

## Unit IV

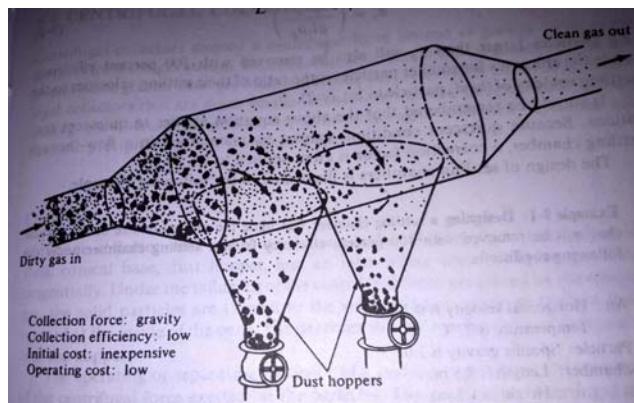
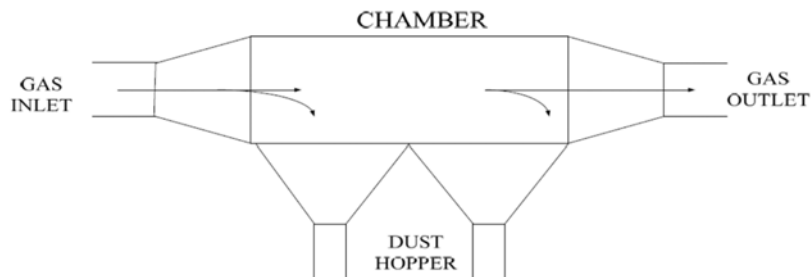
### Air Pollution Control

#### Particulate Control Equipment:

1. **Forced field settlers:** These are those equipment's that relies on field of forces like gravitational, centrifugal and electric.
  - a) **Gravitational settling chamber**
  - b) **Cyclones or centrifugal settlers**
  - c) **Electrostatic Precipitators**
2. **Bag House Filters**
3. **Scrubbers/ Wet scrubbers**

#### a) Gravitational Settling Chambers

Gravitational settling chambers are generally used to remove large, abrasive particles (usually  $>50\ \mu\text{m}$ ) from gas stream. It provides enlarged areas to minimize horizontal velocities and allow time for the vertical velocity to carry the particle to the floor. The usual velocity through settling chambers is between 0.5 to 2.5 m/s.



#### Design of a 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  $L$ , height of settling chamber  $H$ .

$$\frac{v_t}{H} = \frac{v_h}{L}$$

Where  $v_t$ =terminal settling velocity, m/s

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

Where,  $g$ =gravitational constant,  $m/s^2$ ;  $\rho_p$ =density of particle,  $kg/m^3$ ;  $\rho_a$ =density air,  $kg/m^3$ ;  $d_p$ =diameter of particle,  $m$ ;  $\mu_a$ =viscosity of air,  $kg/m \cdot s$ ;  $H$ =height of settling chamber,  $m$ ;  $v_h$ =horizontal flow-through velocity,  $m/s$ ; and  $L$ =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.

$$d_p = \sqrt{\left( \frac{18\mu_a H v_h}{g L (\rho_p - \rho_a)} \right)}$$

All particles larger than  $d_p$  will also be removed with 100% efficiency, while the efficiency for smaller particles is the ratio of their settling velocities to the settling velocity of the  $d_p$  particle.

$$\text{Efficiency } \eta = v_t L / H v_h \times 100$$

**Example:** Calculate the minimum size of the particle that will be removed with 100 percent efficiency from gravitational settling chamber under following conditions.

Air:

Horizontal velocity is 0.3 m/s

Temperature is 77°C

Particle: Specific gravity is 2.0

Chamber: Length is 7.5 m

Height is 1.5 m

At 77°C viscosity of air is  $2.1 \times 10^{-5} \text{ kg/m} \cdot \text{s}$

Using this equation with correction factor of 2

$$d_p = \sqrt{\left( \frac{18\mu_a H v_h}{g L (\rho_p - \rho_a)} \right)}$$

$\rho_a$  is insignificant as compared to  $\rho_p$

$$d_p = [ 2 \times (18 \mu_a \cdot v_h \cdot H / g \cdot L \cdot \rho_p) ]^{1/2}$$

