1 CHAPTER — FLOW OF FLUIDS

Selected Definitions

Fluid flow: It is defined as the flow of substances that are not permanently resistant to distortion.

Fluid Statics: It study the behavior of liquid at rest.

Manometers: These are the devices used to the measurement of pressure.

Fluid Dynamics: It deals with study of fluid in motion.

Laminar flow: It is the flow in which the fluid particles move in straight layers or laminae.

Turbulent flow: It is the flow in which fluid particles move in random manner instead of straight path on increasing the velocity.

Transition flow: It is a mixture of laminar and turbulent flow, with turbulence at the center of the pipe and laminar flow near the edges.

Reynolds number : It is the ratio of inertial forces to viscous forces.

Bernoulli's theorem: This states that Total energy (which consist of pressure energy, kinetic energy and potential energy) per unit mass in steady state are constant.

Potential energy: It is defined as the energy possessed by the body by virtue of its position

Kinetic energy: It is defined as the energy possessed by the body by virtue of its motion

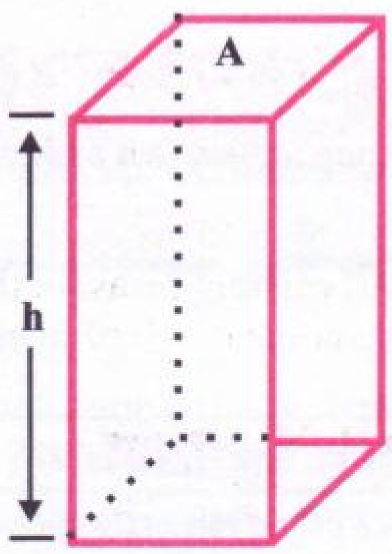
Vena contracta: The point at which diameter of fluid stream get less than initial volume of diameter.

Flow meters: A flow meter is a device used to measure the flow rate or the amount of a gas or liquid moving through pipe.

1.1 INTRODUCTION

A **fluid** is a substance that under an applied shear stress continuously flows. The term Fluids are a subset of the phases of matter and include both liquids and gases. Fluid flow can be defined as the flow of substances that are not permanently resistant to distortion. The study of fluids can be divided into fluid statics and fluid dynamics.

Fluid Statics study the behavior of liquid at rest.



Pressure (P) is weight exerted on an area (A) and expressed as

$$\text{Pressure} = \frac{\text{Weight}}{\text{Area}}$$

or

$$\text{Pressure} = \frac{mg}{A} \quad (1.1)$$

As we know m = pV. So above equation can be written as

$$\text{Pressure} = \frac{pVg}{A} \quad (1.2)$$

or

$$\text{Volume (V)} = h.A \quad (1.3)$$

So

$$\text{Pressure} = pgh \quad (1.4)$$

Where
p is fluid density
g is acceleration of gravity
h is height of liquid column
The static fluid pressure at a given depth does not depend on the total mass, surface area or container geometry. The principle of fluid static is used in working of manometers. The pressure difference (ΔP) is measured in terms of differences in heights of the liquid column.

Solved problem

Exercise 1.1 : What will be the hydrostatic pressure at 20 meters below the surface of the ocean if the density of seawater is 1,030 kilograms per cubic meters.

Solution:

As we know

Pressure = $p$gh

P = (1,030 kg/m^3)(9.8 m/s^2)(20 m)

P = 201,818 Pascal

1.2 MEASUREMENT OF PRESSURE

The devices used for measuring pressure difference are known as Manometers. There are different types of manometer described below:

1. **Simple Manometer:** Simple Manometer are those that measure the pressure at a point in a fluid contained in the pipe or in a vessel. Simple manometer are of many types

Simple Manometer
- **Piezometer**
- **U-tube manometer**
- **Single column manometer**

2. **Differential manometers:** Differential manometers measure the pressure difference between any two points of a fluid contained in a tube or vessel. Differential manometer are of following types

Different Manometers
- **U-tube differential manometer**
- **Inverted U-tube differential manometer**

3. **Inclined Manometer**

1. **Simple Manometer:** A simple manometer is one that consists of a glass tube whose one end is connected to a point where the pressure is measured and the other end is open to the atmosphere.

1.2.1 Piezometer

The piezometer is one of the simplest forms of Manometer. It can be used to measure moderate pressures of liquids. It consists of a glass tube which is inserted into the wall of a vessel. The tube extends vertically upwardly to such a height that the liquid can freely rise therein without overflowing. The pressure at any point in the liquid is the height of the liquid in the tube above that point.

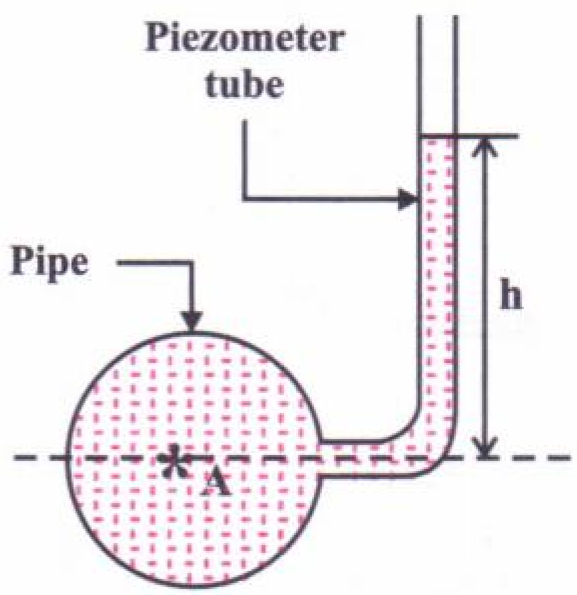


Figure 1.1: Piezometer

The pressure (P) at point A is given by

$$P = \rho g h = wh \quad (1.5)$$

Where

h is height to which the liquid rises in the glass tube.

w is the specific weight of the liquid

Limitations of Piezometer

1. Piezometers can only measure gauge pressures. Not suitable for measuring negative pressures
2. Not used to measure Gas pressures.
3. Piezometers cannot be used when large pressures measured on lighter liquids as this would require very long tubes.

1.2.2 U – tube manometer

The limitations of piezometers can be overcome by the use of U-tube manometers.

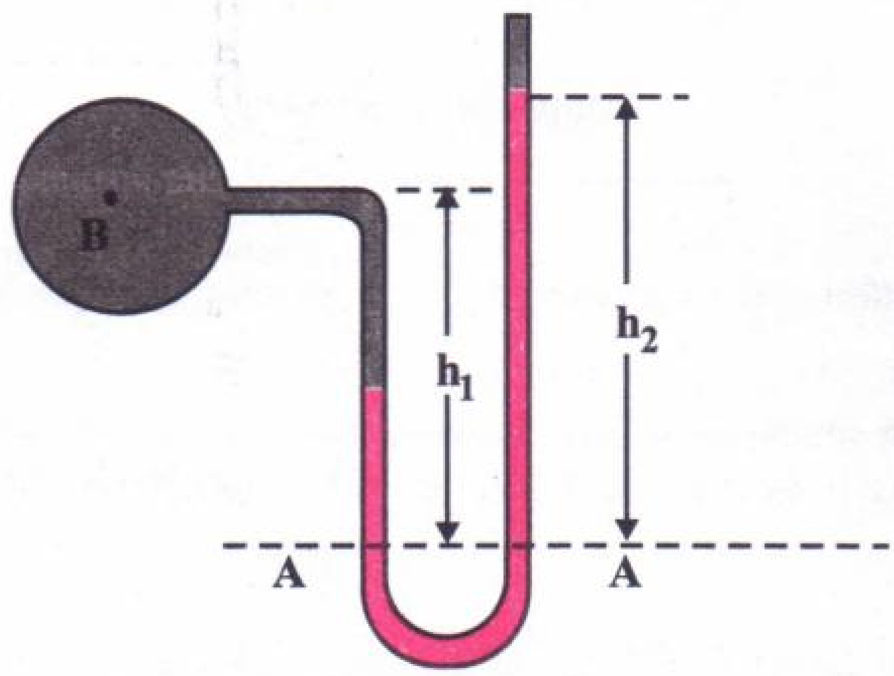


Figure1.2 : U – tube manometer

It consists of a glass tube folded like the letter 'U'. In this type of manometer One end of the U-tube is attached to the point where the pressure is to be measured and the other end is open at atmospheric pressure. The pressure at point B is given by:

$$P = \rho_2 g h_2 - \rho_1 g h_1 \qquad (1.6)$$

Where

ρ_1 = density of light liquid

h_1 = height of light liquid above reference line.

ρ_2 = density of heavy liquid

h_2 = height of heavy liquid above reference line

1.2.3 Single column manometer

It is a modified form of a U-tube manometer in which a reservoir, having a large cross-sectional area (approximately 100 times) compared to the tube area is connected to one of the manometer's limbs. For any variation in pressure, the change in liquid level in the reservoir will be very small, which can be neglected and therefore the pressure is given by the height of the liquid at the other limb. This manometer may be vertical single column manometer or inclined single column manometer.

2. Differential manometers

These are the devices which are used to determine the difference of pressure between two points in a pipe.

1.2.4 U-tube differential manometer

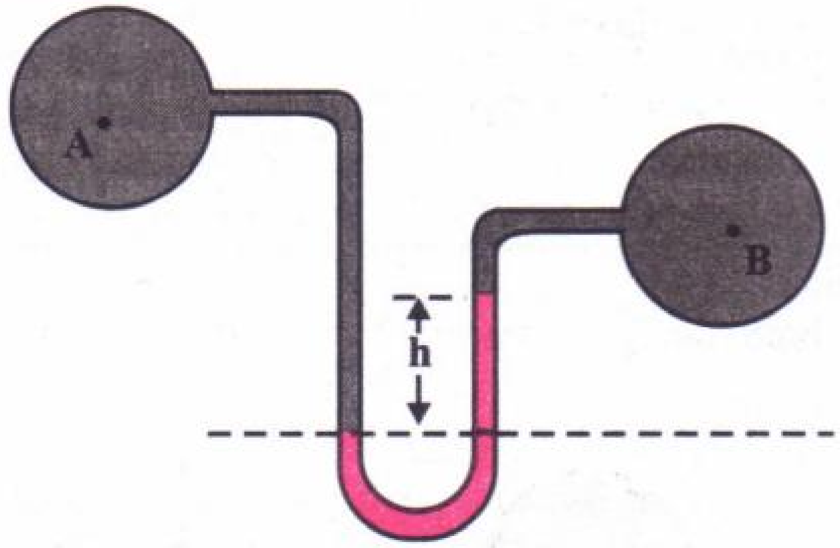


Figure1.3: U-tube differential manometer

Here A and B are the points that have different specific gravity and also at different levels.
These points are connected to U-tube differential manometer.
Let the pressure at point A be P_A and at point B be P_B.

$$P_A - P_B = g \times h\,(\rho_g - \rho_1) \qquad (1.7)$$

where,

h = difference in mercury level in the U-tube

ρ_g = density of heavy liquid

ρ_1 = density of liquid A.

1.2.5 Inverted U- tube differential manometer

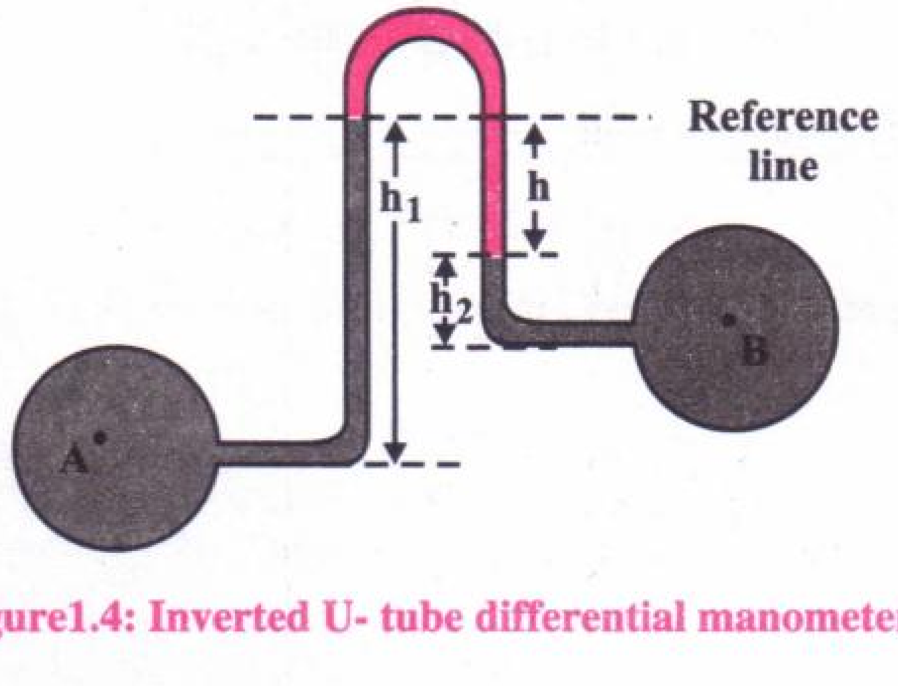


Figure1.4: Inverted U- tube differential manometer

This manometer is used when there is small difference in densities of the two liquids. A and B are points at different levels with liquids of different specific gravity. The manometer consists of a glass tube in shape of an inverted letter "U". The air is present in the center of limbs. Air or mercury is used as manometric fluid. As the two points under consideration are at different pressures, the liquid rises at both ends. If P_A is the pressure at point A and P_B is the pressure at point B;

$$P_A - P_B = \rho_1.g.h_1 - \rho_2.g.h_2 - \rho_g.g.h \quad (1.8)$$

where, ρ_1 = density of liquid at A

ρ_2 = density of liquid at B

ρ_g = density of light liquid

h = difference of light liquid
h_1 = height of liquid in left limb

h_2 = height of liquid in right limb

3. Inclined Manometer

It is an slant manometer. This is used to measure very small pressure difference. Inclination is done to improve sensitivity. The angle of the measuring leg is approximately 10°.

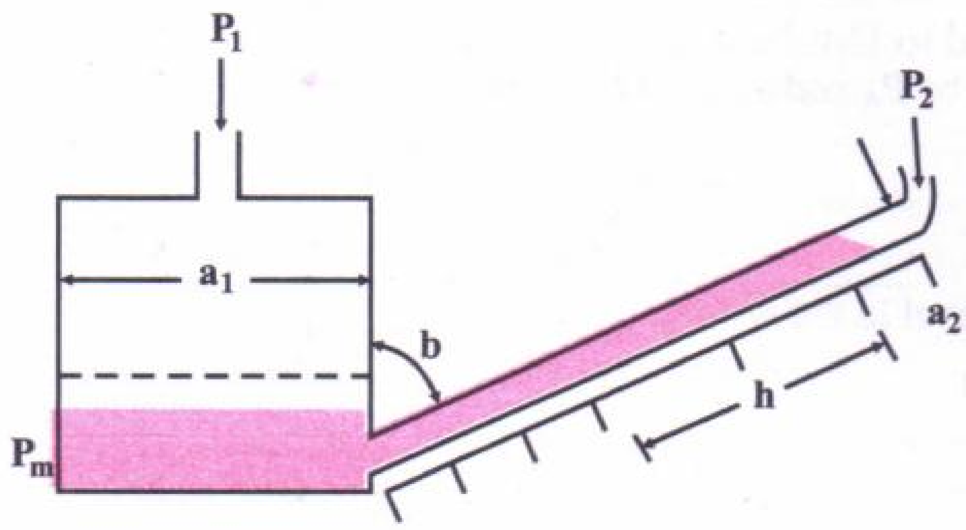


Figure1.5: Inclined Manometer

1.3 FLUID DYNAMICS

It deals with study of fluid in motion.

1.3.1 Types of flow

There are in general three types of fluid flow in pipes

- laminar
- turbulent
- transient

1.3.1.1 Laminar flow

The laminar flow is that in which the fluid particles move in straight layers or laminae. There is no exchange of fluid particles from one layer to another. This is also called streamline flow. Laminar flow typically occurs when small pipes and low flow rates are involved. Shear stress depends almost exclusively on the viscosity and is independent of the density.

Figure1.6: Laminar flow

1.3.1.2 Turbulent flow

When velocity is increased, fluid particles move in random manner instead of straight path. This type of flow is called turbulent flow. As a result, a complete mixing of fluid particles is produced. In turbulent flow vortices, eddies and waves make the flow unpredictable. Turbulent flow generally occurs at high flow rate and with larger pipes. Shear stress for turbulent flow is a function of the density.

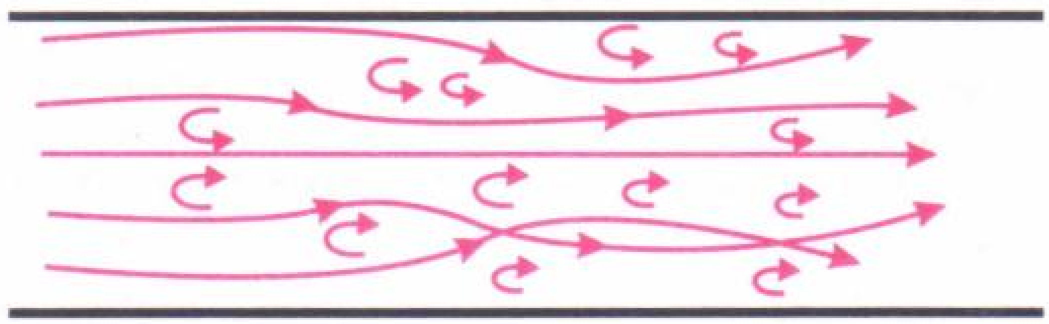


Figure1.7: Turbulent flow

1.3.1.3 Transitional flow

The transition flow is a mixture of laminar and turbulent flow, with turbulence at the center of the pipe and laminar flow near the edges.

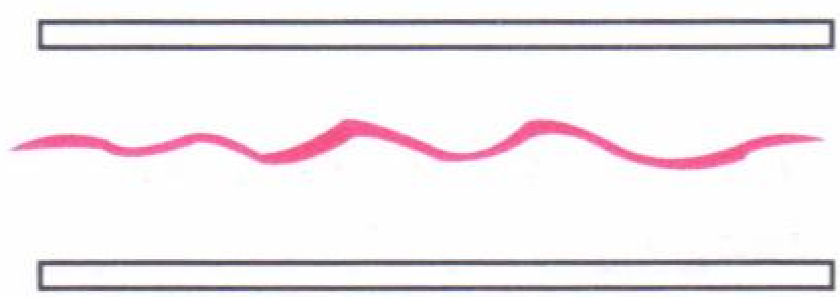


Figure1.8: Transitional flow

Critical velocity is the velocity at which flow changes from laminar to turbulent.

1.4 REYNOLD'S NUMBER

Reynolds number (Re) is a dimensionless number. Turbulent or laminar flow is determined by the Reynolds Number. It gives a measure of the ratio of inertial forces to viscous forces

$$Re = \frac{\text{inertial forces}}{\text{viscous forces}}$$

Reynolds number formula is given by

$$Re = \frac{Dup}{\eta} \quad (1.9)$$

Where

D= diameter of pipe (m)

u= velocity of flow (m/s)

p = density of fluid (kg/m^3)

η =viscosity of fluid

1.4.1 Measurement of fluid flow- Reynold's Experiment

The apparatus consist of glass tank containing water, a small tank containing color liquid or dye and a glass tube with regulating valve (to adjust the velocity of flow) at one end. Water is allowed to flow through glass tube. A liquid dye with same specific weight as water was introduced into glass tube.

