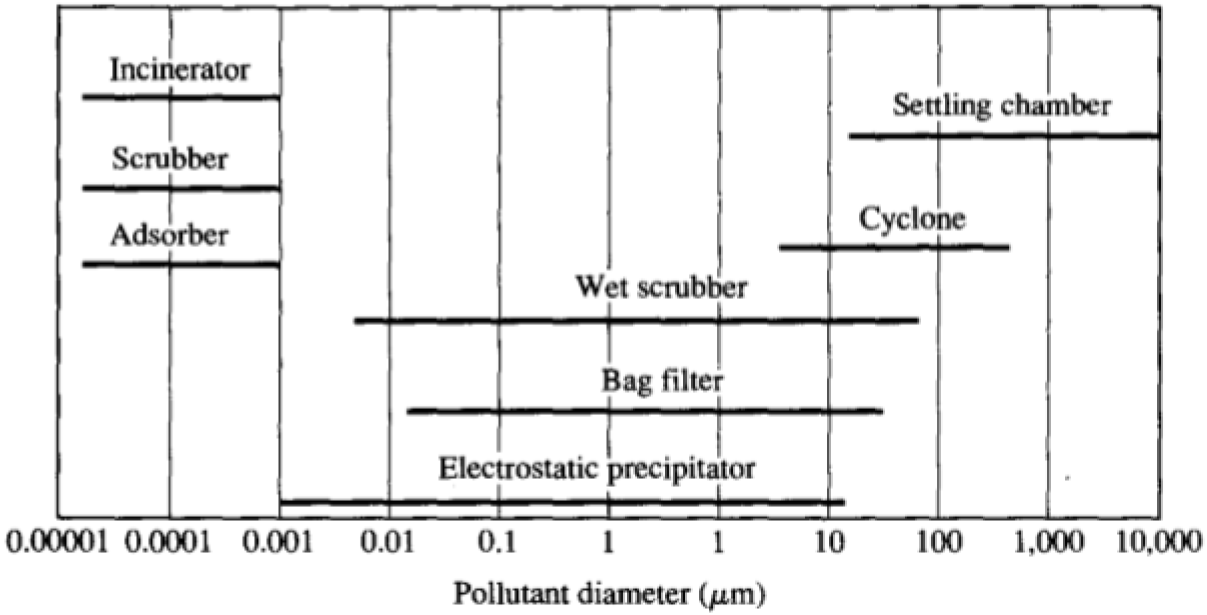
Particulate matter control devices - Effectiveness or efficiency

The effectiveness or efficiency of various air pollution control devices is generally defined as:

$$\text{Efficiency or effectiveness} = \frac{\textit{quanity of particulate matter collected or removed by the device}}{\textit{quantity of particulate matter initally present in the air or gas stream}}$$

Air Pollution Control Methods

Particulate matter control devices *- Effectiveness*



Air Pollution Control Methods – Gas removal

Particulate matter

Settling Chamber

Cyclone

Baghouse filter

Scrubber

Electrostatic Precipitator

Now we will see the second class of air pollution control equipment – that is for gaseous pollutant control

Gas Removal

Absorption

Wet Scrubbing

Adsorption

Incineration

Air Pollution Control Methods – Gas removal

Gas Removal

- The primary gaseous contaminants of concern as air pollutants are SOx, NOx' CO, CO_2, hydrocarbons, and other organic and inorganic gases.

- The principal methods for control of gaseous emissions include absorption, adsorption, and incineration.

- Some of these processes merely move the contaminants to another medium; others change them chemically or even destroy them.

Air Pollution Control Methods – Gas removal

Gas Removal

- In the process of destroying the contaminants, though, as with incineration, new pollutants may be created (e.g., CO_2 or gaseous HCl from the incineration of chlorinated hydrocarbons).

Air Pollution Control Methods – Gas removal

Gas Removal – Wet Scrubbers

- Wet scrubbers, described earlier, can also remove gaseous contaminants by absorbing them into water droplets.
- These devices transfer the pollutant from the air phase to the water phase, where further treatment may be required.
- Only pollutants that are highly soluble in water can be treated effectively.

Air Pollution Control Methods – Gas removal

Gas Removal – Wet Scrubbers

- For less soluble materials, scrubbers may be employed in which a chemical injected into the scrubber water reacts with the pollutants, either chemically altering them or making them easier to remove.
- A common example of this is flue gas desulfurization, in which $S0_2$ in the flue gas may be removed by reacting it with a solution of lime or limestone in water:

Air Pollution Control Methods – Gas removal

Gas Removal – Wet Scrubbers

$$SO_2 + CaO \rightarrow CaSO_3$$

or

$$SO_2 + CaCO_3 \rightarrow CaSO_4 + CO_2$$

Both the calcium sulfite and calcium sulfate (gypsum) can be separated from the absorption water in clarifiers.

Air Pollution Control Methods – Gas removal

Gas Removal – Adsorption systems

- Adsorption systems for removal of air pollutants usually consist of a bed of adsorbing material, such as activated carbon, housed within a pressure vessel through which the contaminated air passes.

- Contaminants are transferred from the air to the adsorber.

- Activated carbon is the most common adsorber used for air pollutants, but other adsorbents can be used, such as activated alumina, silica gel, or molecular sieves. When the adsorber becomes saturated with contaminants, breakthrough will occur and the adsorbent must be replaced or regenerated.

Air Pollution Control Methods – Gas removal

Gas Removal – Adsorption systems

- Incineration or flaring can be used to oxidize carbon monoxide or organic air pollutants (hydrocarbons, organic acids, aldehydes, and ketones, as well as organics containing chlorine, sulfur, and nitrogen) to carbon dioxide and water.

- Both direct flame combustion and catalytic combustion can be used. Catalytic incineration employs the use of catalysts to speed up the oxidation reaction and allow it to proceed at a much lower temperature than is necessary with direct flame combustion.

- Combustion processes cannot be used for all organic wastes; some organics are oxidized to materials that are more toxic than the original material.

Air Pollution Control Methods – Gas removal

Gas Removal – Adsorption systems

- For example, the combustion of trichloroethylene produces phosgene, which was used as a poison gas in World War I. Combustion of other materials can lead to the production of small, but harmful, quantities of dioxins.

References

Paul L. Bishop (2000) Pollution Prevention Fundamentals and Practice, Mc. Graw Hill.

Pandey.G.N and Carney.G.C, “Environmental Engineering” , Tata McGraw Hill, New Delhi,1989