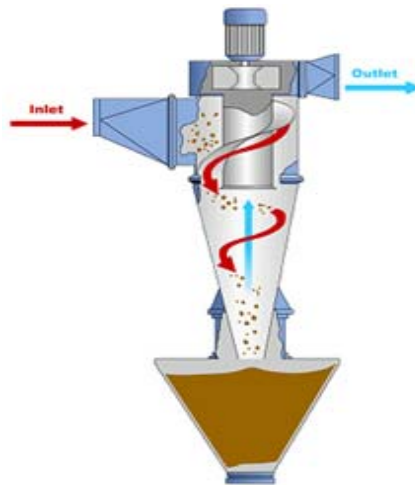
$$d_p = 4.81 \times 10^{-5} \text{ m} \quad 48.1 \mu$$

### b) Cyclones or centrifugal settlers

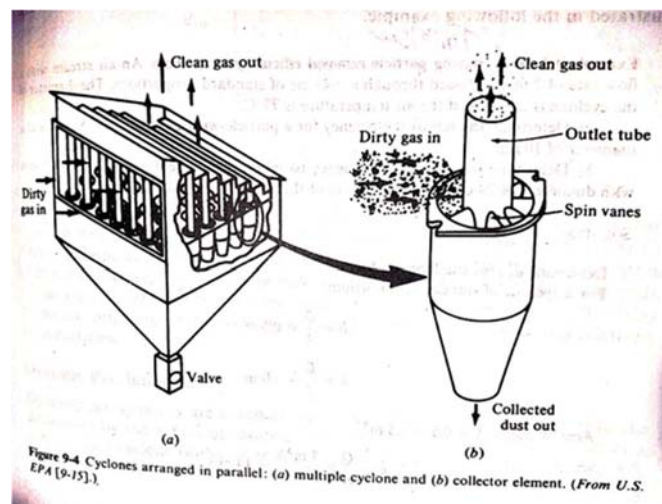
A cyclone separator consists of a cylindrical shell, conical base, dust hopper and an inlet where the dust-laden gas enters tangentially. Under the influence of the centrifugal force generated by the spinning gas, the solid particles are thrown to the wall of the cyclone as the gas spirals upward at 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.