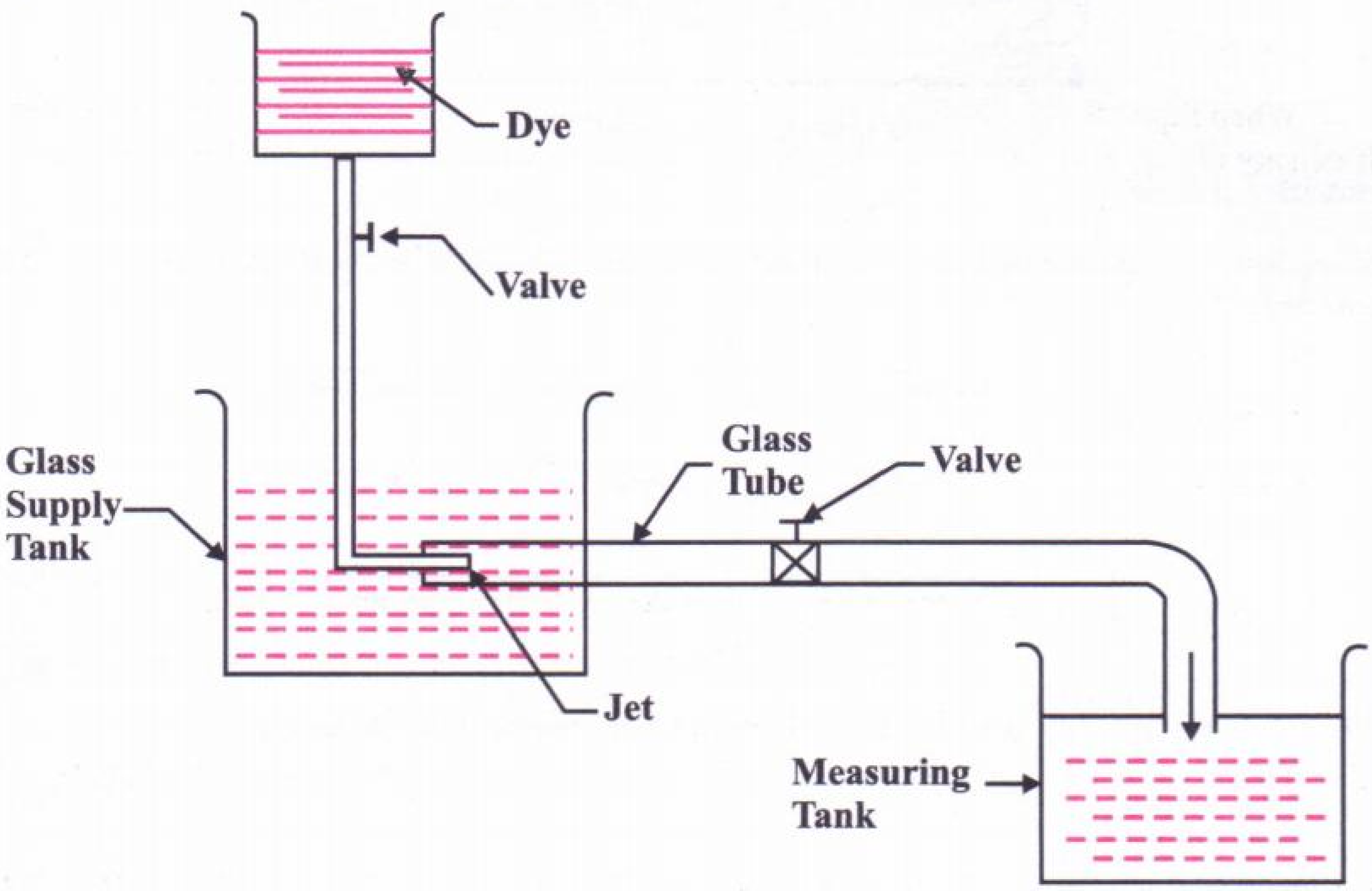


Figure1.9: Setup of Reynold Apparatus

1.4.2 Observations by Reynold's

The following observations are made by Reynold's

1. At low velocity, the dye will move in a line parallel to the tube and also it does not get dispersed (i.e. laminar flow).
2. At velocity little more than before the dye moves in a wave form (i.e. transition flow).
3. At more velocity the dye will no longer move in a straight (i.e. Turbulent flow).

The flow is

- **laminar** when $Re < 2000$
- **transition** when $2000 < Re < 4000$
- **turbulent** when $Re > 4000$

1.4.3 Applications

Reynold's number is used

1. To predict nature of flow.
2. To study flow of incompressible fluid in closed pipes.
3. The stock law equation is modified to include the Reynolds number to study the sedimentation rate in suspension.
4. Heat transfer in liquids also depend on flow.

Solved problems

Exercise1.2: When liquid is flowing through a pipe having diameter 200mm. Tube with mean velocity of oil 2m/sec. If density of liquid is 910 Kg/m^3 and viscosity is 0.35 $N.S/m^2$, then what will be the type of flow?

Solution:

D = 200 mm= 0.2 m

u = 2m/sec

$p = 910\ Kg/m^3$

$\eta = 0.35\ N.S/m^2$

$$Re = Dup/\eta$$

Ans. Or Re = 0.2 * 2 * 910 / 0.35 = 1040 < (2000) i.e. Flow is laminar

1.5 BERNOULLI'S THEOREM AND ITS APPLICATIONS

Bernoulli's theorem is an equation which results when law of conservation of energy is applied to the flow of fluids.

Bernoulli's theorem states that Total energy (which consist of pressure energy, kinetic energy and potential energy) per unit mass in steady state are constant.

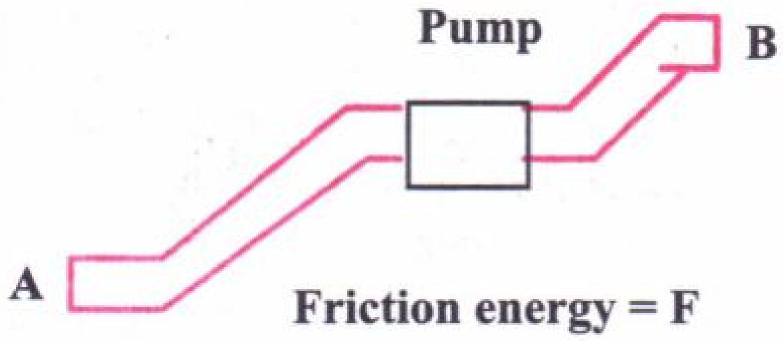


Figure1.10: Development of Bernoulli's theorem

At point A, liquid is flowing through pipe at certain pressure, pressure energy may be written as

$$\text{Pressure energy} = \frac{P_A}{g\rho_A} \qquad (1.10)$$

Where

P_A = Pressure at point A

g = Acceleration due to gravity

ρ_A = Density of the liquid

Potential energy is defined as the energy possessed by the body by virtue of its position

$$\text{Potential energy} = X_A \qquad (1.11)$$

Kinetic energy is defined as the energy possessed by the body by virtue of its motion

$$\text{Kinetic energy} = \frac{U_A^2}{2g} \qquad (1.12)$$

Total energy at point A = Pressure energy + Potential energy + Kinetic Energy

$$\text{Total energy at point A} = \frac{P_A}{g\rho_A} + X_A + \frac{U_A^2}{2g} \qquad (1.13)$$

According to the Bernoulli's theorem, the total energy at point A is constant.

$$\text{Total energy at point A} = \frac{P_A}{g\rho_A} + X_A + \frac{U_A^2}{2g} = \text{constant} \qquad (1.14)$$

After the system reaches the steady state, whenever one kilogram of liquid enters at point A, another one kilogram of liquid leaves at point B

$$\text{Total energy at point B} = \frac{P_B}{g\rho_B} + X_B + \frac{U_B^2}{2g} \qquad (1.15)$$

If there is no gain or loss, then total energy at point A equals to total energy at point B

$$\frac{P_A}{g\rho_A} + X_A + \frac{U_A^2}{2g} = \frac{P_B}{g\rho_B} + X_B + \frac{U_B^2}{2g} \qquad (1.16)$$

For transportation of fluid, pump add certain amount of energy, which can be written as

Energy added by pump (in joules) = W

During transport some energy get converted to heat due to frictional force.

Energy loss due to friction (in joules) = F

$$\frac{P_A}{g\rho_A} + X_A + \frac{U_A^2}{2g} + W - F = \frac{P_B}{g\rho_B} + X_B + \frac{U_B^2}{2g} \qquad (1.17)$$

This is called ***Bernoulli's equation.***

This equation is numerically correct but not theoretically because each term is energy term. In practice pressure are measured in term of height of column of fluid of known density and such height is called head. The terms used in bernoulli's equation are energy terms but they are often called heads. Therefore X terms are called potential heads, $U^2 / 2g$ known as velocity heads, $P/g\rho$ known as pressure heads, F is called friction head and W is the head added by the pump.

Bernoulli's equations are applicable when

- Flow is steady;
- Density is constant (which also means the fluid is incompressible);
- Friction losses are negligible.

1.5.1 Applications of Bernoulli's theorem

1. It is used to measure rate of flow of fluid using flowmeters.
2. It is used in working of centrifugal pumps

1.6 ENERGY LOSSES

When a fluid flows through a pipe, the fluid experiences some resistance due to which part of the energy is lost. This loss of energy is classified as

Energy Losses

- **Friction losses**
- **Losses in fitting**
- **Enlargement losses**
- **Contraction losses**

1.6.1 Friction losses

The fluid flow can be viscous or turbulent. Frictional forces during flow of fluids cause loss in pressure (ΔP). When the flow is whether viscous or turbulent, **Fanning equation** is used to calculate friction loss.

$$\Delta P = \frac{2fu^2L\rho}{g_cD} \tag{1.18}$$

Where

ΔP is pressure drop, (Pa)

f is friction factor

u is velocity of fluid (m/s)

ρ is density of fluid (kg/m^3)

L is length of pipe (m)

D is diameter of pipe (m)

In Practice For viscous flow, **Hagen Poiseuille equation** could be used to calculate pressure drop due to friction

$$\Delta P = \frac{32Lu\eta}{g_cD^2} \tag{1.19}$$

η is viscosity of liquid (pa.s)

Solved Problem

Exercise 1.3: A liquid with density 1.2 g/cc and viscosity 0.9 cp flows through a strainght long pipe having internal diameter 5 cm at the rate of 50 l/hr. The velocity of flow of water is 0.556 cm/sec. The pipe is 1 kilometer long. Calculate pressure loss due to friction. Fanning friction factor is 0.02

Solution

Fanning Equation is

$$\Delta P = \frac{2fu^2L\rho}{g_cD}$$

p=1.2 g/cc

u =0.556 cm/sec

f = 0.02

L = 1 km = 1000 x 100 cm

D = 5cm

$\Delta P = 2 \times 0.02 \times (0.556)^2 \times 1000 \times 100 \times 1.2 / 981 \times 5$

$\mathbf{\Delta P = 0.302\ g/cm^2}$

1.6.2 Losses in fitting

Fanning equation is applicable for losses when liquid flow through straight pipe. But various types of fitting in straight pipe cause disturbance in flow. This results additional loss in energy because of turbulence. Fluid head loss through a fitting can be calculated by the following equation:

$$h = \frac{Kv^2}{2g} \tag{1.20}$$

where

h = pressure loss in terms of fluid head, i.e. fluid head loss

K = manufacturer's published 'K' factor for the fitting

v = velocity of fluid

g = acceleration due to gravity

1.6.3 Enlargement losses

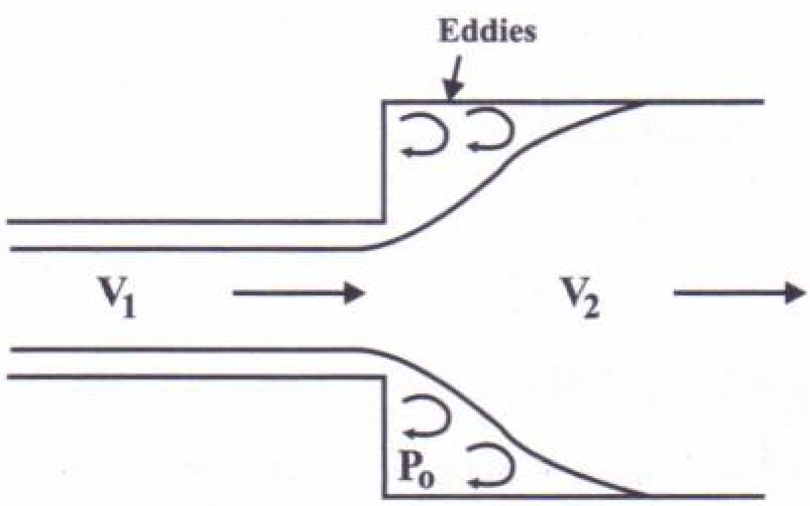


Figure 1.11: Sudden enlargement

If there is **gradual enlargement** in cross section of pipe, then there is no loss of energy. Because fluid adapt itself to changed section without disturbances.

But if there is **sudden enlargement** in pipe cross section , then energy is lost because of formation of eddies. For sudden enlargement with turbulent flow, loss is given by

$$\Delta H_e = \frac{(u_1 - u_2)^2}{2g} \quad (1.21)$$

Where

ΔH_e = loss of head due to sudden enlargement (m)

u_1 and u_2 are velocities in smaller and larger cross section in meter per sec respectively.

1.6.4 Contraction losses

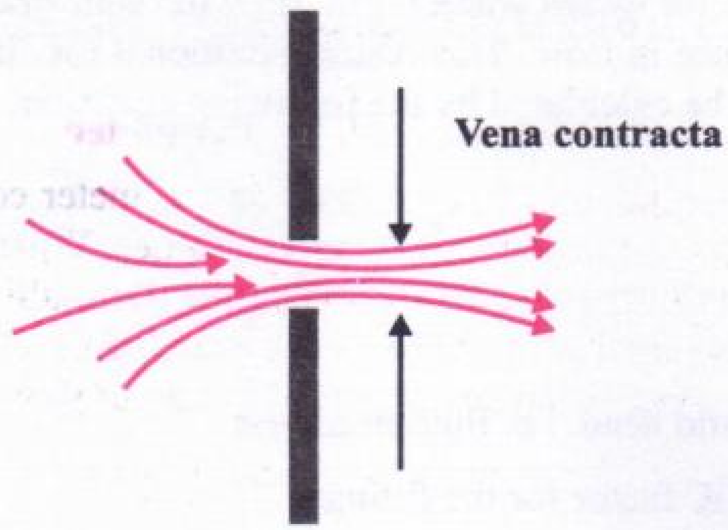


Figure1.12: sudden contraction

When cross section of pipe reduced suddenly, energy is lost because flow of fluid get disturbed. The point at which diameter of fluid stream get less than initial volume of diameter is called **vena contracta.**

Sudden contraction losses : $$\Delta H_c = \frac{Ku_2^2}{2g} \quad (1.22)$$

ΔH_c = loss of head due to sudden Contraction (m)

u_2 is velocity (m/s)

k is constant

1.7 MEASUREMENT OF FLOW (FLOW METERS)

Flow meters: A flow meter is a device used to measure the flow rate or the amount of a gas or liquid moving through pipe.

The most common types of flow meters are:

1.7.1 Orifice meter:

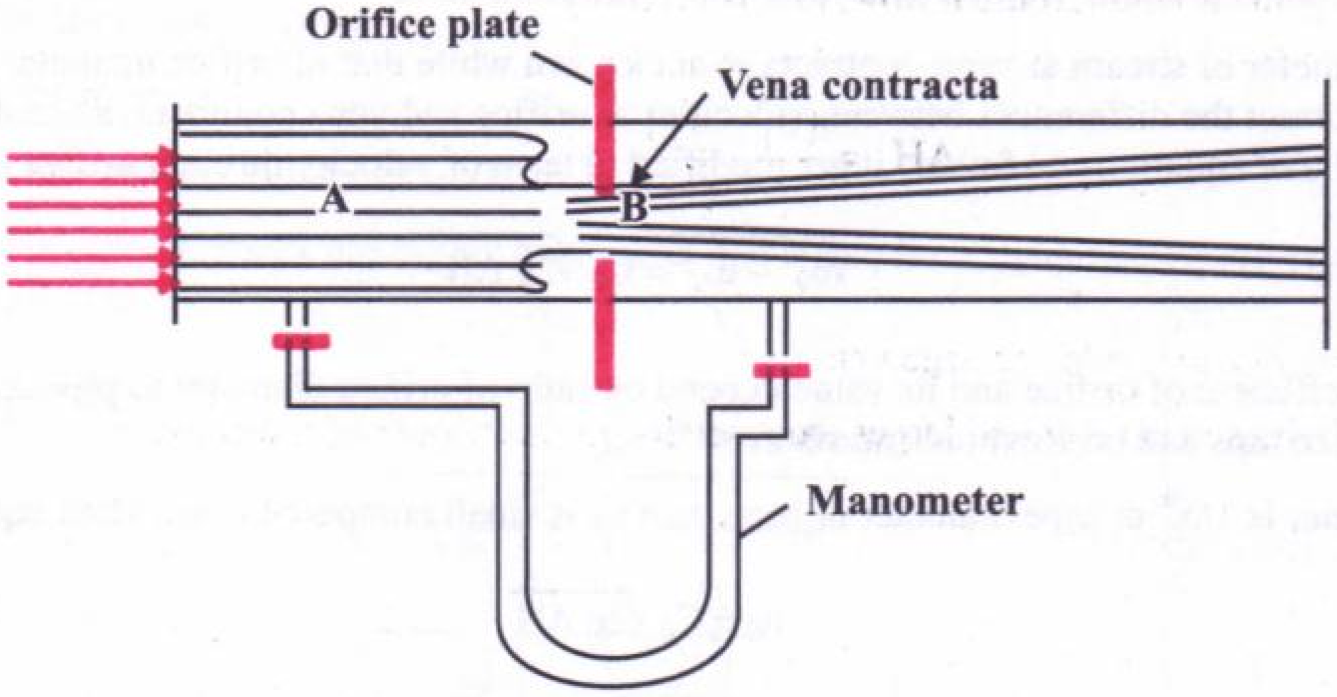


Figure 1.13: Orifice meter

Orifice meter also known as **variable head meter.** The orifice meter consist of thin plate having narrow or sharp aperture. Orifice plate is placed between long straight pipes. When fluid stream passes through narrow constriction, there will be increase in velocity. According to Bernoulli's theorem there will be decrease in pressure at that point. The difference in pressure head between main channel and point of constriction may be read by manometer. This pressure difference is related to rate of flow of fluid.

When Bernoulli's equation is applied between points A and B, then

1. $X_A = X_B$ (As section of pipe is horizontal)
2. F=0 (As friction loss in this short section of pipe is negligible)
3. W =0 (As no work is done on liquid between these two points)

By putting all above points in Bernoulli's theorem, the equation get reduced to

$$u_B^2 - u_A^2 = \frac{2g(P_A - P_B)}{gp} \qquad (1.23)$$

$$u_B^2 - u_A^2 = \frac{2g\Delta P}{gp} \qquad (1.24)$$

or

From the principle of statics $(\Delta P \ / \ gp) = \Delta H$ in meters. So we get

$$u_B^2 - u_A^2 = 2g\ \Delta H \qquad (1.25)$$

$$\sqrt{u_B^2 - u_A^2} = \sqrt{2g\ \Delta H} \qquad (1.26)$$

The flow area becomes minimum at a short distance on the downstream side of the orifice plate which is known as the **vena-contracta.** Point B is selected as **vena-contracta.**

In practice, diameter of stream at vena-contracta is not known while that of orifice diameter is known. Therefore, to correct the differences between velocities at orifice and vena contracta, a constant C_0 is introduced in above equation and further it get modified in term of velocity through orifice (u_0).

$$\sqrt{u_0^2 - u_A^2} = C_0 \sqrt{2g\,\Delta H} \qquad (1.27)$$

Where C_0 is coefficient of orifice and its value depend on ratio of orifice diameter to pipe diameter, on position of orifice taps and on Reynolds number.

If orifice diameter is 1/5th of pipe diameter or less, then u_A is small compared to u_0. Then equation will be

$$u_0 = C_0 \sqrt{2g\,\Delta H} \qquad (1.28)$$

ΔH can be measured in meters by manometer. If cross section of pipe is known, the volume of liquid flowing per hour can be directly determined.

Uses: The orifice meter is relatively cheap & reliable instrument and its installation requires small space. Orifice meter may be used for the measurement of discharge through pipes.

1.7.2 Venturi meter

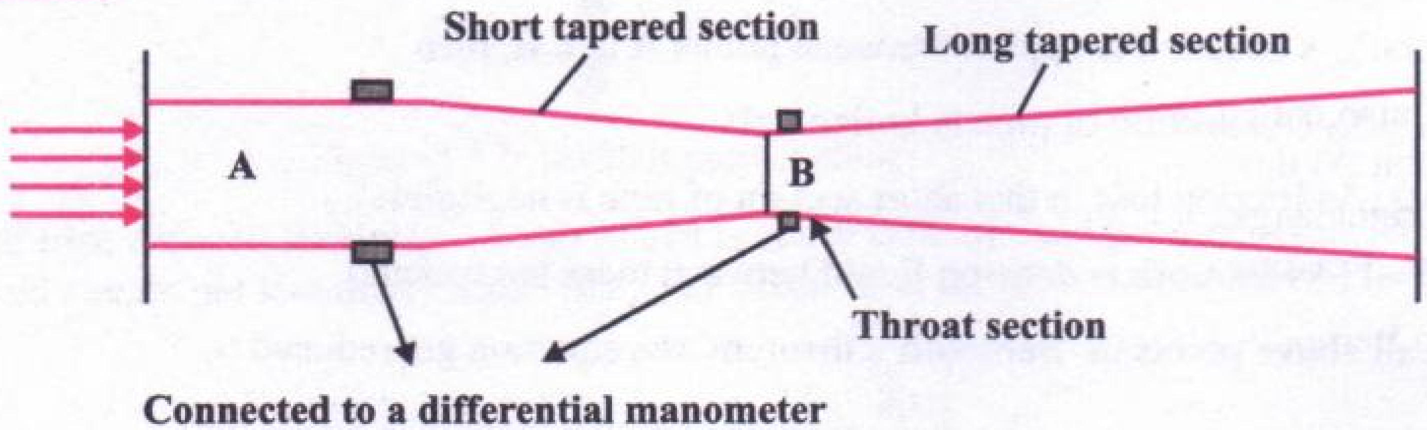


Figure1.14: Venturi meter

Venturi meter is also known as variable head meter. Venturi meter consist of two tapered section with throat (constricted portion) at center. In the upstream cone of the Venturi meter, velocity is increased, pressure is decreased. Pressure drop in the upstream cone is utilized to measure the rate of flow through the instrument . Venturi meter hold same principle as of orifice meter.

$$\sqrt{u_v^2 - u_A^2} = C_v \sqrt{2g\Delta H} \qquad (1.29)$$

And

$$u_v = C_v \sqrt{2g\Delta H} \qquad (1.30)$$

Where

u_v = velocity at throat of venture (m/s)

u_A = velocity at point A (m/s)

C_v = coefficient of the venturi. Value of C_v is 0.98. ($C_v > C_o$)

The disadvantages of Venturi meter are highly expensive and occupies considerable space (L/D ratio of approximate 50)

1.7.3 Pitot Tube

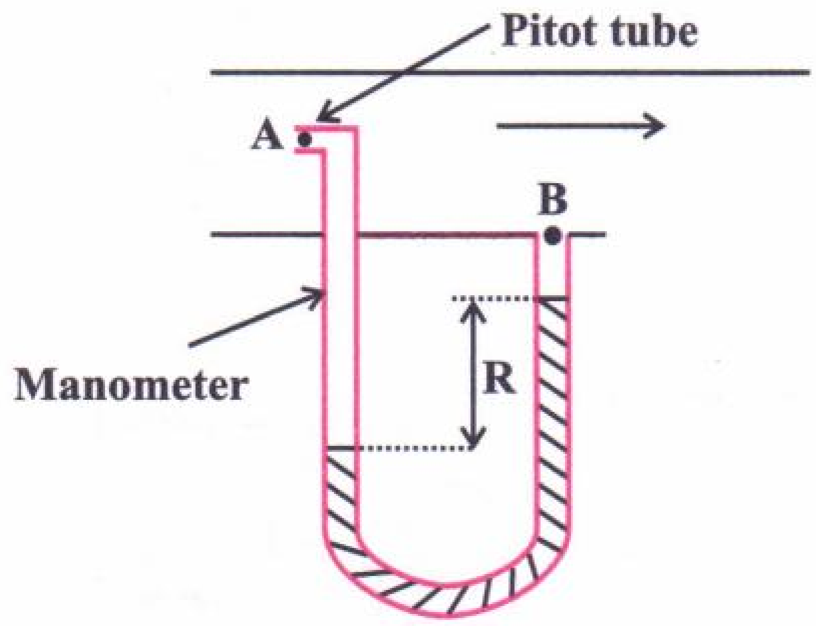


Figure1.15: pitot tube

Pitot tube is also called insertion meter. It consist of two concentrically arranged tubes bent at right angle. The tube (point A) that have pointed upstream measures pressure head and velocity head. The tube (point B) which is at right angle to flow measures pressure head only. The difference in above reading indicates velocity head. Reading (R) of manometer measures velocity head in meters.

According to Bernoulli's equation, velocity head of fluid may be obtained by

$$\Delta H_p = u^2 / 2g \quad (1.31)$$

Where

u = velocity of flow at point of insertion (m/s)

ΔH_p = difference in head from manometer (m)

Advantages

Pitot tube measures velocity at one particular point (only at point of insertion). Average velocity may be calculated from maximum velocity by mean of calibrated chart. Graphic integration is used to calculate mean velocity. But it is tedious process.

Disadvantages

a. They do not give average velocity directly.

Solved problem

Exercise 1.4 : A submarine moves horizontally in the sea and has its axis much below the surface of seawater. A pitot tube properly placed just in front of the submarine is connected to a differential pressure gauge. The difference in head from manometer was found to be 1.478 Find the speed of the submarine.

Solution

As per equation: $\Delta H_p = u^2 / 2g$

$$u_v = \sqrt{2g\Delta H_p}$$

$$u = \sqrt{2\times 9.81\times 1.478}$$

u = 5.38 m/s

1.7.4 Rotameter

It is also known as variable area meter

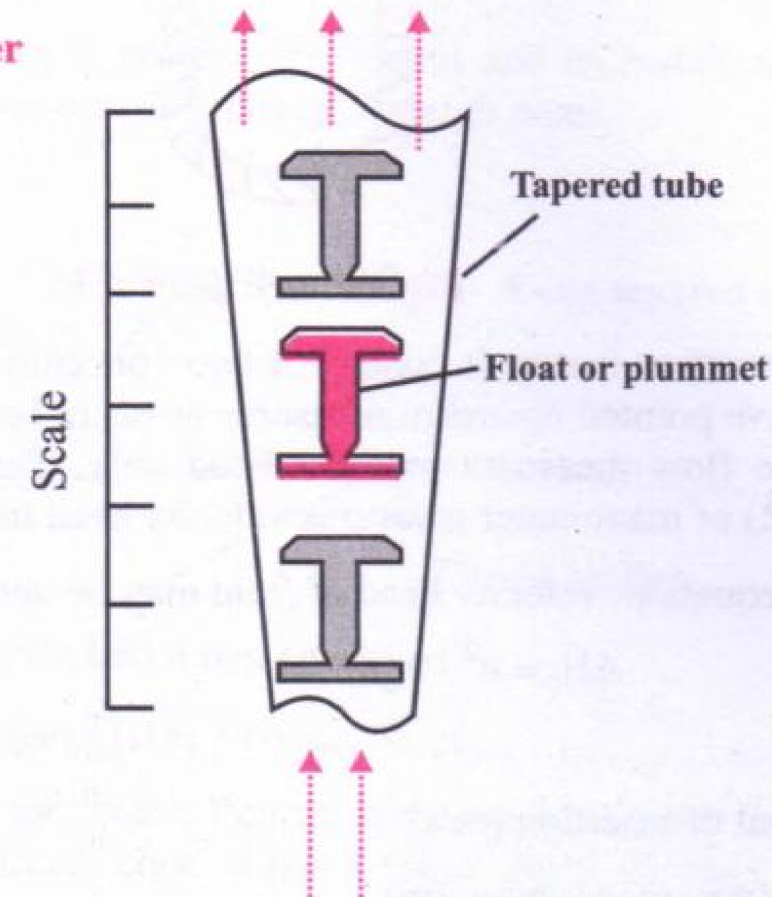


Figure1.16: Rotameter

Rotameter consists of gradually tapered glass mounted vertically in a frame with the large end up. Solid float or pummet is placed in the tube. The diameter of the float is smaller than the diameter of the bottom of the tapered tube. Float is usually made from non-corrosive materials such as aluminium, lead, glass, plastic.

When Fluid flows upward through the tapered tube and suspends freely a float (which is submerged in the fluid). Float is the indicating element.

When no fluid flows through the meter, the rotameter float rests at the bottom of the tube. But as the fluid begins to flow from the lower side of the tube, the float rises . As the flow increases, the float rises further in the tube, thus, increasing the area available for flow keeping differential pressure across it constant. On the other hand, as the flow rate decreases, the float falls in the tube, thus decreasing the area with constant pressure drop across it.

The head loss across the annulus is equal to weight of plummet. The flow may be read by upper edge of plummet as index. The tube is marked in divisions, and the reading of the meter is obtained from the scale reading at the reading edge of the float, which is taken at the largest cross section of the float. A calibration curve must be available to convert the observed scale reading to flow rate.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

Q1. What do you mean by Turbulent flow?

Answer- It is the flow in which fluid particles move in random manner instead of straight path on increasing the velocity.

Q2. Define Reynolds number

Answer- It is the ratio of inertial forces to viscous forces.

Q3. Define Bernoulli's theorem.

Answer- This states that Total energy (which consist of pressure energy, kinetic energy and potential energy) per unit mass in steady state are constant.

Q4. What is Vena contracta?

Answer- The point at which diameter of fluid stream get less than initial volume of diameter.

Q5. What are Manometers

Answer- These are the devices used to the measurement of pressure.

SHORT ANSWER QUESTIONS

Q1. Why Bernoulli's equation are considered numerically correct but not theoretically?

Answer- Bernoulli's equation is numerically correct but not theoretically because each term is energy term. In practice pressure are measured in term of height of column of fluid of known density and such height is called head. The terms used in bernoulli's equation are energy terms but they are often called heads. Therefore X terms are called potential heads, $U^2 / 2g$ known as velocity heads, $P/g\rho$ known as pressure heads, F is called friction hed and W is the head added by the pump.

Q2. What happen when there is gradual and sudden enlargement in the pipe cross section?

Answer- If there is **gradual enlargement** in cross section of pipe, then there is no loss of energy. Because fluid adapt itself to changed section without disturbances.

But if there is **sudden enlargement** in pipe cross section , then energy is lost because of formation of eddies. For sudden enlargement with turbulent flow, loss is given by

$$\Delta H_e = \frac{(u_1 - u_2)^2}{2g}$$

Q3. What happen when cross section of pipe reduced suddenly?

Answer- When cross section of pipe reduced suddenly, energy is lost because flow of fluid get disturbed. The point at which diameter of fluid stream get less than initial volume of diameter is called **vena contracta.**

Q4. Write Applications of Bernoulli's theorem.

Answer- 1. It is used to measure rate of flow of fluid using flowmeters.

2. It is used in working of centrifugal pumps

Q5. Which equation is used to calculate frictional losses?

Answer- Frictional forces during flow of fluids cause loss in pressure (ΔP). When the flow is whether viscous or turbulent, **Fanning equation** is used to calculate friction loss.

$$\Delta P = \frac{2fu^2L\rho}{g_c D}$$

***Q6. A liquid with density 1.5 g/cc flows through a straight long pipe having internal diameter 4 cm at the rate of 70 l/hr.* The velocity of flow of water is 0.656 cm/sec. The pipe is 1 kilometer long. Calculate pressure loss due to friction. Fanning friction factor is 0.03**

Answer- $\Delta P = 0.98$ **g/cm²**

LONG ANSWER QUESTIONS

1. What is manometer? Explain simple and differential manometer.

   (Refer article 1.2)

2. Distinguish between laminar, turbulent and transient flow

   (Refer article 1.3.1)

3. Write note on

   a. Reynold's experiment

      (Refer article 1.4)

   b. Fanning equation

      (Refer article 1.6.1)

   c. Hagen Poiseuille equation

      (Refer article 1.6.1)

4. Derive and explain Bernoulli's theorem.

   (Refer article 1.5)

5. Write note on

   a. Orifice meter

      (Refer article 1.7.1)

   b. Rotameter

      (Refer article 1.7.4)

6. Write note on

   a. Venturi meter

      (Refer article 1.7.2)

b. Pitot tube

(Refer article 1.7.3)

7. What are the different type of losses which fluid encounter when flow through pipes?

(Refer article 1.6)

MULTIPLE CHOICE QUESTIONS

1. Which of the following is not type of manometer:

a. Piezometer

b. U- tube

c. V-tube

d. Single column manometer

2. Reynolds number gives a measure of the ratio of

a. inertial forces to viscous forces

b. viscous forces to inertial forces

c. Inertial force to atomic number

d. viscous forces to atomic number

3. If Reynolds number, Re < 2000, indicates flow is

a. Laminar

b. Turbulent

c. Transient

d. All of the above

4. When the flow is whether viscous or turbulent, which equation is used to calculate friction loss?

a. Fanning equation

b. Bernoulli's equation

c. Stokes law equation

d. Hagen Poiseuille equation

5. Which of the following is not type of flow meters

a. Orifice meter

b. Pitot tube

c. Potentiometer

d. Rotameter

6. The point at which diameter of fluid stream get less than initial volume of diameter is called

a. Vena contracta

b. Critical point

c. Eutectic point

d. Freezing point

7. Which of the following is also known as variable head meter

a. Orifice meter
b. Rotameter
c. Venturi meter
d. Pitot tube

8. Which of the following is also called slant manometer

a. Inclined manometer
b. Inverted U tube differential manometer
c. Simple manometer
d. U tube differential manometer

9. Which of the following statement is true for pitot tube

a. It measures velocity at one particular point
b. It is also called insertion meter
c. Average velocity may be calculated from maximum velocity by mean of calibrated chart.
d. All of the above

10. What is the main disadvantage of Orifice meter?

a. Power lost due to sudden contraction
b. Costly
c. Require more man power
d. Chances of corrosion

11. Bernoulli's theorem deals with law of conservation of

a. Energy
b. Mass
c. Volume
d. Momentum

12. Pitot tube is used for measurement of

a. Pressure
b. Velocity at a point
c. Mass
d. Density

ANSWERS

1. c 2. a 3. a 4. a 5. c 6. a 7. a 8. a 9. d 10. a 11. a 12. b

2 CHAPTER SIZE REDUCTION

Selected Definitions

Size reduction: It is the process of reducing large substances into smaller particles.

Kick's law: This law states that energy required to reduce size of particle is proportional to ratio of initial size of a typical dimension to the final size of that dimension.

Rittinger's law : This law states that the energy required for the size reduction of unit mass is proportional to the new surface area produced.

Bond's Law: This law states that energy used for size reduction is proportional to new crack length.

Moh's Scale: It is a device used to measure the hardness of material.

Stress: It is defined as force per unit area.

Strain: It is defined as the amount of deformation that an object undergoes in relation to its original size and shape.

Elastic deformation: Elastic deformation occur when compression is applied at any point along the line below the yield value, the material will go back and return to its original shape. This type of deformation is reversible.

Plastic deformation: Plastic deformation occur when compression is applied above the yield value then the substance break down and will not return to its original form after removing stress. This type of deformation is not reversible.

Cutting - It is the process in which material is cut by means of a sharp blade or blades.

Compression - It is a process in which the material is crushed between the rollers by application of pressure.

Impact - It is a process in which the material is more or less stationary and is hit by an object moving at high speed

Attrition - In attrition, the material is subjected to pressure as in compression, but the surfaces are moving relative to each other, resulting in shear forces which break the particles

2.1 INTRODUCTION

Size reduction or comminution or Diminution or Pulverizations is the process of reducing large substances into smaller particles. Size reduction machines for large particle sizes (i.e. particles above 40 mm), are known as crushers, while the particle sizes below this are processed by mills. Size Reduction is an important operation in many pharmaceutical applications. For pharmaceutical purpose, mono- size particles are best of use. For solid materials, grinding and cutting are used as a size reduction process, while emulsification or atomization for liquid material are used.

2.2 ADVANTAGES OF SIZE REDUCTION

1. For effective mixing particles of uniform size are desirable. As content uniformity is important in case of potent and low dose drugs formulations
2. Size reduction increase surface area of material and this further improve rate of dissolution.
3. During compression of tablet, particle size should be small so that powder can easily flow into dies.
4. Extraction of active constituent become effective if smaller particles are used.
5. Drying will be effective when small sized granules or powders are used.

2.3 DISADVANTAGES OF SIZE REDUCTION

1. Thermolabile substances get decomposed during size reduction. This is due to heat produced during milling
2. There are chances of contamination during milling and grinding.

2.4 OBJECTIVES OF SIZE REDUCTION

1. **Increase surface area:** Reduced size leads to increased surface area. For example: The dissolution rate of the solid drug particles increases many times after the size reduction. Micronized form of Griseofulvin, an antifungal drug, shows about five times better absorption.
2. **Ease of Mixing:** Reducing the size of particles in a narrow range makes mixing easier.
3. **Stability of suspension:** The fine particle size in pharmaceutical suspensions decreases sedimentation rate.
4. **Dosage form:** Pharmaceutical capsules, insufflations (ie, inhaled powders directly into the lungs), suppositories and ointments require the particle size to be less than 60 mm in size.
5. **Stability of emulsion:** The stability of emulsion can be increased by decreasing size of oil globules.
6. **Reduce Irritation:** Ophthalmic preparations and preparation meant for external application to skin should be free from coarse and gritty particles to avoid irritation.
7. **Increase absorption:** The rate of drug absorption will be higher if the particle size will be small.
8. **Appearance:** By reducing particle size, physical appearance of ointment, creams, paste can be enhanced.

2.5 LAWS GOVERNING SIZE REDUCTION

A number of theories have been proposed to establish a relationship between energy input and the degree of size reduction produced.

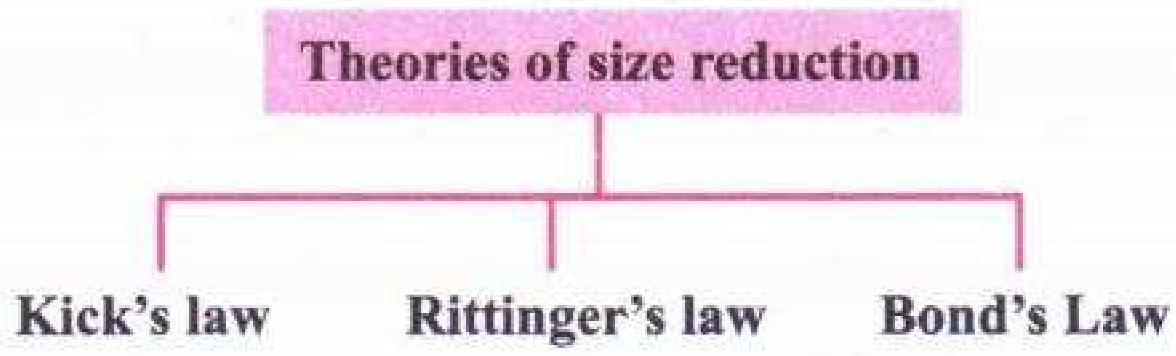


Figure 2.1: Theories of size reduction

2.5.1 Kick's law

According to this law, energy required to reduce size of particle is proportional to ratio of initial size of a typical dimension to the final size of that dimension.

$$E = K_K \ln\left(\frac{d_1}{d_2}\right) \quad (2.1)$$

Where

E = energy required per mass of feed
K_k = Kick's constant
d_1 = average initial size of pieces (m)
d_2 = average size of ground particles (m)

d_1/d_2 = is size reduction ratio (RR). and it is used to evaluate relative performance of different type of equipments. Coarse grinding has RR value below 8:1 while in fine grinding ratio can exceed 100:1.

Application: Kick's law gives reasonably good results for coarse grinding where there is a relatively small increase in surface area per unit mass.

2.5.2 Rittinger's law

This law states that the energy required for the size reduction of unit mass is proportional to the new surface area produced.

$$E = K_R\left(\frac{1}{d_2} - \frac{1}{d_1}\right) \quad (2.2)$$

Where

E = energy required per mass of feed
K_R = Rittinger's constant
d_1 = average initial size of pieces (m)
d_2 = average size of ground particles (m)
$1/d$ = s (surface area)
So equation will become

$$E = K_R\,(S_n - S_i) \quad (2.3)$$

S_i is initial specific surface area

S_n is new surface area

Application: Rittinger's law gives better results with fine grinding where there is a much greater increase in surface area

2.5.3 Bond's Law

This law states that energy used for size reduction is proportional to new crack length.

$$\frac{E}{W} = \sqrt{\frac{100}{d_2}} - \sqrt{\frac{100}{d_1}} \tag{2.4}$$

Where

E = energy required per mass of feed

W = Bond Work Index work required to reduce a unit weight

d_1 = diameter of sieve aperture that allows 80% of mass of feed to pass (in meters)

d_2 = diameter of sieve aperture that allows 80% of mass of ground material to pass (in meters)

Solved problems

Exercise 2.1: A material is crushed in black jaw crusher such that average size of particle reduced from 60 mm to 10 mm and 13 KW energy is consumed. How much energy consumed to crush same material of average size from 85 mm to 15 mm.

a. Suppose when Rittinger's law is applied
b. Suppose when Kick's law is applied

Solution

a. According to Rittinger's law

$$E = K_R\left(\frac{1}{d_2} - \frac{1}{d_1}\right)$$

$13 = K_R\,(1/10 - 1/60)$

$K_R = 154.76$ KW/ Kg mm

So energy required to crush 85 mm to 15 mm

$E = 154.76\,(1/15 - 1/85)$

E = 7.74 KJ/Kg

b. According to Kick's Law

$$E = K_K \text{In}\left(\frac{d_1}{d_2}\right)$$

$13 = K_K \ln(60/10)$

K_k = 7.26 KW/ (Kg/s)

So energy required to crush 85 mm to 15 mm

E = 7.26 ln (85/15)

E = 12.5 KJ/kg

2.6 FACTORS AFFECTING SIZE REDUCTION

It include

1. **Hardness**
   It is a surface property of the material. The hardness of material is measured by a devised known as Moh's Scale. The Moh scale is from 1 to 10. Material of hardness 1 to 3 are classified as soft (eg talc, waxes), 4 to 7 intermediate (Limestone and bauxite) and 8 to 10 hard (Quartz and diamond). The harder the material the more difficult it is to reduce in size.
2. **Toughness**
   The Toughness of a material is sometimes more important than the hardness. A soft but tough material may present more problems in reducing size than a hard but brittle substance. For example, it is difficult to break the rubber than a blackboard chalk stick.
3. **Abrasiveness**
   Abrasiveness is a property of hard materials. During the grinding of abrasive substances, the final powder may be contaminated with more than 0.1 percent of the grinding mill's worn metal.
4. **Stickiness**
   Stickiness is a property which causes considerable difficulty in reducing the size because the material get adhere to the grinding surfaces or the screen meshes may blogged.
5. **Slipperiness**
   It is the opposite of stickiness. It can also lead to size reduction difficulties as the material acts as a lubricant and decreases the efficiency of grinding surfaces.
6. **Softening temperature**
   During size reduction process, sometimes heat is generated which can cause some substances to soften, and the temperature at which this occurs may be important. Waxy substances, such as stearic acid, or drugs containing oils or fats are examples that may be affected. Some methods can be used to overcome this like cooling the mill, either by a water jacket or by passing a stream of air through the equipment.
7. **Moisture content**
   The moisture content influences a number of properties that may affect size reduction, For example, hardness, toughness or viscosity. In general the materials must be dry or moist and not merely moist. Usually, less than 5 percent moisture is adequate if the substance is to be ground dry or more than 50 if it is being subjected to wet milling

2.7 MECHANISMS OF SIZE REDUCTION

The size reduction mechanism differs according to the nature of the material and each drug may require separate treatment. The fracture occurs preferably along lines of weakness. Fresh surfaces can be created or existing cracks and fissures can be opened, the former requiring much more energy.