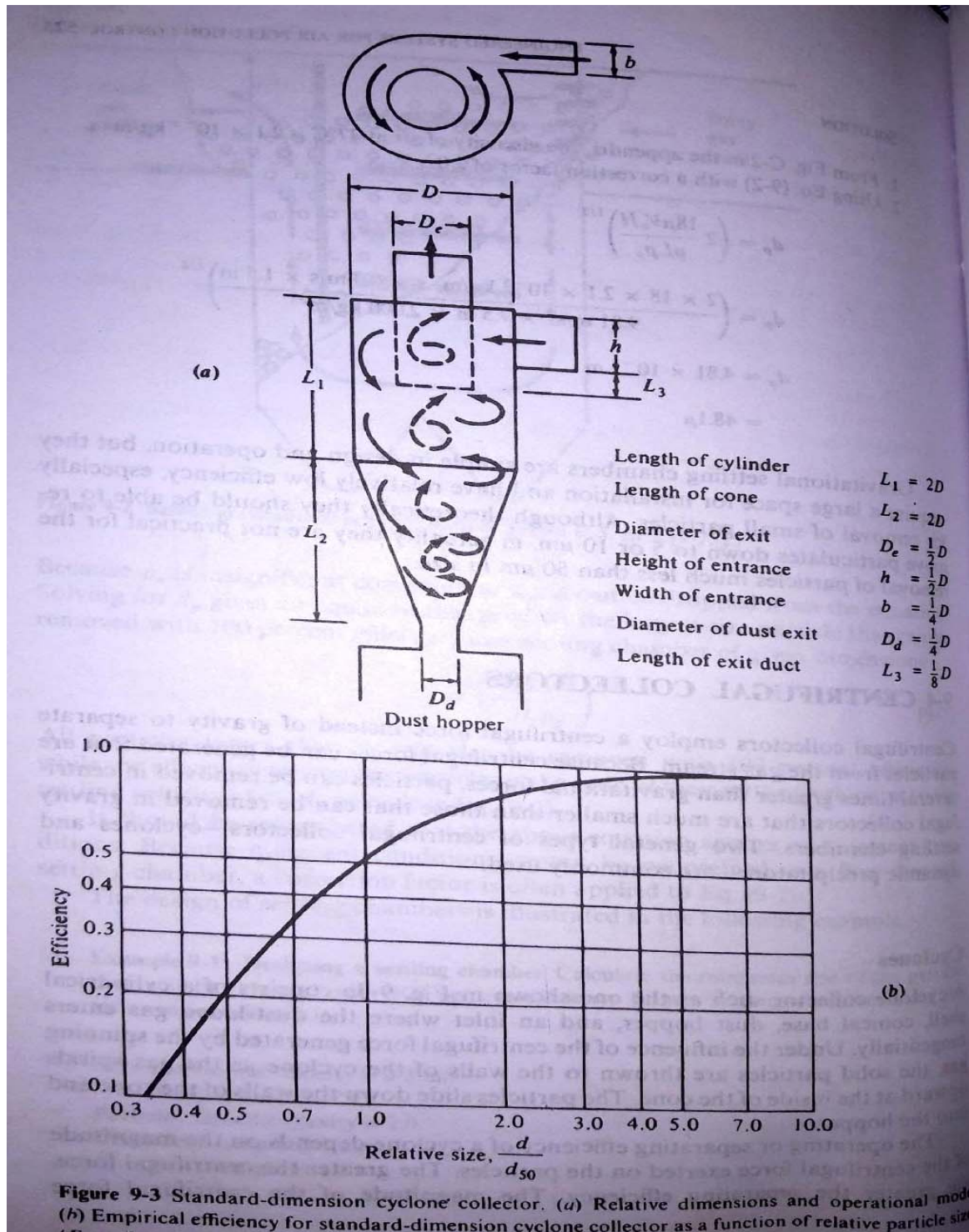
$$F_c = M_p \frac{v_i^2}{R}$$

Where,  $F_c$ =centrifugal force ;  $M_p$ =particulate mass, Kg;  $v_i$  equals particle velocity and  $R$  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 decreasing  $R$ . Large-diameter cyclone have good collection efficiencies for particles 40 to 50  $\mu\text{m}$  in diameter.



**Cyclone** (<https://www.rcuniverse.com/forum/composites-fabrication-repair-97/11637417-cyclone-dust-collector-project.html>)







- The size of the particles is determined by the following equation based on the work by Lapple (Lapple equation)

$$d_{50} = (9\mu b / 2 \pi N_e V_i \rho_p)^{1/2}$$

$d_{50}$  = Diameter of the particle that is collected with 50 percent efficiency, m

$\mu$  = gas viscosity, kg/m.s

$b$  = width of cyclone inlet, m

$N_e$  = number effective turns within the cyclone

$V_i$  = inlet gas velocity, m/s

$\rho_p$  = density of particulate material, kg/m<sup>3</sup>

- The collection efficiency of particles both larger and smaller than  $d_{50}$  is determined by the ratio  $d_{50}$  as shown in figure 9-3(b) Peavy 2013

**Advantage:** Relatively inexpensive, simple to design and maintain; requires less floor area; low to moderate pressure loss.

**Disadvantage:** Requires much head room; collection efficiency is low for smaller particles, quite sensitive to variable dust loading and flow rates.

...in the following example. ... calculations are

**Example 9-2: Determining particle removal efficiency in cyclones** An air stream with a flow rate of 7 m<sup>3</sup>/s is passed through a cyclone of standard proportions. The diameter of the cyclone is 2.0 m, and the air temperature is 77°C.

(a) Determine the removal efficiency for a particle with a density of 1.5 g/cm and a diameter of 10 μm.

(b) Determine the collection efficiency based on the above if a bank of 64 cyclones with diameters of 24 cm are used instead of the single large unit.