Size reduction is energy-inefficient process, since only a small percentage of the energy supplied is used to subdivide the particles. Much of the energy is spent in overcoming the friction and inertia of the machine parts, the friction between the particles and the deformation of the particles without breaking them. This energy is released as heat.

The particles to be reduced may be subjected to one or the combination of three forces

1. Compression
2. Shear
3. Tension

Compression is crushing force, shear is cutting force and tension is force that tend to elongate a particle or pull it apart.

By increasing the compression force, the flaws (discontinuity or imperfection) in the unit particle structure increase to a critical value. This is called yield value.

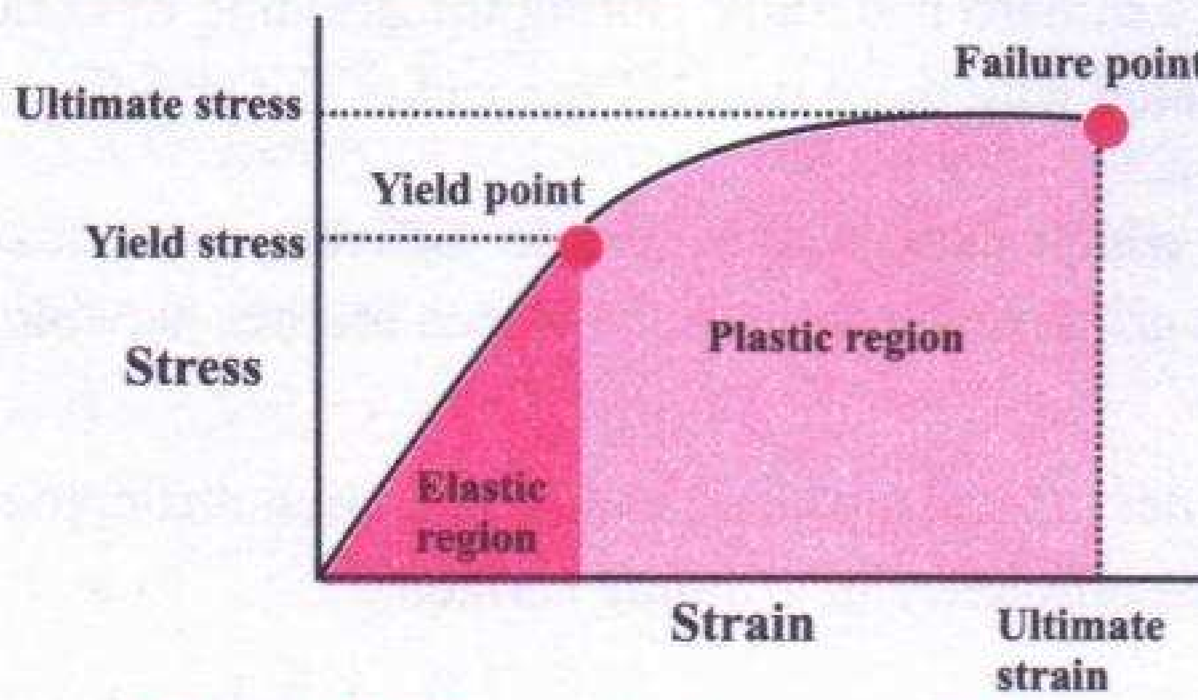


Figure 2.2: Stress-strain properties

The figure shows that there is increase in deformation with increased stress up to the yield value and then breakage occur. Compression at any point along the line below the yield value, the material will go back and return to its original shape and this is called **elastic deformation**. While compression above the yield value will result **plastic deformation** in which the substance break down and will not return to its original form after removing stress.

2.8 CLASSIFICATION OF SIZE REDUCTION EQUIPMENTS

The common mode of size reduction are as follows:

1. **Cutting** – Here the material is cut by means of a sharp blade or blades. Ex: Cutter mill
2. **Compression** – In this method, the material is crushed between the rollers by application of pressure. Ex: Roller mill

3. **Impact** – the impact occurs when the material is more or less stationary and is hit by an object moving at high speed or when the moving particle strikes a stationary surface. In any case, the material is broken into smaller pieces. Usually both will be carried out, as the substance is hit by a moving hammer and the formed particles are then thrown against the casing of the machine. Example: hammer mill
4. **Attrition** – In attrition, the material is subjected to pressure as in compression, but the surfaces are moving relative to each other, resulting in shear forces which break the particles. Example: Fluid energy mill

   On small scale, Mortar and Pestle are simple equipment for grinding. In this method material is broken by application of attrition and pressure. The size reduction of vegetable drugs may be done by slicing, rasping or contusion. Slicing or cutting are used to cut the large piece into smaller pieces so that faster drying of the material could be done. Rasping or grating are done with graters and this is especially used in case of soaps and waxes. Contusion or bruising is done by using mortar and pestle.

Table 2.1: Type of mill and their action

Name of Mill	Action of Mill
Fluid energy mill	Impact and attrition
Ball mill	Impact and attrition
Edge runner mill	Crushing and shearing
End runner mill	Crushing and shearing
Hammer mill	Impact

2.9 HAMMER MILL

Method of size reduction: Impact

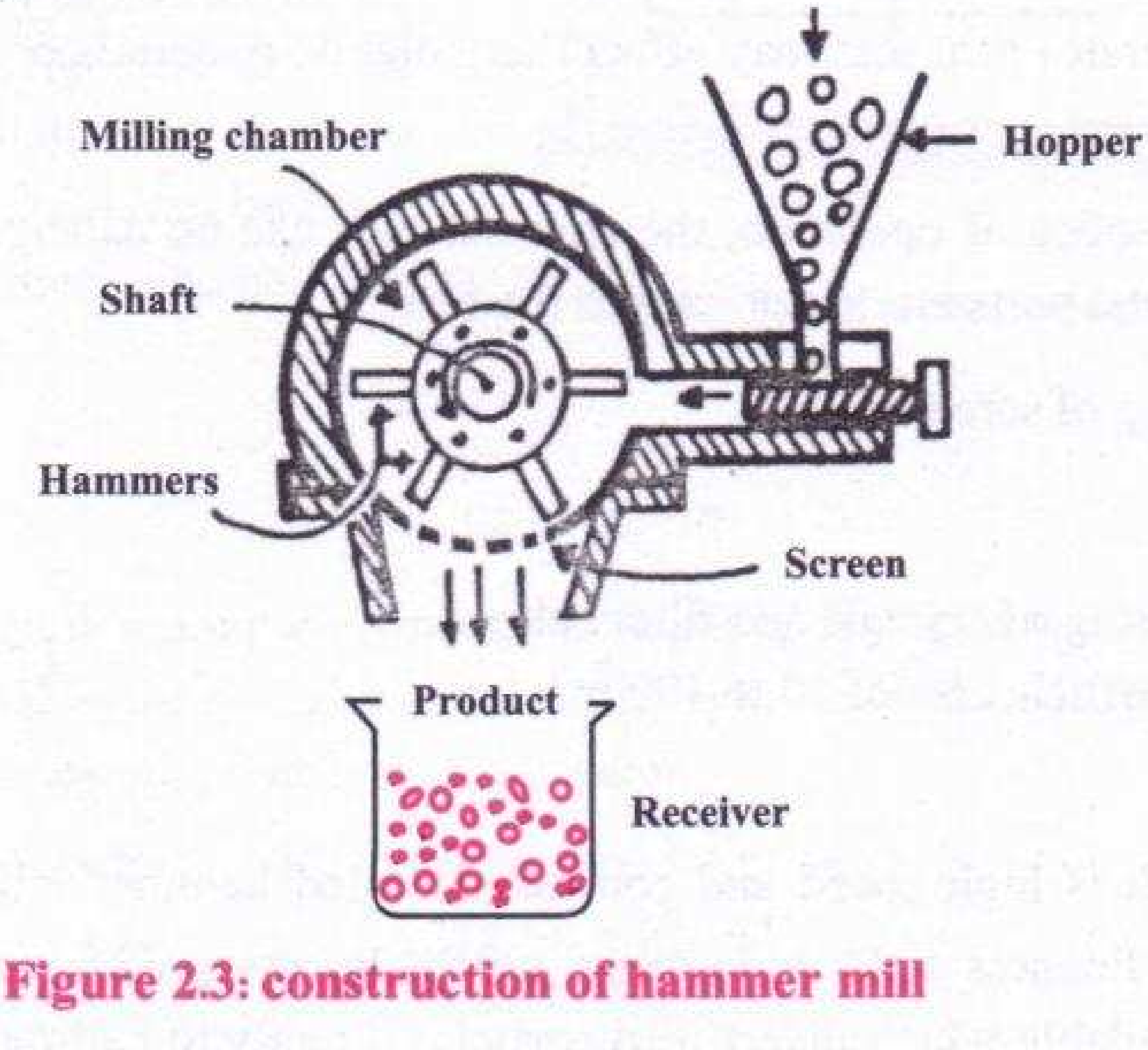


Figure 2.3: construction of hammer mill

Principle: Hammer mill based on principle of impact between hammer (which is in continuous motion) and powder. Due to high speed material get pulverized.

Construction

Hammer mill consists of a housing frame, enclosing a central shaft to which four or more hammers are attached. Hammers are made of stainless steel. Shaft is either horizontal or vertical type. Hammers blades can be flat edges or sharp edges or both on each side. The lower part of the casing consists of screen through which materials can pass after size reduction. Screen are prepared by metal sheet with perforated holes. The screen can be changed according to the particle size required. The material is collected in a container placed below the screen. The unit is enclosed in a chamber.

Working

The hopper is used to place the feed material. The material from the hopper flows vertically and then horizontally. The hammers are in continuous motion and rotating at a speed of 8000 to 15000 revolutions per minute. When the feed material strikes with the rotary hammer, the material breaks down into smaller pieces. Then these particles pass through the screen.

Advantages:

a. It is rapid in action, and is capable of grinding many different types of materials.
b. The fineness of product can be regulated by variation of rotor speed, hammer type and size and shape of mesh.
c. Operation is done in chamber. So dust can be minimized.
d. Small space requires for setup of mill
e. No surface moves against each other so very little problem of contamination of mill materials.

Disadvantages:

a. High speed generates heat that may affect thermolabile materials or drugs containing gum, fat or resin.

b. Due to the high speed of operation, the hammer mill can be damaged if some foreign materials such as stone, metal parts etc. are present in the feed.

c. Chances of clogging of screen.

Applications:

1. Used for Powdering of crystals and filter cakes.
2. Used to obtain particle size of 10 to 400 mm.

Variants

1. **Micro Pulverizers:** It is high speed and controlled sealed hammer mill. It is use for non abrasive materials. It provide fineness upto wide range (99.9% by using 325 mesh screen). An air injection feeder system are available which divert feed particles directly to hammer tip. A replaceable liner for

mill housing cover is made with multiple serrations. The wide variety of screens can be fitted . Round perforated screen and herring bone slot screen are used for grinding of fibres and crystalline materials respectively.

2. **Hammer Crusher:** In this, the pivoted hammers are mounted on the horizontal axis. The size reduction takes place by impact between the hammer and breaker or cutting plates. A cylindrical grating are provided under the rotor. Hammer crushers are available in reversible and non-reversible design with screen cage. Hammer speed varies from 500 to 1800 rpm. The capacity of the machine varies from 200 lb/ hour to 1500 tons / hour.
3. **Vertical impact pulverizer:** These are available as (i) coarse pulverizer for product size above 14 mesh and upto 4 mesh (ii) a fine pulverizer for 14 mesh product size and (iii) as fine as 100% passing 325 mesh and (iv) combination of either fine or coarse pulverization.

2.10 BALL MILL OR PEBBLE MILL

This is also known as tumbling mills.

Method of size reduction: Impact and Attrition

Principle: In the ball mill, Impact and Attrition both are responsible for the size reduction. Rapidly moving balls are used for comminution of brittle material.

Construction :

The ball mill consists of a hollow metal cylinder mounted on shaft and rotating about its horizontal axis. The cylinder can be made of metal, porcelain or rubber. Inside the cylinder balls or pebbles are placed. The balls occupy between 30 and 50% of the volume of the cylinder. The diameter of the balls depends on the size of the feed and the diameter of the cylinder. The diameter of the balls varies from 2cm to 15cm. The balls can be made of metal, porcelain or stainless steel. The ball acts as a grinding medium.

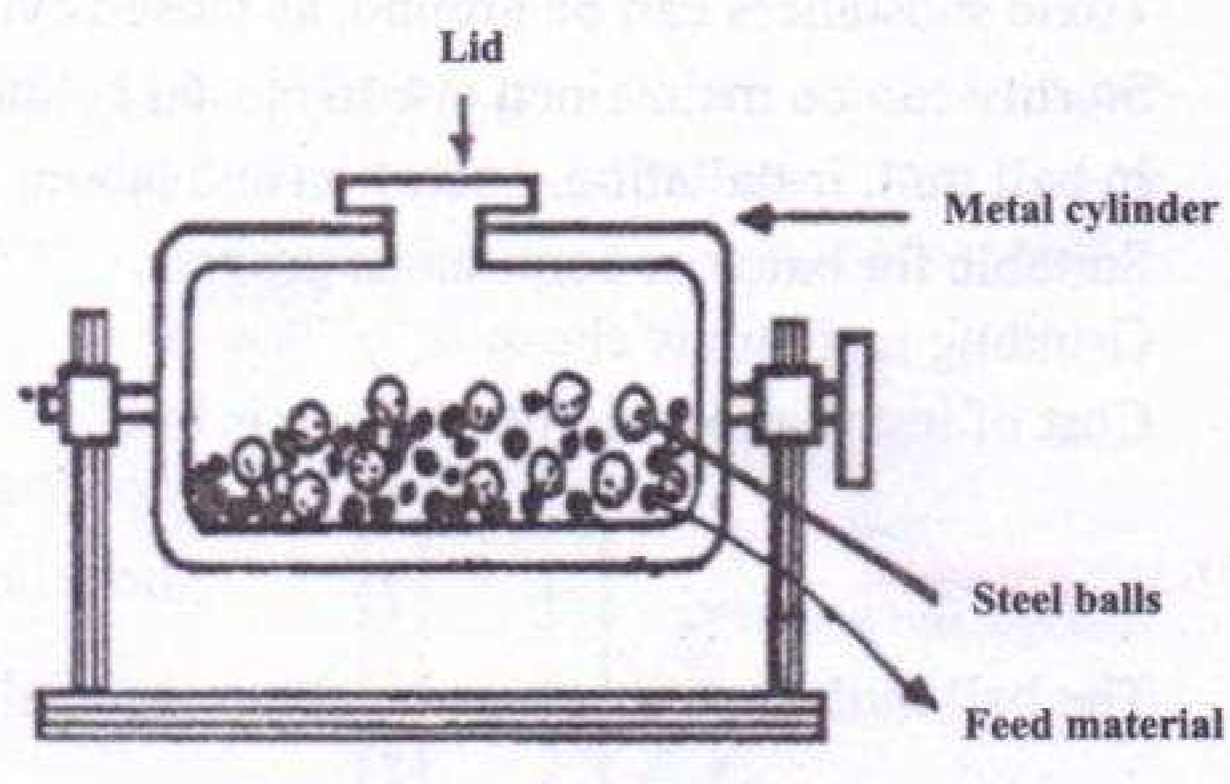


Figure 2.4: Construction of Ball mill

Working :

The material to be ground is kept in a hollow cylinder. The material is placed up to 60% of the volume. A fixed number of balls is placed in the cylinder and then the cylinder is closed. The mill is allowed to rotate. Speed of rotation is an important point of consideration.

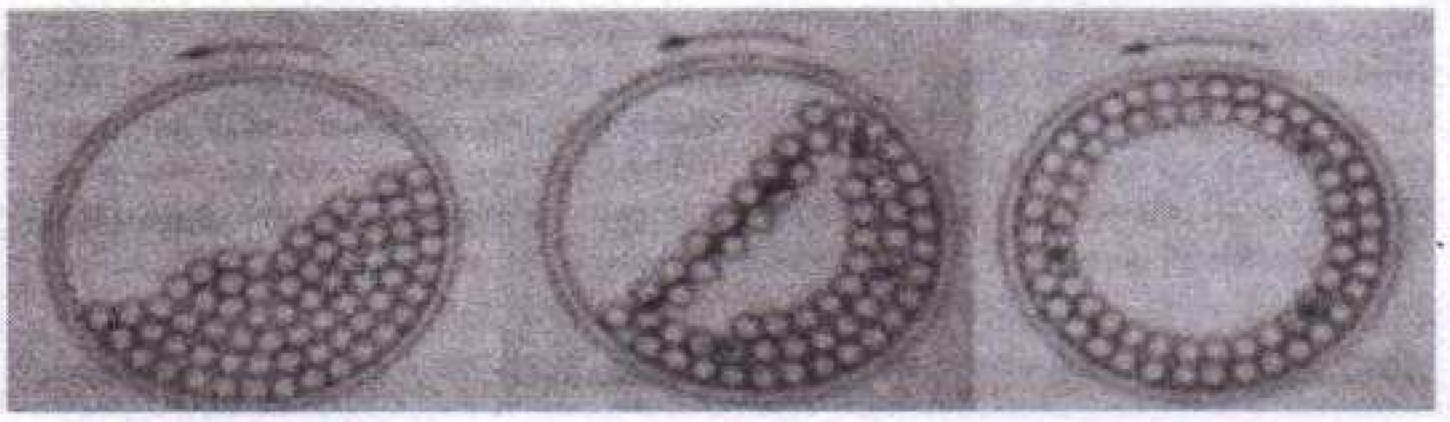


Figure 2.5: Speed of balls

At low speed, the mass of balls will slide or roll up one over another and will only produce an insignificant amount of size reduction. At high speeds, the balls are thrown to the cylinder wall due to centrifugal force and no grinding will occur. At 2/3rd speed centrifugation just occurs which is called the critical speed of the ball mill. At this speed the balls are carried almost to the top of the mill and then fall in a cascade across the diameter of the mill. In this way, the maximum size reduction is obtained by impact of the particles between the balls and by attrition between the balls. It is usually 0.5 cycles per second (cps).

Advantages:

1. Very fine powder can be obtained.
2. Suitable for both wet and dry grinding processes.
3. Toxic substances can be ground, as closed cylinder are used.
4. Sterlity can be maintained due to closed cylinder system.
5. In ball mill, installation, operation and labour costs are low.
6. Suitable for batch or continuous process.
7. Grinding medium is cheap
8. Cost of installation and production is low.

Disadvantages:

1. The ball mill is a very noisy machine especially when metal cylinder is used.
2. Ball mill is a slow process.
3. Soft, tacky, fibrous material cannot be milled by ball mill. These materials may cause problems by caking on the sides of the mill
4. Wear occurs from the balls and the inside surface of the cylinder hence there is possibility of contamination of product with mill material.