**SOLUTION**

1. Determine  $d_{50}$  for the large cyclone.  
For a cyclone of standard proportions

$$b = \frac{D}{4} = 0.5 \text{ m}$$

$$h = \frac{D}{2} = 1.0 \text{ m}$$

Area of inlet =  $1 \times 0.5 = 0.5 \text{ m}^2$

$$v_i = \frac{Q}{A} = \frac{7 \text{ m}^3/\text{s}}{0.5 \text{ m}^2} = 14 \text{ m/s}$$

At this inlet velocity,  $N_e \approx 5$  turns

At  $77^\circ\text{C}$ ,  $\mu = 2.1 \times 10^{-5} \text{ kg/m} \cdot \text{s}$

Using Eq. (9-4).

$$d_{50} = \left( \frac{9 \times 2.07 \times 10^{-5} \text{ kg/m} \cdot \text{s} \times 0.5 \text{ m}}{2\pi \times 5 \times 14 \text{ m/s} \cdot 1500 \text{ kg/m}^3} \right)^{1/2}$$

$$= 1.19 \times 10^{-5} \text{ m}$$

$$= 12 \mu\text{m}$$

$$\frac{d}{d_{50}} = \frac{10}{12} = 0.83$$

From Fig. 9-3b the efficiency for the  $10\text{-}\mu\text{m}$  particle is found to be about 42 percent.

2. Determine the  $d_{50}$  for the small cyclone.

$$b = \frac{D}{4} = \frac{0.24}{4} = 0.06 \text{ m}$$

$$h = \frac{D}{2} = \frac{0.24}{2} = 0.12 \text{ m}$$

$$\text{Area of inlet} = 0.06 \times 0.12 = 7.2 \times 10^{-3} \text{ m}^2$$

$$\text{Area of all inlets} = 64 \times 7.2 \times 10^{-3} \text{ m}^2$$

$$= 0.45 \text{ m}^2$$

$$\text{Inlet velocity} = \frac{7 \text{ m}^3/\text{s}}{0.46 \text{ m}^2} = 15 \text{ m/s}$$

$$d_{50} = \left( \frac{9 \times 2.1 \times 10^{-5} \text{ kg/m} \cdot \text{s} \times 0.06 \text{ m}}{2\pi \times 5 \times 15 \text{ m/s} \times 1500 \text{ kg/m}^3} \right)^{1/2}$$

$$= 4.0 \times 10^{-6} \text{ m}$$

$$= 4.0 \mu\text{m}$$

$$\frac{d}{d_{50}} = \frac{10}{4} = 2.5$$

From Fig. 9-3b, the efficiency for the  $10\text{-}\mu\text{m}$  particle is about 88 percent.

### c) Electrostatic Precipitators (ESPs)

ESP uses an electric field on electrically charged particles to separate liquid or solid aerosols from gas stream. The aerosol is deliberately charged and passed through an electric field causing the particles to migrate towards an oppositely charged electrode which act as a collection surface gravity or periodic vibration is used to remove the particle from the precipitator.

ESPs are characterized high efficiency even for small particles. They can handle large volume of gas can be designed for wide temperature range. But ESP require large space their capital cost is high and they are not flexible after installations to the changes in operating conditions.

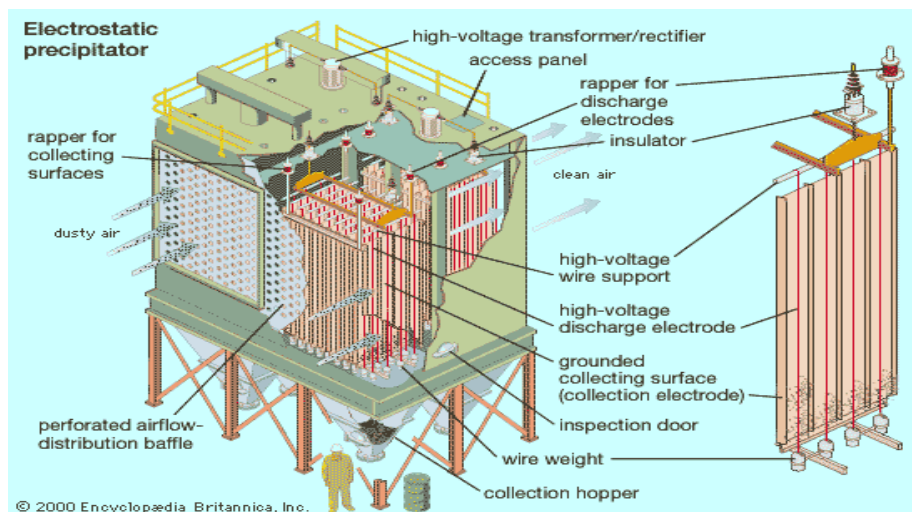
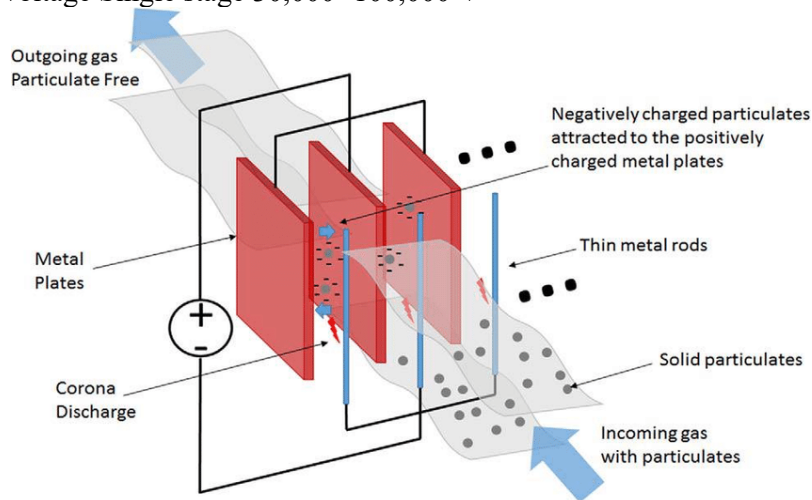
The electrostatic precipitator is one of the most widely used device for controlling particulate emission at industrial installations ranging from power plants, cement and paper mills to oil