Applications :

1. Size of 5 to 100 mm or less are obtained.
2. Ophthalmic and parenteral products can be produced.

Various types of ball mills:

1. ***Hardinge mill***: In this type of ball mills the cylinder has a conical end towards a discharge point. In this mill the larger balls remain inside the cylinder and the smaller balls are placed in the conical portion. As a result, coarser grinding occurs in the cylinder portion and a finer grinding takes place at the apex of the conical part. The product is finer and more uniform than the general cylindrical ball mill.
2. ***Tube mill***: Tube mills are generally charged with flint pebbles instead of metal balls. Tube mill can grind finer product than the conventional ball mill. Their construction is also simple and generally used for grinding hard material. Tube mill has higher length/ diameter ratio as compared to Ball mill.
3. ***Rod mill***: This is modification of tube mill. Instead of balls or pebbles, rods are used as grinding material. This rods are useful with sticky materials since rods do not form aggregates like balls.
4. ***Vibration mill***: In this type of mills vibratory movements are given instead of rotation. The cylinder is mounted on springs which sets up vibration by electromagnetic means. The cylinder moves through a circular path with an amplitude of vibration up to about 20mm and a rotational frequency of 15 to 50 per second. Grinding efficiency is also better in this type of mill.
5. ***Continuous ball mill:*** This equipment is placed on a small slope so that the powder can pass from one chamber to the next chamber through a screen attached to each chamber so that finally fine product can be obtained.

2.11 FLUID ENERGY MILL OR JET MILL

This is also known as micronizers or ultrafine grinders.

Method of size reduction: Impact and Attrition

Principle: Fluid energy mill based on principle of Impact and Attrition. Size reduction take place by high velocity collision between particle.

Construction:

It consists of a loop of pipe, which has a diameter of 20 to 200 mm. The height of the loop may be up to 2m. Several nozzles are fitted at the bottom of the pipe. Generally 2 to 6 grinding nozzles are present. A classifier is fitted at the product collection point. Normally compressed air are used.

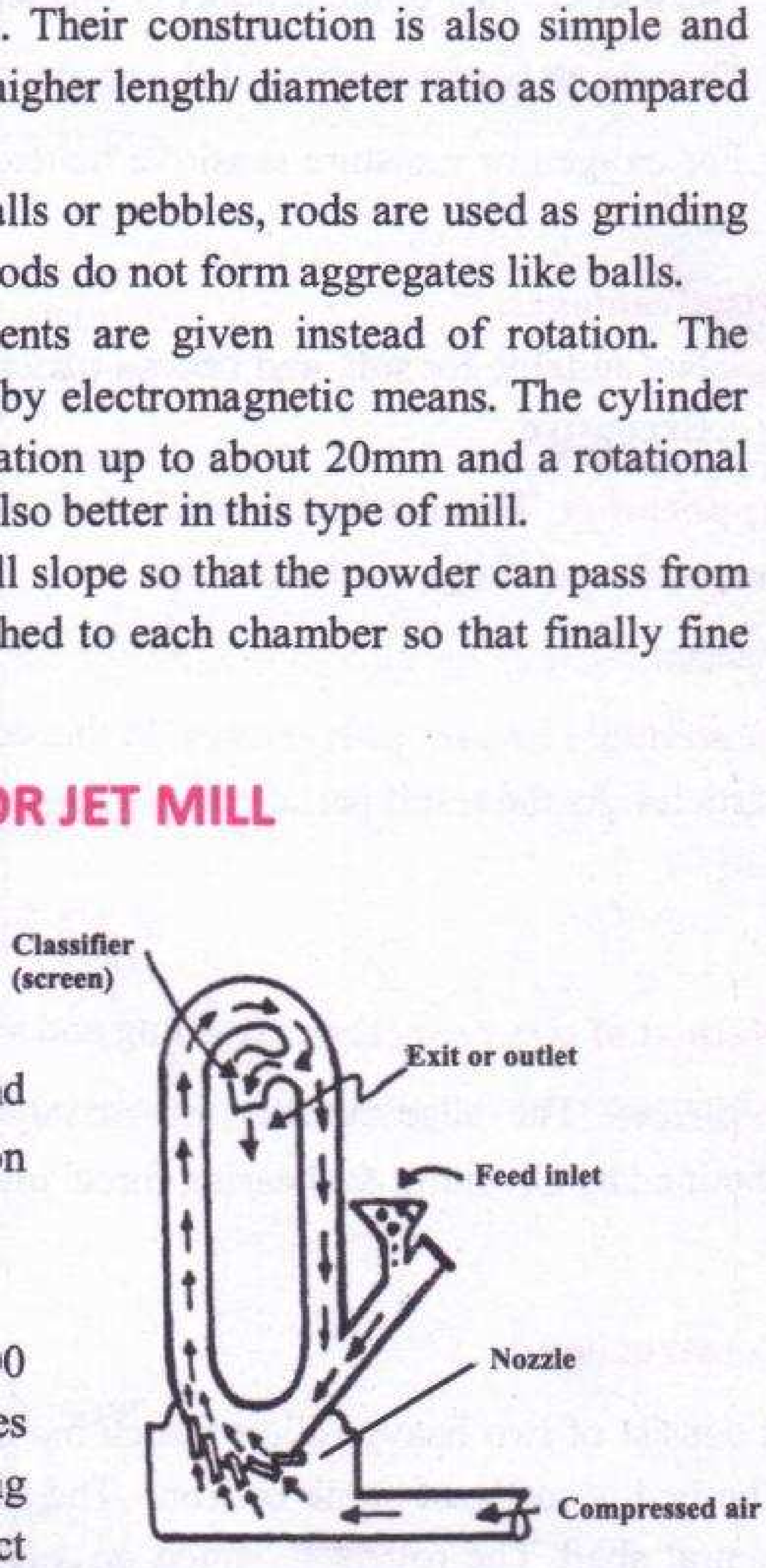


Figure2.6: Construction of fluid energy mill

Working

The air is injected at very high pressure through nozzles at the bottom of the loop. Compressed air of 600kilopascals to 1.0 megapascals is normally used. This results in a high circulation velocity that produces turbulence. The solids are introduced into the stream through the feed inlet. As a result of the high degree of turbulence, impacts and attrition occur between the particles. A classifier is installed in the system so that only finer sized particles are collected as products and larger particles are sent back into the air stream for further reduction of size. The feed to the mill is previously of reduced size and passed through a 100-meshes screen. The size of the product may be 5mm or below.

Advantages:

1. This mill is suitable for thermolabile substance because no heat is produced.
2. The particle size of the product is smaller when compared to other methods.
3. There is no contamination of the product.
4. For oxygen or moisture sensitive materials inert gases like nitrogen can be used instead of normal air.

Disadvantages:

1. Not suitable for soft, and fibrous material milling.
2. Expensive.

Application: This method is used where fine powders are required like micronization of griseofulvin (an antifungal drug), antibiotics etc.

Variant:

Centrifugal impact pulverizers: In this equipment, rotor is spinned to accelerate centrifugal force on particles. As the result particle move toward impactors and on striking final reduction is obtained.

2.12 EDGE RUNNER MILL

Method of size reduction: Crushing and shearing

Principle: The edge runner mill mainly works on the attrition and impaction. Size reduction is obtained by Crushing & shearing force involved during the movement of stones.

Construction:

It consist of two heavy rollers which moves on the bed. The bed is made of stone or iron. The roller rotate on central shaft. The rollers mounted on a horizontal shaft & also move around the bed.

Working:

The material to be ground is placed on the bed. The scraper is used which continuously remove material that get adhere to side of pan and return back it to crushing zone. The stones continuously revolve on its axis. Size reduction is obtained by shearing along with crushing.

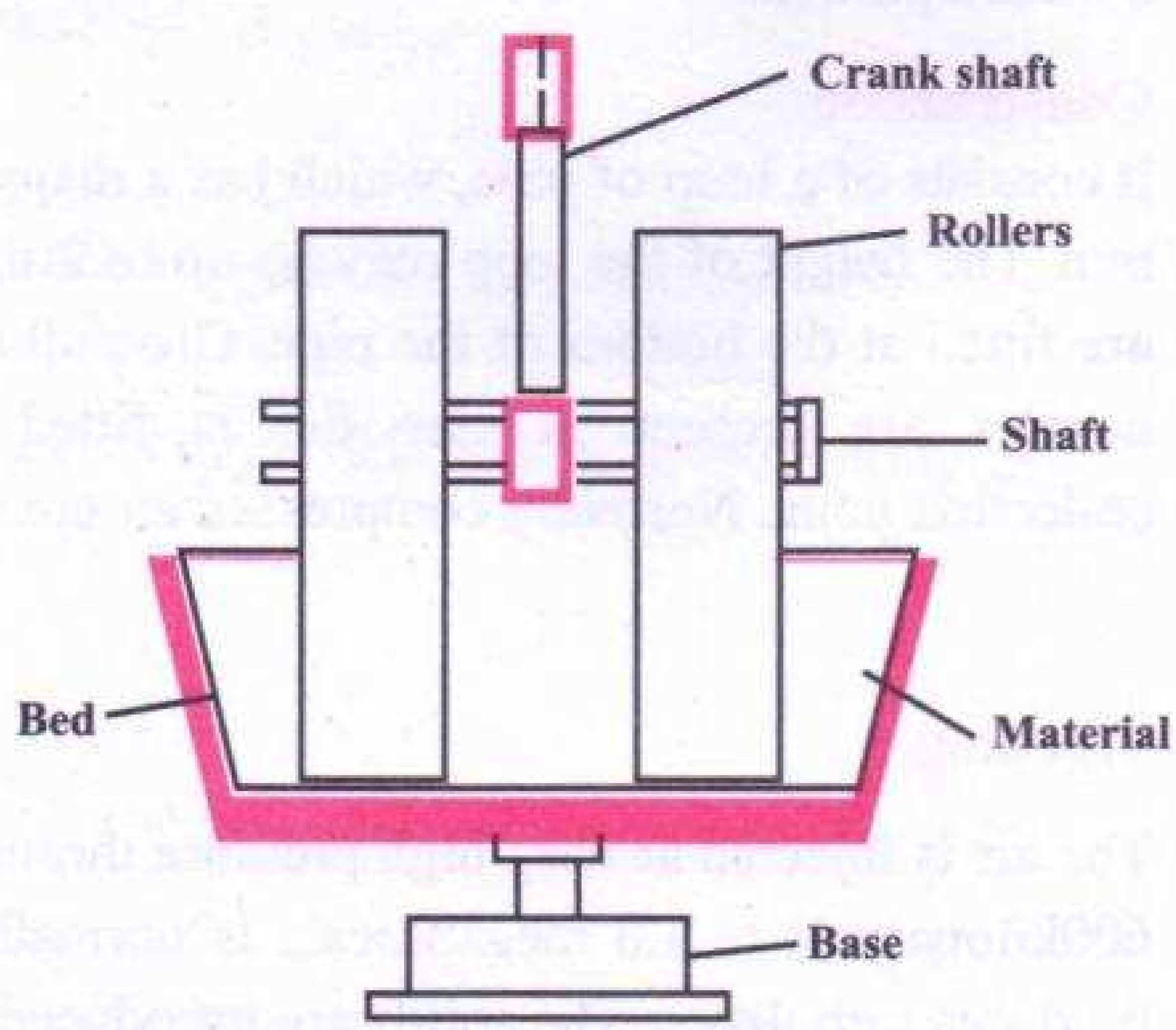


Figure 2.7: Construction of edge runner mill

The material is ground for a definite period and then it is passed through the sieves to get the powder of the required size.

Applications

1. Edge runner mill used to get very fine particles sized materials.
2. It is used to crush or grind all types of the drugs.

Advantages

1. It is mostly used for all types of the drugs.
2. Very fine particle size is obtained.
3. The major advantage is that during operation less attention is required.
4. It does not require any frequent clean up.
5. Simple in structure.

Disadvantages

1. It occupy more space than other size reduction machine.
2. Chances of contamination of product due to roller material.
3. Not used for sticky materials.
4. It cause noise pollution.
5. This is batch type of mill and energy consumption is high.

2.13 END RUNNER MILL

Method of size reduction: Crushing and shearing

Principle:

Size reduction is done by crushing due to weight of pestle and shearing also involves due to pestle and mortar movement.

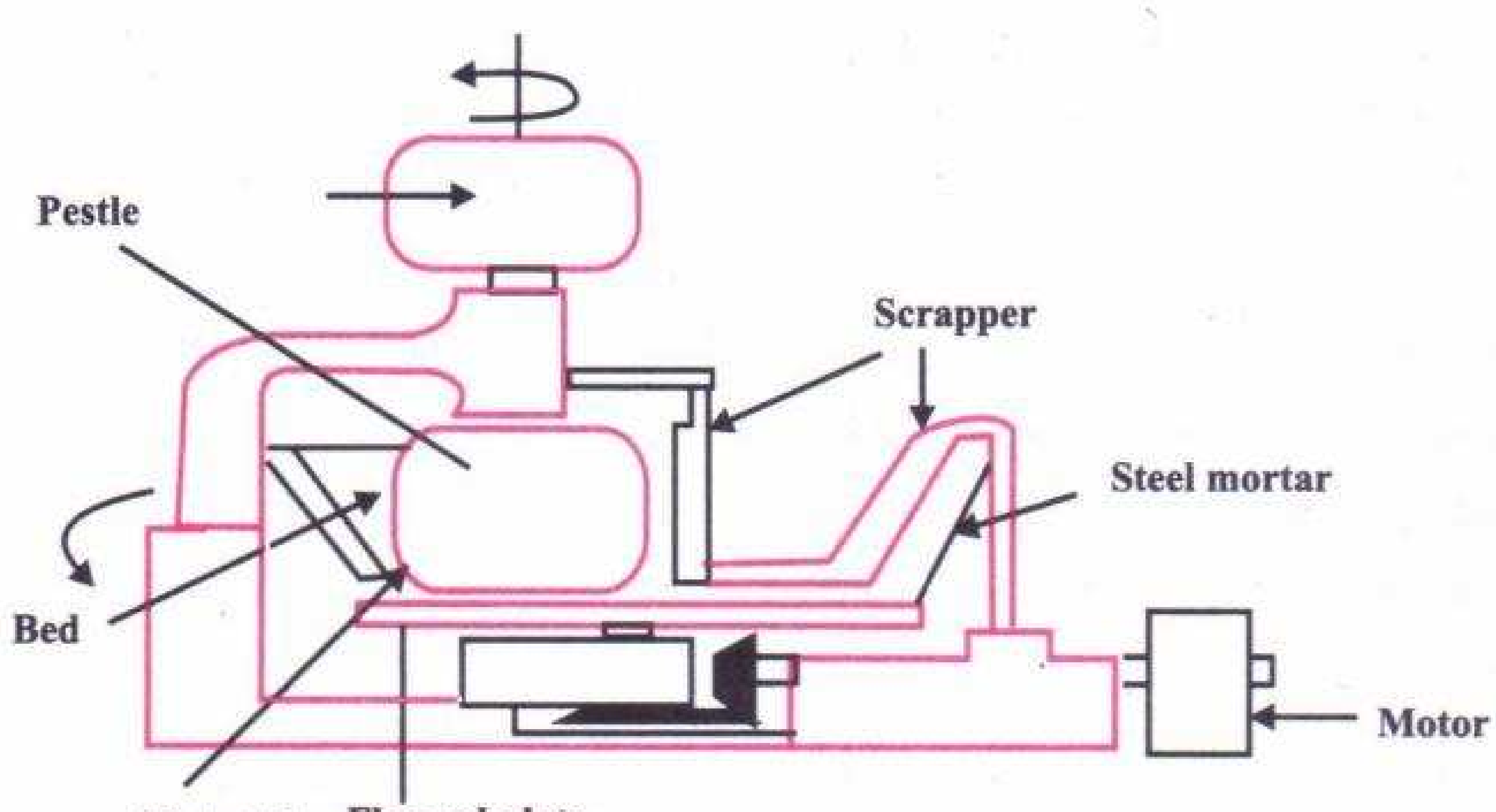


Figure 2.8: Construction of end runner mill

Construction:

It consist of mechanical mortar and pestle. Mortar is shallow. Mortar is made of steel and attached to a flanged plate. Mortar with plate can be rotated at high speed. The pestle is dumb bell shaped. The bottom of pestle is flat rather than round. Pestle can be raised to done emptying and cleaning. It consist of bed of stone which can be rotated. A scrapper is also present which force the material to grinding surface.

Working:

The material whose size is to be reduced is placed in mortar. The scrapper is used to push the material in crushing zone. The mortar revolves at high speed and the revolving mortar causes the pestle to revolve. The resulting material passed through sieve to get powder of sufficient size. During the process, size reduction is achieved by crushing and shearing.

Applications:

End runner mill is suitable for fine grinding.

Disadvantages:

End runner mill is not suitable for drugs which are unbroken or slightly broken condition.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

1. **Define Stress**

   Answer- It is defined as force per unit area.

2. **What do you mean by Plastic deformation?**

   Answer- Plastic deformation occur when compression is applied above the yield value then the substance break down and will not return to its original form after removing stress. This type of deformation is not reversible.

3. **What is Kick's law?**

   Answer- This law states that energy required to reduce size of particle is proportional to ratio of initial size of a typical dimension to the final size of that dimension.

4. **What is Rittinger's law?**

   Answer- This law states that the energy required for the size reduction of unit mass is proportional to the new surface area produced.

5. **What do you mean by Size reduction?**

   Answer- It is the process of reducing large substances into smaller particles.

SHORT ANSWER QUESTIONS

Q1. How Stickiness of material affect size reduction?

Answer- Stickiness is a property which causes considerable difficulty in reducing the size because the material get adhere to the grinding surfaces or the screen meshes may blogged.

Q2. Which mill is suitable for thermolabile products and why?

Answer- Fluid Energy mill is suitable for thermolabile substance because no heat is produced. Fluid energy mill based on principle of Impact and Attrition. Size reduction take place by high velocity collision between particle.

Q3. How END RUNNER MILL works?

Answer- Size reduction is done by crushing due to weight of pestle and shearing also involves due to pestle and mortar movement.

Q4. Write disadvantages of hammer mill?

Answer- a. High speed generates heat that may affect thermolabile materials or drugs containing gum, fat or resin.

b. Due to the high speed of operation, the hammer mill can be damaged if some foreign materials such as stone, metal parts etc. are present in the feed.

c. Chances of clogging of screen.

Q5. How speed of ball affect size reduction in working of Ball mill?

Answer- At low speed, the mass of balls will slide or roll up one over another and will only produce an insignificant amount of size reduction. At high speeds, the balls are thrown to the cylinder wall due to centrifugal force and no grinding will occur. At 2/3rd speed at which centrifugation just occurs is called the critical speed of the ball mill. At this speed the balls are carried almost to the top of the mill and then fall in a cascade across the diameter of the mill. In this way, the maximum size reduction is obtained by impact of the particles between the balls and by attrition between the balls.

LONG ANSWER QUESTIONS

1. Define comminution. Explain the objectives of size reduction.
   (Refer article 2.1,2.4)
2. Explain Laws governing size reduction
   (Refer article 2.5)
3. Describe principles, construction, working, uses, merits and demerits of Hammer mill
   (Refer article 2.9)
4. Describe principles, construction, working, uses, merits and demerits of Ball mill
   (Refer article 2.10)
5. Describe principles, construction, working, uses, merits and demerits of Fluid energy mill
   (Refer article 2.11)
6. Describe principles, construction, working, uses, merits and demerits of Edge runner mill
   (Refer article 2.12)
7. Describe principles, construction, working, uses, merits and demerits of End runner mill
   (Refer article 2.13)

MULTIPLE CHOICE QUESTIONS

1. As compared to Ball mill, tube mill

a. Has higher length/diameter ratio
b. Has large ball size
c. Produce coarse size particle
d. All of the above

2. Ball Mill is used for

a. Attrition
b. Very fine grinding
c. Coarse grinding
d. Both a and c

3. In End runner mill, Size reduction is done by

a. Cutting
b. Crushing and shearing
c. Impact
d. Heating

4. Size reduction is also known as

a. Comminution
b. Compaction
c. Segregation
d. Seperation

5. Which of the following is not variant of Hammer mill

a. Micro Pulverizers
b. Hammer crusher
c. Vertical impact pulverizer
d. Hardinge mill

6. Which of the following law states that the energy required for the size reduction of unit mass is proportional to the new surface area produced.

a. Rittinger's law
b. Bond's Law
c. Fourier's Law
d. Kick's Law

7. The process in which the material is crushed between the rollers by application of pressure is called

a. Compression
b. Impact
c. Attrition
d. Cutting

8. Which of the following factors affects size reduction?

a. Hardness
b. Toughness
c. Abrasiveness
d. All of the above

9. The fineness of product in hammer mill can be regulated by altering

a. Rotor speed
b. Feed rate
c. Clearance between hammers and grinding plate
d. All of the above

10. Which of the following are objectives of size reduction?

a. Increase surface area
b. Stability of suspension
c. Increase absorption
d. All of the above

11. In Ball Mill, maximum size reduction is obtained at

a. Low speed
b. Very high speed
c. Critical speed
d. High speed

ANSWERS

1. a 2. b 3. b 4. a 5. d 6. a 7. a 8. d 9. a 10. d 11. c

3 CHAPTER SIZE SEPARATION

Selected Definitions

Size separation: It is a process that involves the separation of particles of desired size from the mixture of various size particles.

Oversize: The particles that get remain on screening surface

Undersize: The material that pass through screening surface

Coarse powder: It is powder in which all the particles pass through a No. 10 sieve and not more than 40 percent through a No 44 sieve

Moderately coarse powder: It is powder in which all the particles pass through a No. 22 sieve and not more than 40 percent through a No. 60 sieve.

Moderately fine powder: It is powder in which all the particles pass through a No. 44 sieve and not more than 40 percent through a No. 85 sieve.

Fine powder: It is powder in which all the particles pass through a No. 85 sieve.

Very fine powder: It is powder in which all the particles pass through a No. 120 sieve

Mesh: These are the holes in the screen.

Mesh number: This indicate number of holes included in a length of 1 inch.

Aperture of screen: It is the clear space between wires of screen opening and it is given in term of mm.

Screen Number: It is number of meshes in a linear length of 25.4mm.

Nominal aperture size: It is gap between two adjacent wires.

Hindred settling : When particles are so close and continuosly collide with each other. This cause pushing of lighter particles by heavy particles.

3.1 INTRODUCTION

Size separation is also known as sieving, sifting, screening. Size separation is a process that involves the separation of particles of desired size from the mixture of various size particles.

Size reduction gives particles of varying sizes. Sifting is done to get narrow size particles.

Size reduction alone is not sufficient to obtain mono-size or narrow size range powder. Therefore, size reduction and size separation should be combined to obtain powders of desired size.

3.2 APPLICATION OF SIZE SEPARATION

Size separation can be used

1. To prepare granules of desired size to ensure good flowability.
2. To separate undesirable particles
3. To measure particle size and size distribution
4. To know the efficiency of size reduction equipments
5. To get uniform dosage form.
6. Monosize particles undergo less segregation
7. During filling the capsule, the particles must be uniform in weight and doses.

3.3 MECHANISM OF SIZE SEPARATION

Size separation is done by following methods:

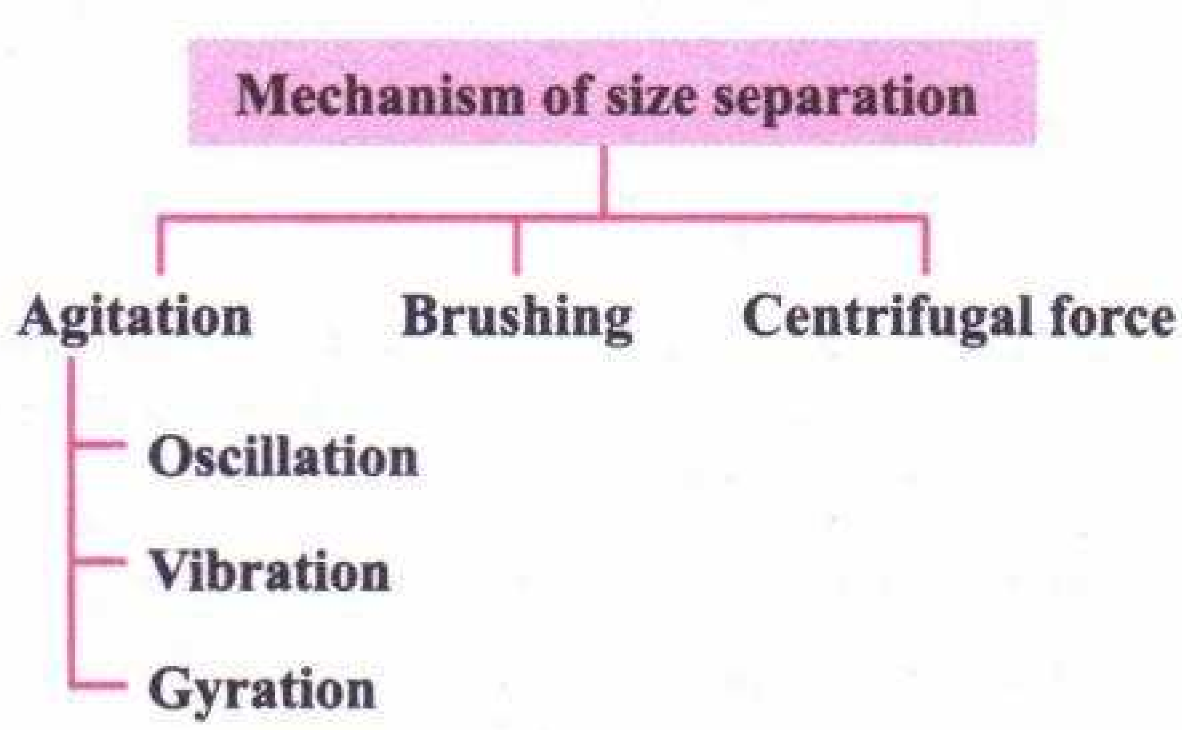


Figure 3.1: Mechanism of size separation

3.3.1 Agitation:

In this sieves are agitated in number of ways.

a. **Oscillation:** The sieve is rack mounted that oscillate back and forth. It is a simple method, but the material can roll on the surface of the sieve. The reciprocating movement is induced by ordinary eccentric on the rotating shaft.
b. **Vibration:** In this method, sieve is vibrated at high speed by mean of eccentric device either electrically or mechanically.
c. **Gyration:** In this method, the sieve is rubber mounted and connected to the eccentric flywheel. This gives a small amplitude rotational movement to the sieve, which in turn gives rotational movement to the particles that help pass them through the sieve.

Advantages:

a. Simple method
b. Inexpensive

Disadvantage:

a. Chances of clogging of sieve if powder is not dried.
b. Size reduction occur due to collision between particle during agitation

3.3.2 Brushing method:

In this method, the brush is used to move the particles on the surface of the sieve and to keep the meshes clear. The brush is rotated in the center in the case of a circular sieve, but the spiral brush is rotated in the longitudinal axis in the case of a horizontal cylindrical sieve. It is used to separate the size of the greasy or sticky powder.

3.3.3 Centrifugal method:

In this method, the high speed rotor is fixed inside a vertical cylindrical sieve, so that during rotation the particles are thrown out by the centrifugal force. The air stream can be generated by means of air jet in the equipment, which helps in the separation of particles. Example: Cyclone Separator and Air Separator.

Advantage: Chances of blockage of sieve is less.

3.4 OFFICIAL STANDARDS OF POWDERS

In sieving process the particles that get remain on screening surface is known as **oversize** and the material that pass through screening surface are known as **undersize**.

Generally powders are classified as coarse and fine powders.

In Indian Pharmacopoeia, powders are classified as: coarse, Moderately coarse, Moderately fine, fine and very fine. The degree of coarseness or finenes is determined with reference to nominal mesh aperture size.

Table 3.1: The relevant grades of powder and sieve number are shown in the table:

Grade of powder	Sieve through which all particles must pass	Sieve through which not more than 40 per cent of particles pass
Coarse	10	44
Moderately coarse	22	60
Moderately fine	44	85
Fine	85	Not specified
Very fine	120	Not specified

3.4.1 Coarse powder

It is powder in which all the particles pass through a No. 10 sieve (having nominal mesh aperture size 1.7mm) and not more than 40 percent through a No. 44 sieve (having nominal mesh aperture size 355 µm), this is usually referred to as a 10/44 powder.

3.4.2 Moderately coarse powder

It is powder in which all the particles pass through a No. 22 sieve (having nominal mesh aperture size 710 µm) and not more than 40 percent through a No. 60 sieve (having nominal mesh aperture size 250 µm), this is usually referred to as a 22/60 powder.

3.4.3 Moderately fine powder

It is powder in which all the particles pass through a No. 44 sieve (having nominal mesh aperture size 355 µm) and not more than 40 percent through a No. 85 sieve (having nominal mesh aperture size 180 µm), this is usually referred to as a 44/85 powder.

3.4.4 Fine powder

It is powder in which all the particles pass through a No. 85 sieve (having nominal mesh aperture size 180 µm).

3.4.5 Very fine powder

It is powder in which all the particles pass through a No. 120 sieve (having nominal mesh aperture size 125 µm).

When a fineness of powder is described by a number, all particles must pass through the specified sieve.

In preparation of tinctures, moderately coarse powder is used. There are following examples of crude drugs for which specific grade of powder is required.

1. For preparation of liquid extract of Ashoka (stem bark), coarse powder is used.
2. For preparation of liquid extract of Nux vomica (seeds), Rauwolfia (roots) moderately coarse powder is specified.
3. For preparation of liquid extract of Ergot (sclerotia) moderately fine powder is specified.
4. For preparation of liquid extract of Ipecac (root) and Ephedra (stem) fine powder is specified.

3.5 SIEVES

Sieves are used for size separation. Test sieves determine the efficiency of screening devices. Most of Sieves used for pharmaceutical purpose are of wire mesh type. Each sieve is given a definite number which denotes number of the meshes present in a length of 2.54 cm or one inch.

3.5.1 Material of construction:

Sieves are woven from wire of brass, bronze, stainless steel. Sieves should not be coated with any material. It should be non reactive with material used. The material used for construction should be resistant to corrosion.

Generally **Iron wire** is used as screen material because it is cheap but their disadvantage are corrosive nature and chances of contamination by iron. These disadvantages can be overcome by coating iron with galvanizing agent which increase the strength and also make it corrosion resistant.

Brass , Phosphor-bronze and stainless steel are the metals used due to their corrosion resistant, good strength and non contamination qualities.

Non metals such as nylon and terylene are also suitable because they avoid risk of metallic contamination.

For special purpose **punched plates or perforated screens** are used. These sieves are made by drilling holes of varying thickness in metal plate. The holes may be round, rectangular or square.

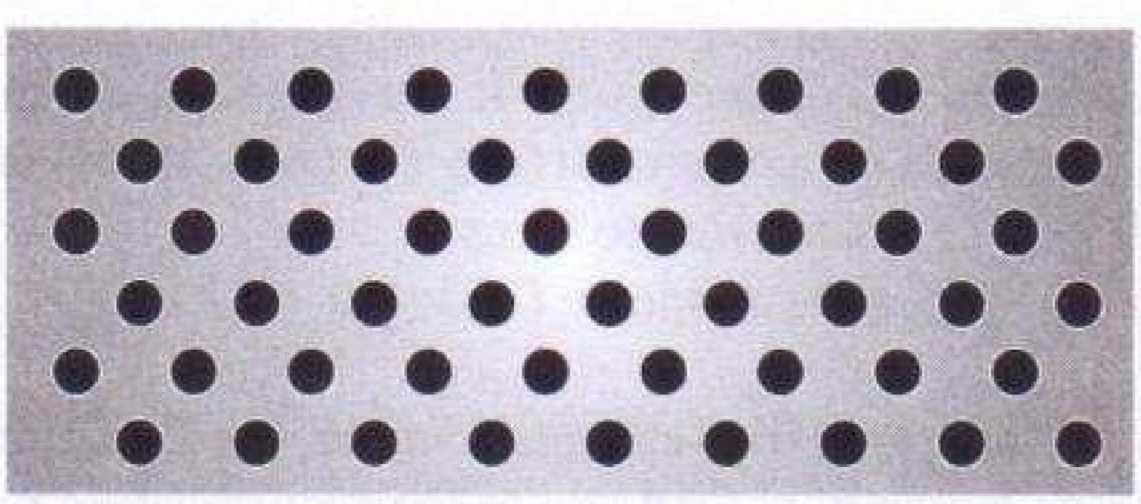


Figure 3.2: perforated screens

For separation of fine powder **Bolting cloth sieves** are used. They are woven from twisted multi strand fibres made of silk, nylon and cotton. Nylon cloths are generally designated for their micrometer opening and also their availability in different grades.

3.5.2 Standards of sieve

Holes in the screen is called **Mesh. Mesh number** indicate number of holes included in a length of 1 inch. **Aperture of screen** is the clear space between wires of screen opening and it is given in term of mm. **Screen Number** denotes number of meshes in a linear length of 25.4mm. **Nominal aperture size** indicates gap between two adjacent wires.

Sieves may be designated by opening size. The common standards used for used for sieves are

a. **Tyler Standard sieve series :** It is U.S. standard sieve. They are available in mesh number 4-325.
b. **U.S. Standard sieve series:** It is used in U.S.A.
c. **British Standard sieve series (B.S.S):** It is available in mesh number 5-300. It is extensively used in UK.
d. **U.S.ASTM:** It is "American Society of Testing Materials" standard sieve series. It is available in mesh number 4-325.
e. **German DIN (Deutsche Industrienormein):** It is commonly used in Europe and Germany.
f. **F.S.S.**: It is French Standard Sieve. It is available in mesh number 17-38.
g. **IP standard Sieve series**: It is commonly used in India
h. **International test sieve series (ISO)**: It is used world wide.

3.5.3 Sieve Analysis

The International standards Organization (ISO) fix lowest a sieve diameter of 45μm. Powders are generally defined as particles having a maximum diameter of 1000 μm, so this is the upper limit. In practice, sieve analysis can be performed in a range of 5 to 125,000 μm. Sieve analysis used to monitor material quality based on particle size.

3.6 SCREENING EQUIPMENTS

General classification of equipments for size separation

a. **Grizzlies** are used for large size or coarse material above 50mm. They are generally not used in pharmacy.
b. **Vibrating screens** are used in routine work. It provide high efficiency and large capacity. In this, vibrating motion is imparted to screen surface by cams or by electromagnetic means. They are generally used for sieving of coarse size to fines.
c. **Oscillating screens** operate at low speed (300-400 oscillations per minute) in plane parallel to screen.
d. **Reciprocating screen** operated by eccentric under the screen that provides oscillation. The movement ranging from gyratory at feed end to the reciprocating movement at discharge end.
e. **Trommels or revolving screen** consist of cylindrical screens rotated at its axis. They are used for separation of particles above 13mm. They are not in practice in pharmacy.

3.7 SIEVE SHAKERS

Principle:

The particles of different sizes are separated by passing them through number of sieves in nest which oscillates back and forth continuously to reciprocating motion.

Figure3.3: Construction of sieve shaker

Construction:

Shaking screen consists of metal frame to which a screens are fixed. The standard sieves of different mesh numbers (as mentioned in IP and USP) are used.

Working:

The sieves are arranged in such a way that the largest aperture will be at the top and smallest aperture will be at the bottom. A sieve nest consist of 6 to 8 sieves. Powder sample having weight of 50 gm is placed on top most sieve. Then close the sieve set and fixed it on to mechanical shaker apparatus. Then start shaking the sieve set for stipulated time (20 minutes). Then all sieves are disassembled. The powder retained on each sieve is collected and weighed.

Advantages:

1. It require less power requirement.
2. Inexpensive
3. Easy to use

Disadvantages:

1. During shaking, attrition may occurs.
2. Chances of clogging of sieve if powder is not properly dry.

3.8 CYCLONE SEPARATOR

Principle:

Cyclone separators are mainly used to separate the solids from fluids. This is based on principle of centrifugal force. The separation process depends on particle size as well as on density of particles.

Construction:

It consist of vertical, cylindrical vessel. It has conical base or bottom. The upper portion of vessel is fitted with tangential inlet. The outlet is arranged at base. The outlet for air or vapor is provided at center of top, which extend inwardly into separator to prevent air short circuiting directly from inlet to outlet of fluids.

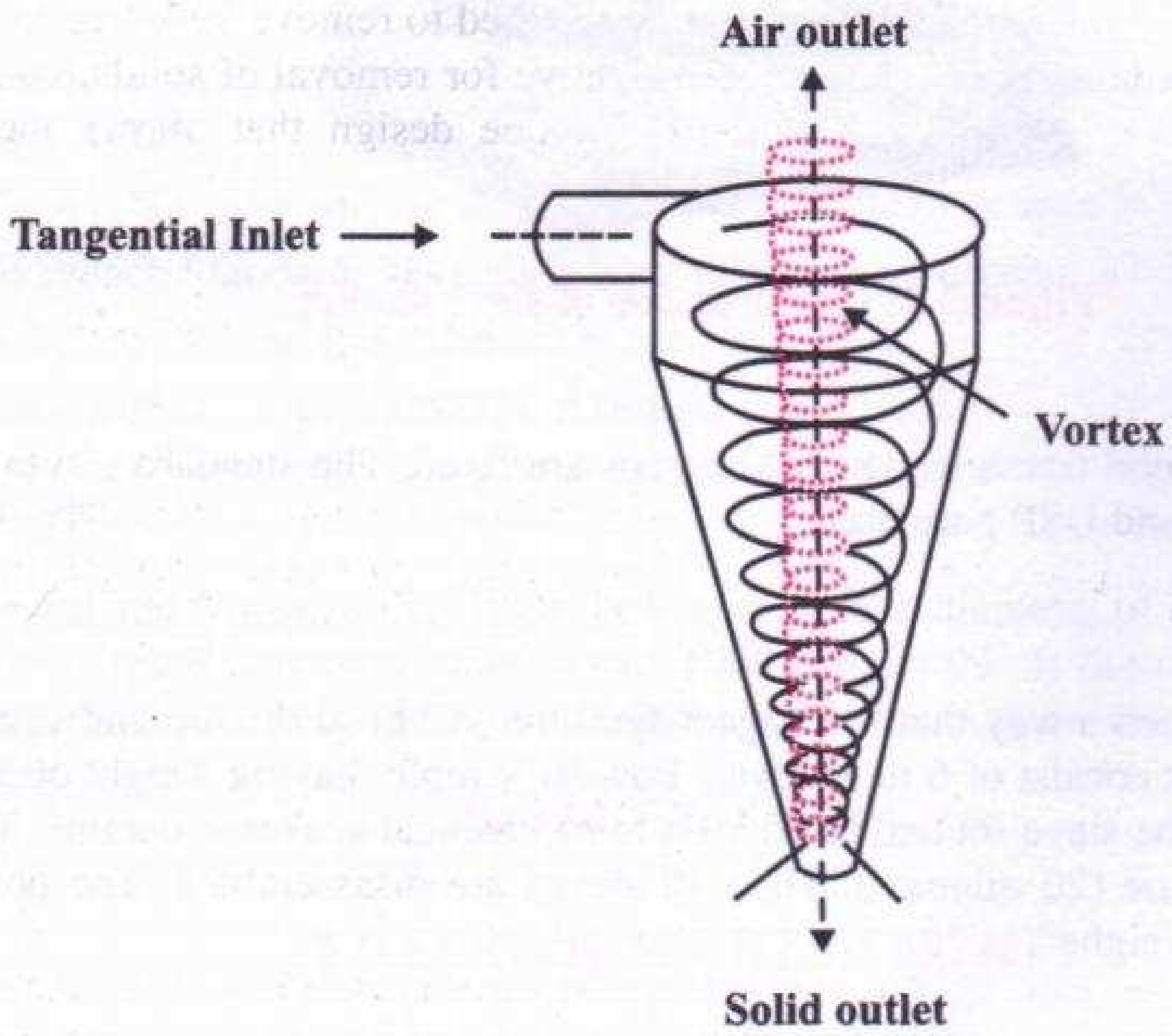


Figure 3.4: Construction of cyclone seperator

Working:

The solids are suspended in gas or air stream and are introduced tangentially at very high velocity into the vessel. A tangential inlet is the most common type of inlet because it is least expensive and most efficient. Then the rotary motion takes place inside the vessel. As a result vortex formation occur. The centrifugal force and the vortex throw the solids to the wall. The coarse solid particles fall into the conical bottom and are collected through solid outlets. The air or vapor can escape from the central outlet at the top.

Pharmaceutical Uses:

1. Used to separate solids from fluids.
2. Used for separating heavy or coarse fraction from fine dust.

Variants:

High-performance cyclones have a diameter greater than 1.5 m and are suitable for separating particles of 20 μm or more.

"High efficiency" cyclones (pencil cyclones) have a diameter between 0.4 and 1.5 m and can be used to separate particles of 10 μm or more.

Wet Cyclone: In order to increase the separation efficiency of fine particles (<20 μm), water is sprayed into the cyclone inlet tube immediately before the cyclone. The water is adhered to the fine particles and removed as a slurry.

Dorrclone: In this apparatus, the slurry enters tangentially near the top. The larger or heavier particles (the coarser ones) are thrown to the sides and slide to the bottom, where they are collected. The remaining air or liquid (the fines) along with the smaller and lighter solid removed out of the top. Small diameter cyclones can handle higher flow rates more efficiently. Its advantages are low capital cost, high efficiency for particles of 5 - 200 microns, high flow volume, lack of moving parts reduces wear.

Vertical Cyclone Separator : Vertical cyclone separators are used to remove 99% free liquids and solids of 5 microns and larger. These separators are particularly effective for removal of solids, such as iron sulfides. The high efficiency of these separators is due to the unique design that allows the separator to be approximately 1/3 the diameter of a conventional separator.

Single-cyclone separators : They create a dual vortex to separate fine dust. The main vortex spirals downward and bring most of the coarser dust particles. The internal vortex created near the bottom of the cyclone, spirals upward and carries finer dust particles.