refineries. Electrostatic precipitator is a physical process by which particles suspended in gas stream are charged electrically and, under the influence of the electrical field, separated from the gas stream. The precipitator system consists of a positively charged collecting surface and a high voltage discharge electrode wire suspended from an insulator at the top and held in position by weight at the bottom. At a very high DC voltage, of the order of 50kV, a corona discharge occurs close to the negative electrode, setting up an electric field between the emitted and the grounded surface.

The particle laden gas enters near the bottom and flows upward. The gas close to the negative electrode is, thus, ionized upon passing through the corona. As the negative ions and electrons migrate toward the grounded surface, they in turn charge the passing particles. The electrostatic field then draws the particles to the collector surface where they are deposited. Periodically, the collected particles must be removed from the collecting surface. This is done by rapping or vibrating the collector to dislodge the particles. The dislodged particles drop below the electrical treatment zone and are collected for ultimate disposal.

ESP are of two types

1. Low voltage two stage 6000V-12,000V
2. High voltage Single stage 30,000- 100,000 V



**Advantage:**

- Maintenance is nominal, useless corrosive and adhesive materials are present in flue
- gases.
- They contain few moving parts.
- They can be operated at high temperature up to 300°C-450° C.

**Disadvantage:**

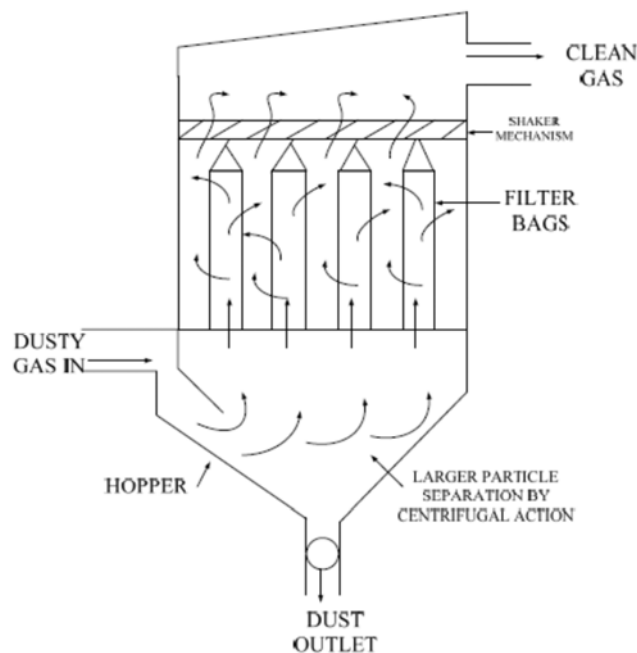
- Higher initial cost.
- Sensitive to variable dust loading and flow rates.
- They use high voltage, and hence may pose risk to personal safety of the staff.
- Collection efficiency reduces with time

**Fabric Filters/Bag House Filters**

In a fabric filter system, the particulate-laden gas stream passes through a woven or felted fabric that filters out the particulate matter and allows the gas to pass through. Small particles are initially retained on the fabric by direct interception, inertial impaction, diffusion, electrostatic attraction, and gravitational settling. After a dust mat has formed on the fabric, more efficient collection of submicron particle is accomplished by sieving.

Filter bags usually tubular or envelope-shaped, are capable of removing most particles as small as  $0.5\mu\text{m}$  and will remove substantial quantity of particles as small as  $0.1\mu\text{m}$ . Filter bags ranging from 1.8 to 9 m long, can be utilized in a bag house filter arrangement.

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



**Fig: Bag House Filter**



**Fabric and Fibre Characteristics:** Fabric filter may be classified according to filtering media: woven fabric or felt cloth. Woven fabrics have a definite long-range repeating pattern and have considerable porosity in the direction of gas flow. These open spaces must be bridged by impaction or interception to form a true filtering surface. Felted cloth consists of randomly oriented fibres, compressed into a mat and needled to some loosely woven backing material to improve mechanical strength. The choice of fabric fibre is based primarily on operating temperature and the corrosiveness or abrasiveness of the particle. Cotton is the least expensive fibre, and is preferably used in low temperature dust collection service. Silicon coated glass fibre cloth is commonly employed in high temperature applications. The glass fibre must be lubricated to prevent abrasion. All fibre may be applied to the manufacture of woven and felt type fabrics.

**Fabric Filter System:** Fabric filter systems typically consist of a tubular bag or an envelope, suspended or mounted in such manner that the collected particles fall into hopper when dislodged from fabric. The structure in which the bags are hanged is known as a bag-house. Generally, particle laden gas enters the bag at the bottom and passes through the fabric while the particles are deposited on the inside of the bag. The cleaning is accomplished by shaking at fixed intervals of time.

**Advantage:** Fabric filters can give high efficiency, and can even remove very small particles in dry state.

**Disadvantage:** High temperature gasses need to be cooled. The flue gasses must be dry to avoid condensation and clogging. The fabric is liable to chemical attacks.

**Scrubbers/ Wet Scrubbers: Self Study**

## Tutorial 2

### Unit -IV

#### Assume suitable data if missing

1. A gravity settling collector is to be used to remove particulates having diameter of  $100\mu\text{m}$  and density of  $1.5\text{ g/cm}^3$ . What is the maximum gas velocity that can be used if the chamber is 100 m long, 2m high? The desired collection efficiency is 90%.
2. What is the smallest diameter of particle having a density of  $2\text{ g/cm}^3$  which can be collected with efficiency of 85% in a gravity settling chamber 12 m long, 3 m high, gas velocity 0.78 m/s.
3. It is desired to construct a settling chamber to remove particles from air stream of  $120\text{ m}^3/\text{min}$ . The specific gravity of particle is 2.5. The chamber is strapped to the ceiling of an industrial building and the space is limited vertically to 2 m and horizontally 1.5 m. Determine the length require to remove 100% of  $50\mu\text{m}$  particle.
4. A cyclone of standard dimension  $D= 1.6\text{m}$  processes  $4.5\text{m}^3/\text{s}$  of air having a temperature of  $77^\circ\text{C}$ . Determine  $d_{50}$  if the specific gravity of particle is 1.2. Assume number of turns to be 5 and  $\mu= 2.07\times 10^{-5}\text{ kg/ms}$ .
5. Flow rate of an air stream pass through a cyclone of standard proportion is  $7.5\text{ m}^3/\text{s}$ . the diameter of cyclone is 2.6 m and its viscosity of air  $2.07\times 10^{-5}\text{ kg/ms}$ .
  - a) Work out other dimensions of this cyclone units
  - b) Determine the size of the particles that can be removed with 50% efficiency.
  - c) Using the relative size efficiency curve (**figure 9-3**) determine the efficiency for removal of  $10\mu$  particle.
  - d) Determine the collection efficiency for  $10\mu\text{m}$  particle if 70 cyclones with 24 cm diameter are used instead of one large unit.

Assume  $Ne= 5$ ,  $\rho_p= 1.5\text{ g/cm}^3$ .
6. Explain the working of spray towers and cyclone scrubbers with suitable diagram.
7. Explain the greenhouse effect. How it is related to Global Warming?