Multi Cyclone separator: It consists of a numbers of cyclones of small diameter. Multiple Cyclones are more efficient than single cyclones because they are longer and of smaller diameter. The longer length provides a longer residence time while the smaller diameter creates a greater centrifugal force.

3.9 AIR SEPARATOR

Principle

The air separator uses the same principle as the cyclone separator. However, for size separation of fine material cyclone separator alone is not efficient. For such separations, an air stream combined with the centrifugal force is used. The finer particles are entrained by the air and the coarser particles are thrown by centrifugal force, which fall into the bottom.

Construction

Air separator consists of a cylindrical vessel having feed inlet at upper part of vessel. The base is conical. A rotating disc and rotating blades are fitted on a shaft placed at the centre of the vessel. Two outlets are provided at the base of the vessel: one is for the finer particles and the other for coarse or heavy particles.

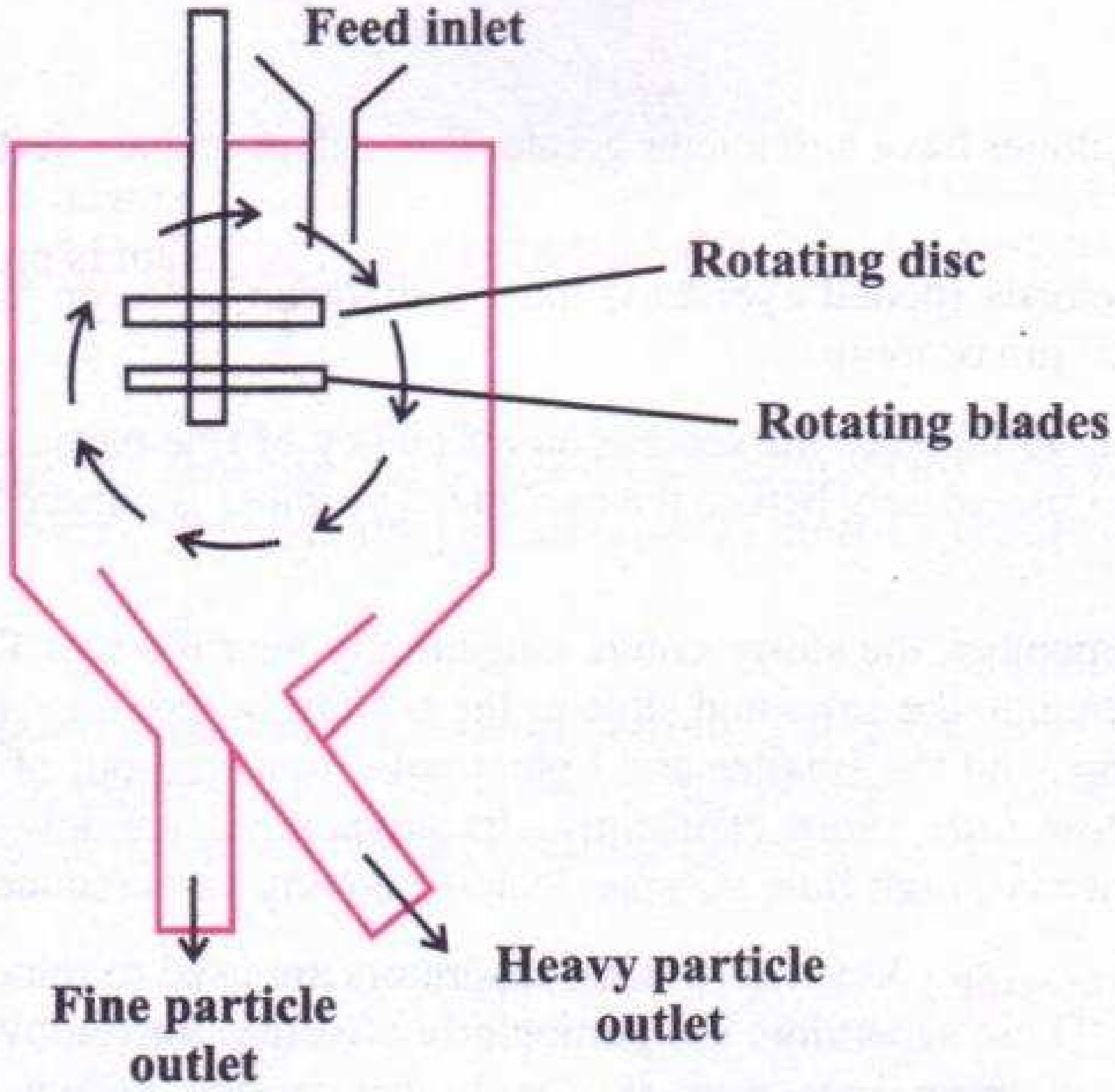


Figure 3.5: Construction of Air Separator

Working

The feed (powder) enters the centre of the vessel through the feed inlet. The admitted feed falls on the rotating blade and the rotating disc. The rotating disc produces an air jet in the direction indicated in the diagram. The fine particles are collected by the air stream and brought into the space of the settling chamber, where the air velocity is sufficiently reduced so that the fine particles fall out and are eliminated through the fine particle outlet. Particles too heavy to be collected by the air stream are removed at the outlet of coarse particles.

The main features of Air separator is ease of installation, the rotor speed is adjustable, high product capacity, air flow can be adjusted and easy to maintain.

Pharmaceutical Applications

Air Separator are used for separation of dry powders in micron-sized that could not be separated by traditional sieves.

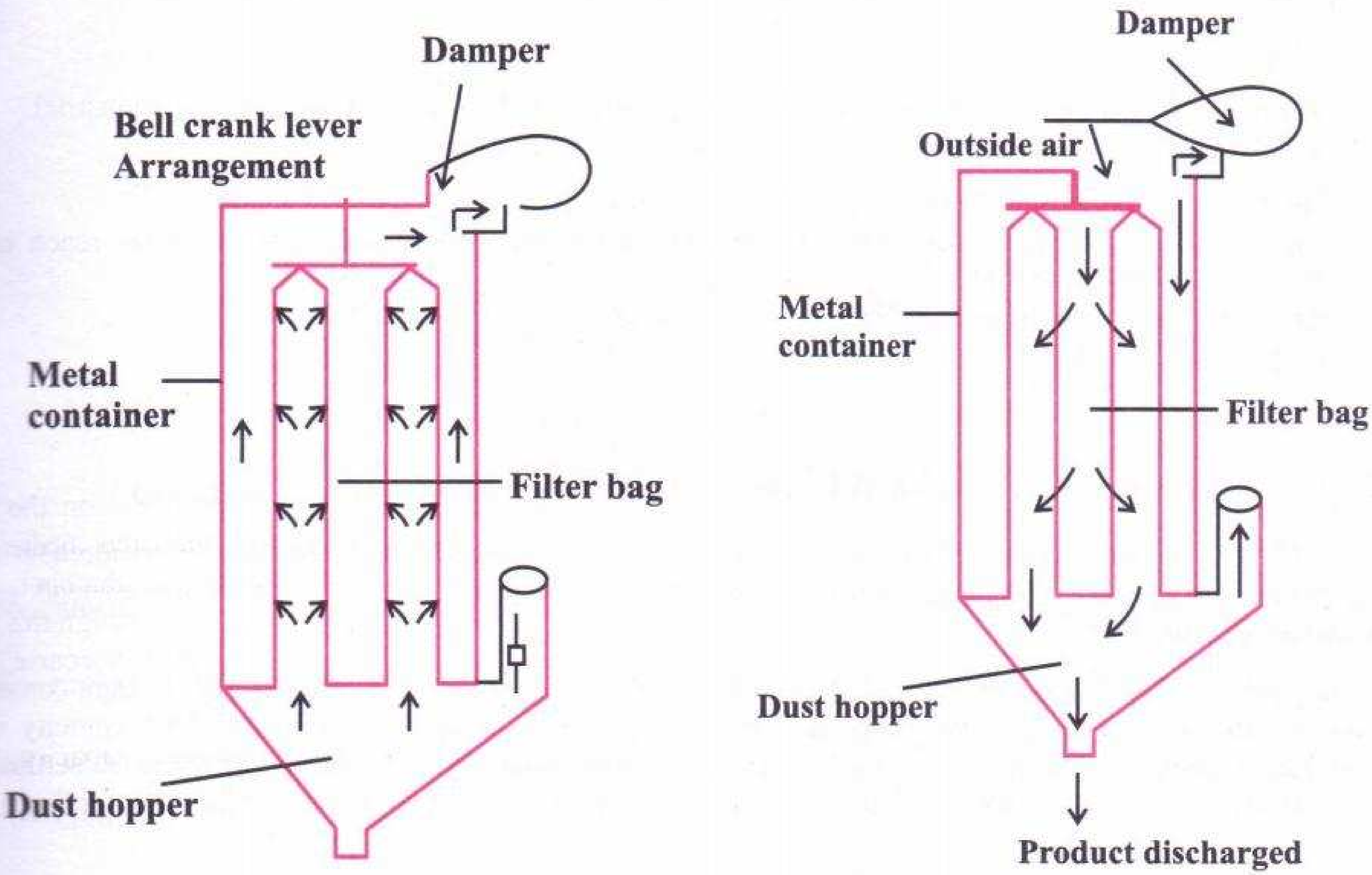
3.10 BAG FILTER

Principle

The separation is performed in two stages. In the first stage, the gas-containing dust is passed through a bag (made of cloth) by applying suction and because of this separation occurs. In the next step, the bags are shaken by applying pressure so that the powder adhering to the bag falls and collected from base.

Construction

A series of bags (made of cotton or wool fabric) are suspended in a metal container. In the bottom portion, hopper is arranged to receive the feed. A bell-crank lever arrangement is provided at the top of the vessel to change the filtering action to shaking.



(a) **Filtering period** **b. Shaking period**

Figure 3.6: Bag Filter

Working

***Filtering period*:** During this period the gas containing dust enters through the hopper. Then it is passed inside the bags and at the top of the apparatus. The vacuum fan produces a pressure below the atmospheric pressure inside the apparatus. As a result, the particles get trapped within the bags.

***Shaking period*:** During this period, the bell-crank lever rotates and changes the position of damper. The outside air enters through the top in the metal casing and therefore the vacuum is broken. At the same time, it causes violent shaking or jerking action to the bags. Dust or fine particles are displaced from the bags. The maximum portion of dust falls into the hopper which is withdrawn further from the conical base.

Pharmaceutical Uses

1. Bag filters are also commonly referred to as fabric dust collectors that are used in large industrial units to separate dust particles from dusty gases.
2. Bag filters are the most efficient and cost effective type of industrial dust collectors.
3. Bag filters are considered the most efficient among all dust collectors because they can reach an efficiency level of up to 99%.
4. Bag filters are also used along with a cyclone separator.
5. They are used to clean the air of a room

3.11 WET SIEVING METHOD

This method is used when particles are too small to be screened properly or when there is difference in settling rates of particles of different sizes. The methods of particle size separation are depend on sedimentation or elutriation.

When particles are settled independently of one another, this condition is called free settling. A stage comes when acceleration of particles become zero and particles get settle at constant velocity. This velocity is called terminal settling velocity. Size separation by sedimentation utilizes the differences in settling velocities of the particles with different diameter (d) and these can be related to Stoke's law. According to this law

$$U_t = \frac{d^2 (\rho_s - \rho) g}{18\eta} \tag{3.1}$$

Where

U_t = Terminal settling velocity
d = diameter of the particle
ρ_s = density of the particle
ρ = density of the liquid
g = acceleration due to gravity
η = viscosity of the liquid.

The rate of sedimentation depends on the diameter of the particle, density of the liquid and particle, viscosity of the liquid and the acceleration due to gravity.

When particles are so close and continuously collide with each other. This cause pushing of lighter particles by heavy particles. This is called Hindred settling. Stoke's law is not applicable in case of hindered settling.

3.12 CONTINUOUS SEDIMENTATION TANK

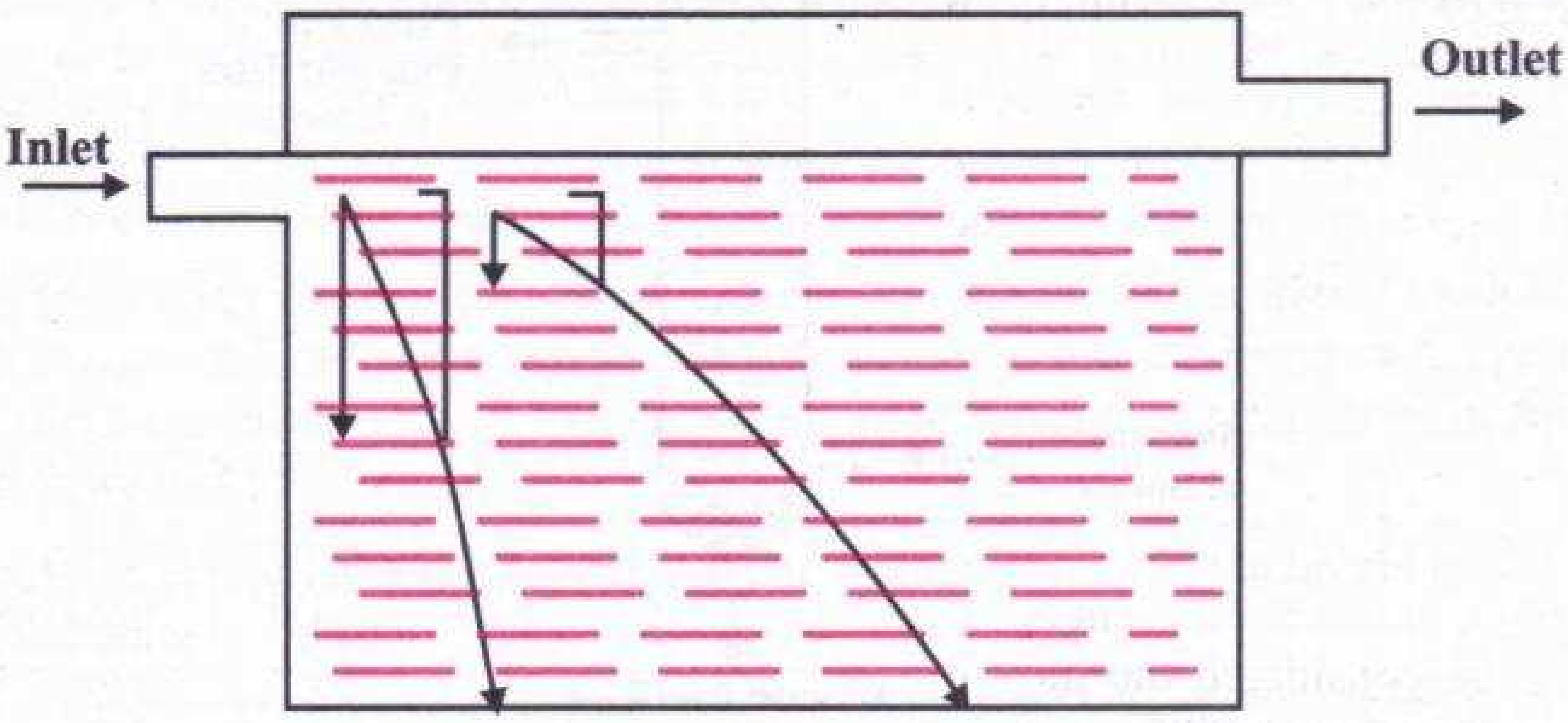


Figure 3.7: Continuous sedimentation tank

It consists of a shallow tank with inlet and outlet pipes. When a suspension of the solids in water is placed in a tank and allowed to stand. The particles in the tank will be actuated by a force that can be divided into two components:

(i) a horizontal component due to the flow of liquid carrying the particles forward and

(ii) a vertical component due to gravity, which causes the particles to fall towards the bottom of the tank. This component is governed by Stoke's Law.

According to Stoke's Law, the velocity of sedimentation is proportional to the square of the diameter of the particles. The settling rate of particles depends on density. Thus, the particles will be deposited at the bottom of the tank in such a way that the larger particles will settle close to the inlet and the finer particles near the outlet. Then the particles of different size fractions can be collected from the floor of the tank.

The main advantages of these methods are simple, inexpensive, continuous in operations and it provides a clear separation of the particles in many size fractions as required.

3.13 ELUTRIATION METHOD

In elutriation method, the fluid movement is to the opposite direction of the sedimentation of the particle.

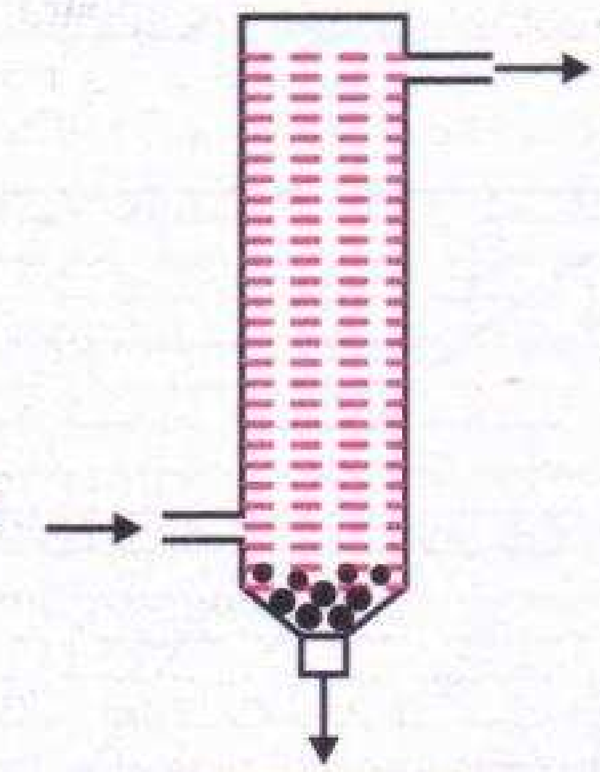


Figure3.8: Simple apparatus for Elutriation

The apparatus consists of a vertical column. An suspension of solid is introduced through the inlet near the bottom of the column. An outlet for coarse particles is also available at the base. The fluid and fine particles overflow from the top of the column. Due to the velocity gradient across the column, it results in the separation of particles of different sizes.

3.14 DOUBLE CONE CLASSIFIER

Principle

The Principle of separation based on elutriation. In elutriation method the fluid flows in opposite direction to the sedimentation movement.

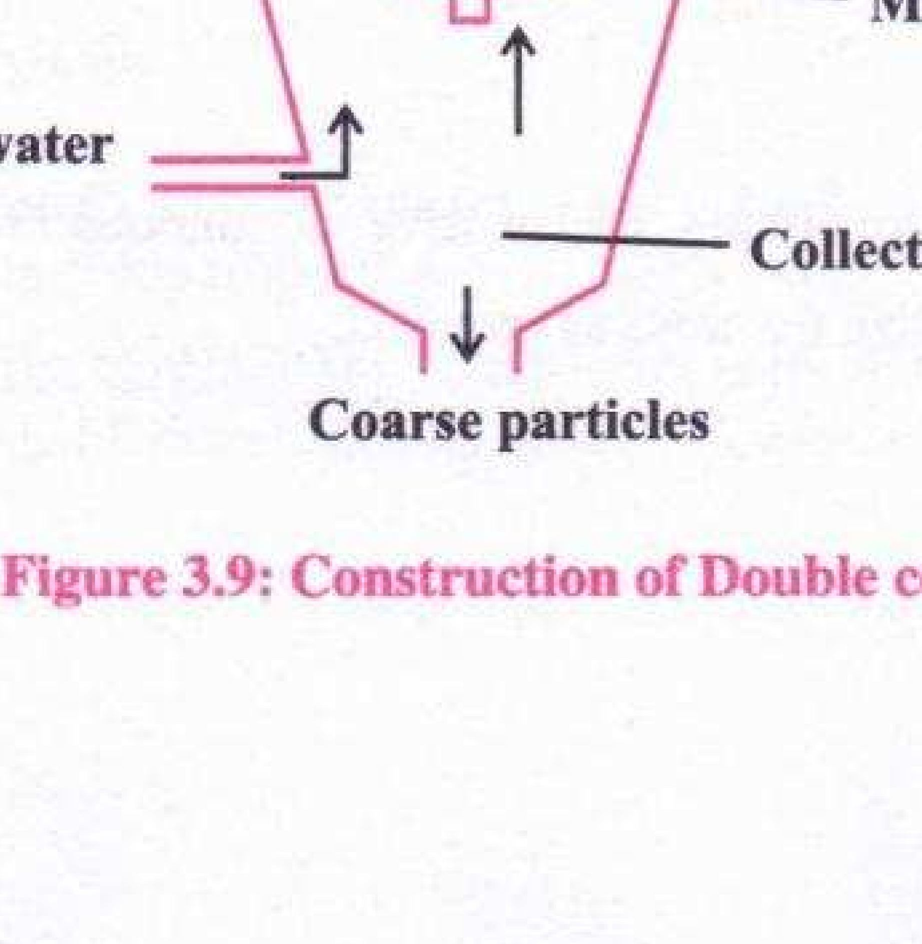


Figure 3.9: Construction of Double cone classifier

Construction

It consist of two cones of different sizes which are placed one in another. At the top on the outside surface of the outer cone *discharge launder* is fitted. Feed enters through inner cone present at the top. At the bottom of equipment Hydraulic Water inlet is provided. Inside the apparatus mixing port is also fitted. At the bottom a collector is provided to collect the coarse particles. The inner cone is shorter than the outer cone. The inner cone can be rotated along its vertical axis.

Working

The feed enters the inner cone and the water is introduced through the water inlet at the bottom. The particles enters from the inner cone and encounter an upward stream of water at the lower end. The fine particles pass upwards and are collected in the discharge launder. The coarse particles are deposited in the collector and the coarse material are removed at intervals.

The degree of separation is regulated by the speed of the water supply and the height of the inner cone regulated by the hand wheel.

REVIEW QUESTIC

VERY SHORT ANSWER QUESTIONS

Q1. Define Size separation

Answer- It is a process that involves the separation of particles of desired size from the mixture of various size particles.

Q2. What are Moderately coarse powder?

Answer- It is powder in which all the particles pass through a No. 22 sieve and not more than 40 percent through a No. 60 sieve.

Q3. Define Mesh number?

Answer- It is number of holes included in a length of 1 inch.

Q4. Define Screen Number.

Answer- It is number of meshes in a linear length of 25.4mm.

Q5. What is Hindred settling?

Answer- When particles are so close and continuosly collide with each other. This cause pushing of lighter particles by heavy particles.

SHORT ANSWER QUESTIONS

Q1. What are the disadvantage of using Iron wire as screen material and how it can be overcome?

Answer- The disadvantage of using iron wire is corrosion and chances of contamination by iron. These disadvantages can be overcome by coating iron with galvanizing agent which increase the strength and also make it corrosion resistant.

Q2. Why non metals are preferred over metal as screen material?

Answer- Non metals such as nylon and terylene are also suitable because they avoid risk of metallic contamination.

Q3. Why Multiple Cyclones are more efficient than single cyclones?

Answer- Because Multiple Cyclones are longer and of smaller diameter. The longer length provides a longer residence time while the smaller diameter creates a greater centrifugal force.

Q4. Write Principle of Bag filter.

Answer-The separation by size of the fines (or dust) of the ground powder is realized in two stages. In the first stage, the gas-containing dust is passed through a bag (made of cloth) by applying suction and because of this separation occurs. In the next step, the bags are shaken by applying pressure so that the powder adhering to the bag falls and collected from base.

Q5. Write objectives of size separation.

Answer- Size reduction gives particles of varying sizes. Sifting is done to get narrow size particles. Size reduction alone is not sufficient to obtain mono-size or narrow size range powder. Therefore, size reduction and size separation should be combined to obtain powders of desired size.

LONG ANSWER QUESTIONS

1. (a) Define Size separation. What are the objectives of size separation? What is the importance of Size separation in Pharmacy?
   (Refer article 3.1, 3.2)
   (b) Describe official standards of powder
   (Refer article 3.4)
2. What are the different materials used for construction of sieve?
   (Refer article 3.5.1)
3. With neat diagram, describe the principle, working, and applications of Cyclone separator.
   (Refer article 3.8)
4. With neat diagram, describe the principle, working, and applications of Air separator.
   (Refer article 3.9)
5. Describe principle, construction and working of Double Cone classifier.
   (Refer article 3.14)
6. Describe different mechanism of size separation
   (Refer article 3.3)
7. Describe specifications of standard sieves as per IP
   (Refer article 3.5.2)
8. Write principle, construction and working of sieve shakers.
   (Refer article 3.7)

MULTIPLE CHOICE QUESTIONS

1. **The process in which heavier component in mixture settles down when water is added to it is called**
   a. Sedimentation
   b. Filtration
   c. Condensation
   d. Evaporation
2. **Metal used for construction of sieve is**
   a. Stainless Steel
   b. Nylon
   c. Terylene
   d. Magnesium

3. The mode of motion in size separation methods

a. Agitation
b. Brushing
c. Centrifugal force
d. All of the above

4. Screen Number denotes number of meshes in linear length of

a. 25.4 mm
b. 0.254 mm
c. 254 mm
d. 2.54 mm

5. In elutriation, fluid movement is to the _______________ direction of the sedimentation of the particle.

a. Opposite
b. Parallel
c. Perpendicular
d. None of the above

6. Size separation can be used

a. To prepare granules of desired size to ensure good flowability.
b. To measure particle size and size distribution
c. To know the efficiency of size reduction equipments
d. All of the above

7. Nominal aperture size indicates

a. gap between two adjacent wires
b. clear space between wires of screen opening
c. number of meshes in a linear length
d. number of holes

8. British Standard sieve series (B.S.S) is extensively used in

a. UK
b. India
c. U.S.A
d. British

9. The rate of sedimentation depends on

a. the diameter of the particle
b. density of the liquid and viscosity of the liquid
c. the acceleration due to gravity
d. All of the above

10. Which of the following is/are variants of Cyclone separators

a. Dorrclone
b. Wet cyclone
c. Vertical Cyclone Separator
d. All of the above

ANSWERS

1.a 2.a 3.d 4.a 5.a 6.d 7.a 8.a 9.d 10.d

4 CHAPTER HEAT TRANSFER

Selected Definitions

Heat transfer: It is the process of transferring heat from an object at high temperature to an object at a lower temperature.

Conduction: It is the process of transfer of heat between two substances that are in physical contact without mixing.

Convection: It is the process of transfer of thermal energy from hot places to cold places by mixing of warmer portion with cooler portion of same material.

Radiation: It is the process of transmission of heat through the empty space by electromagnetic radiation.

Fourier's Law of heat transfer: This law states that rate of heat flow through a uniform material is proportional to the area (m^2) and the temperature difference while it is inversely proportional to the length of path of the flow(m).

Forced convection: If the mixing of fluid is accomplished by use of agitator or stirrer. Such a process in heat transfer is known as forced convection

Natural convection: When a body of fluid is heated then mixing of fluid is accomplished by currents set up.

Black body: It is a body that radiate maximum amount of energy at given temperature.

Emissivity: It is defined as ratio of energy emitted by actual body to energy emitted by black body.

Absorptivity: It is fraction of energy absorbed

Grey body: It is a body whose absorptivity remain constant at a given temperature at all wavelength of radiation.

Heat exchangers: These are the devices used to transfer heat from hot gas to liquid through metal wall.

Heat Interchangers: These devices are used to transfer heat from one liquid to other liquid or one gas to other gas via metal wall.

Baffles: These are circular discs of metal sheet having perforated sheet on one side to receive tubes

4.1 INTRODUCTION

All matter is composed of molecules and atoms. These atoms are always in different types of movement (translation, rotation or vibration). The movement of atoms and molecules produce heat or thermal energy. The more atoms or molecules move, the more heat or thermal energy they will have. Heat transfer include transferring heat from an object at high temperature to an object at a lower temperature. The main objectives of heat transfer process:

1. To study different mode of heat transfer
2. To determine the rate of heating and cooling
3. To plan changes in new heat transfer equipments
4. To determine the efficiency of existing heat exchange equipments.

4.2 APPLICATIONS

1. Heat is required for drying of wet mass during production of tablet.
2. During distillation, heat is required to convert liquid into vapor. Therefore individual component get condensed at other place,
3. In case of steam distillation, steam is required which is in direct contact with material
4. To prepare vegetable extract by process of evaporation, heat is supplied to liquid. Therefore vapors are formed which are removed.
5. For crystallization of drugs, supersaturation is achieved by heating saturated solution.
6. For sterilization of pharmaceuticals, dry heat is required for sterilization of glasswares and containers while steam is required for autoclaving.
7. For different processes such as boiling, fusion etc, heat is also required.

4.3 MECHANISM OF HEAT TRANSFER

The heat can travel from one place to another in three ways: Conduction, convection and radiation. The heat will always find a way to transfer from the higher system to the lower system. Heat transfer is a dynamic process.

4.3.1 CONDUCTION

Conduction is the transfer of heat between two substances that are in physical contact without mixing. The better the conductor, the sooner the heat will be transferred. The metal is a good conductor of heat. Conduction occurs when a substance is heated, the particles acquire more energy and vibrate more. These molecules then bump into the neighbouring particles and transfer some of their energy to them. It then continues and transmits the energy from the hot end to the most to the colder end of the substance.

4.3.2 CONVECTION

In convection, thermal energy is transferred from hot places to cold places by mixing of warmer portion with cooler portion of same material. For example water boiling in a pan. Another good example of convection is in the atmosphere. The surface of the earth is heated by the sun, warm air rises and cool air enters. If motion of fluid is due to difference in density which occur by difference in temperature, then it is called natural convection. If motion of fluid is due to mechanical mean, then it is called forced convection.

4.3.3 RADIATION

Radiation is a method of heat transfer that does not related to any contact between the heat source and the heated object, as in the case of conduction and convection. The heat can be transmitted through the empty space by electromagnetic radiation. This process of energy transfer is known as radiation. Examples of radiation are the heat of the sun or the heat generated by the filament of a bulb.

4.4 HEAT TRANSFER BY CONDUCTION

Heat flow when there is temperature gradient. If one end of a metal rod is at a higher temperature, then the energy will be transferred down towards the cold end. The higher velocity particles collide with the slower particles with a net transfer of energy to the slower particles.

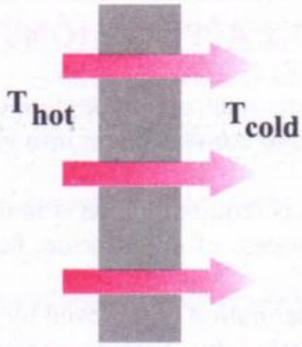


Figure 4.1: Mechanism of heat transfer

The basic rate equation is

Rate = driving force / resistance

The driving force is temperature drop across the solid surface. Greater will be rate of heat flow if temperature drop is greater. The term resistance is expressed by Fourier's Law

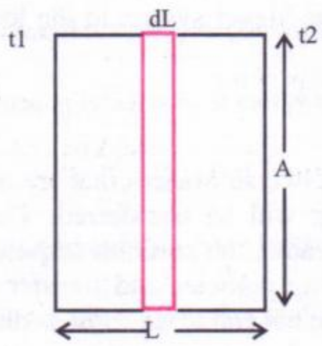


Figure 4.2: Heat transfer through metal wall by conduction

If heat is transferred through a metal wall having area A and thickness L. Let t_1 is higher temperature uniform on the one face of the wall while t_2 is uniform but lower temperature maintained on the another face of wall. The flow will be from higher temperature side to lower temperature side.

Fourier's Law state that rate of heat flow through a uniform material is proportional to the area (m^2) and the temperature difference while it is inversely proportional to the length of path of the flow(m).

$$\text{Rate of heat flow } \alpha \frac{\text{Area} \times \text{Temperature difference}(\Delta t)}{\text{Thickness}} \quad (4.1)$$

Or $$q \alpha \frac{A.\Delta t}{L} \tag{4.2}$$

Or $$q = \frac{K_m.A.\Delta t}{L} \tag{4.3}$$

Where Km is mean proportionality constant

If heat flow is at right angle to plane A and suppose to be in steady state. Consider at an intermediate point in the wall having thickness dL of a thin section. This is parallel to plane A. Fourier law for this thin section is shown as

$$\frac{dQ}{d\theta} = \frac{-K.A.dt}{dL} \tag{4.4}$$

where

Q= heat transfer

θ = time

k = proportionality constant. It is function of temperature and independent on length

dt / dL= temperature gradient

Negative or minus (-) sign indicate decrease in temperature in the direction of flow.

For steady state heat transfer, equation will become

$$\frac{dQ}{d\theta} = \text{constant} = q = \frac{-K.A.dt}{dL} \tag{4.5}$$

or $$\frac{q.dL}{A} = -kdt \tag{4.6}$$

By integrating the above equation between 0 to L

$$q\int_0^L \frac{dL}{A} = -\int_{t_1}^{t_2} k\,dt = \int_{t_2}^{t_1} k\,dt \tag{4.7}$$

$$qL / A = k_m (t_1 - t_2) = k_m \Delta t \tag{4.8}$$

k_m is arithmetic mean value of k between temperature t_1 and t_2 and considered as constant.

In steady state heat transfer q remain constant. The term Δt indicates driving force. The equation (4.3) will be

$$q = \frac{\Delta t}{L / k_m A} \tag{4.9}$$

So $$\text{Resistance} = L / k_m A \quad (4.10)$$

Fourier's law describe resistance in quantitative way.

4.5 FLOW OF HEAT THROUGH COMPOUND RESISTANCE IN SERIES

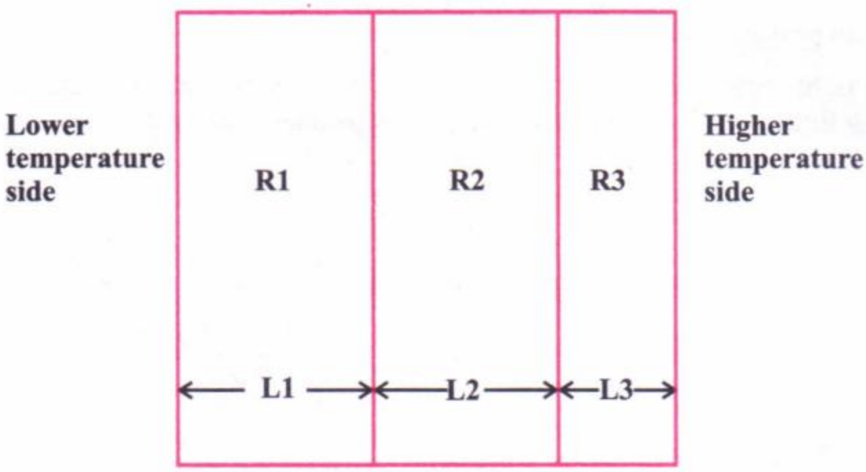


Figure 4.3: Flow of heat through compound resistance in Series

Suppose a flat wall made of series of layer having thickness of three layers are L_1, L_2, L_3 and conductivities k_1, k_2, k_3. The area of entire wall is A. Temperature drop across three layers is Δt_1, Δt_2, Δt_3. The Resistance of three layers R_1, R_2, R_3.

If Δt is overall temperature drop over the three layers, then $\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3$

$\Delta t_1 = q_1 . L_1 / k_1 A$ and $\Delta t_2 = q_2 . L_2 / k_2 A$ and $\Delta t_3 = q_3 . L_3 / k_3 A$

$$\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3 = \frac{q_1 L_1}{k_1 A} + \frac{q_2 L_2}{k_2 A} + \frac{q_3 L_3}{k_3 A} \quad (4.11)$$

The entire heat must pass from first resistance also pass from second and third. So heat q is

$$q = q_1 + q_2 + q_3 \quad (4.12)$$

$$q = \frac{\Delta t}{L_1 / k_1 A + L_2 / k_2 A + L_3 / k_3 A} \quad (4.13)$$

or

$$q = \frac{\Delta t}{R_1 + R_2 + R_3} \quad (4.14)$$

When heat flow through number of resistances in series, the temperature difference are total temperature drop and individual thermal resistance is to the total thermal resistance expressed mathematically as

$$\Delta t : \Delta t_1 : \Delta t_2 : \Delta t_3 = R : R_1 : R_2 : R_3 \tag{4.15}$$

4.6 HEAT FLOW THROUGH THICK WALL CYLINDER

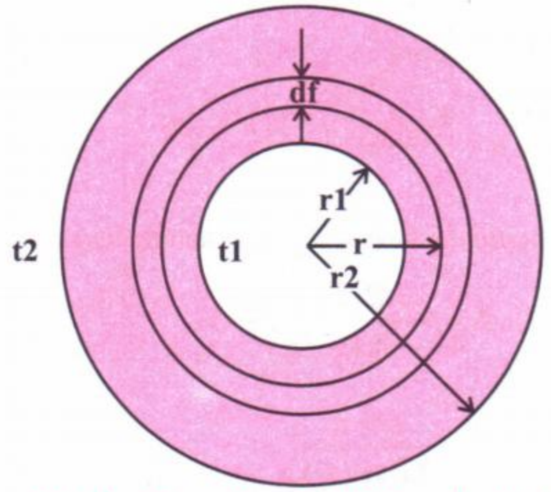


Figure 4.4: Heat flow through thick wall cylinder

Consider a hollow cylinder having r_1, r_2 and r is radius of inner wall, radius of outer wall and radius of thin cylinder respectively. t_1 is temperature of inside surface (higher) and t_2 is temperature of outside surface (lower). dr is thickness of thin section. N is the length of hollow cylinder. Km is mean thermal conductivity of material of cylinder.

The rate of heat transfer is expressed as

$$q = -k\frac{dt}{dr}(2\pi rN) \tag{4.16}$$

where $A = 2\pi rN$ and $dL = dr$

On rearranging the equation by considering variables radius and temperature

$$dr / r = \frac{-2\pi Nk}{q} dt \tag{4.17}$$

Integrating the above equation

$$\int_{r_1}^{r_2} dr / r = \frac{-2\pi N}{q} \int_{t_1}^{t_2} kdt = \frac{2\pi N}{q} \int_{t_2}^{t_1} kdt \tag{4.18}$$

$$\ln r_2 - \ln r_1 = \frac{2\pi N K_m}{q}(t_1 - t_2) \quad (4.19)$$

$$q = \frac{2\pi N K_m (t_1 - t_2)}{\ln(r_2 / r_1)} \quad (4.20)$$

Comparing this equation with general form

$$q = \frac{K_m A_m (t_1 - t_2)}{L} \quad (4.21)$$

Here A_m is heat transfer area of cylinder having length N and radius r_m. And $L = r_2 - r_1$,

$$A_m = \frac{2\pi N (r_2 - r_1)}{\ln(r_2 / r_1)} \quad (4.22)$$

$$r_m = \frac{r_2 - r_1}{\ln(r_2 / r_1)} \quad (4.23)$$

Hence

Where r_m is logarithm mean radius. It is used to calculate heat flow in case of thick walled tube. The arithmetic mean radius $(r_1 + r_2)/2$ provide value within 10% of r_m if r_2/r_1 is less than 3.2. Its value will be 1% if r_2/r_1 is less than 1.5.

4.7 HEAT TRANSFER BY CONVECTION

When a body of fluid is heated then mixing of fluid is accomplished by currents set up. This is called natural convection. If the mixing of fluid is accomplished by use of agitator or stirrer. Such a process in heat transfer is known as forced convection. The flow of fluid flow through pipeline can be either viscous or turbulent in nature. When fluid follows viscous flow, the velocity is zero at actual surface of wall. The layer of fluid adjacent to wall act as stagnant film. Also in case of turbulent flow, stagnant film is observed. The fluid is in turbulent flow at the centre while viscous flow is observed at surface of fluid. A film of buffer layer exist between these type of flow. The resistance offered by these films for flow of heat is large because these films are thin. Beyond these films, turbulence cause rapid equalization of temperature.

On cold side, surface or film coefficient h_1 is defined as

$$h_2 = \frac{q}{A_2(t_d - t_2)} \quad (4.25)$$

$1/h_2A_2$ is known as thermal resistance

To determine overall heat transfer from $1/h_1A_1$ thermal resistance on hot fluid side, $1/h_2A_2$ is thermal resistance of cold fluid side and L/kA_m resistance of metal wall., the equation will be written as

$$q = \frac{\Delta t}{1/h_2A_1 + L/k_mA_m + 1/h_2A_2} \quad (4.26)$$

On multiplying both numerator and denominator of right side of equation by A_1, we get

$$q = \frac{A_1\Delta t}{1/h_1 + LA_1/kA_m + A_1/h_2A_2} \quad (4.27)$$

Then overall heat transfer U_1 is expressed as

$$U_1 = \frac{A_1\Delta t}{1/h_1 + LA_1/kA_m + A_1/h_2A_2} \quad (4.28)$$

The equation (4.27) can be written as

$$q = U_1 \Delta t A_1 \quad (4.29)$$

The rate of heat transfer is product of overall heat transfer coefficient, area of heating surface and temperature drop.

The overall heat transfer coefficient for tubular metal wall is

$$U_1 = \frac{1}{1/h_1 + LD_1/kD_m + D_1/h_2D_2} \quad (4.30)$$

When one particular area is more convenient than other. Let assume h_2 is much greater than h_1, then the (D_1/D_2h_2) become small as compared to $1/h_1$. As well as resistance of tube wall is also small as compared to $1/h_1$. The ratio (D_1/D_m) and (D_1/D_2) can be disregarded. The equation will be

$$U_1 = \frac{1}{1/h_1 + L/k + 1/h_2} \quad (4.31)$$

The equation is used in case of thin walled tube with larger diameter and also for thin walled plates. In these cases, area A can be used for A_1, A_m and A_2. The error will be negligible. In these cases $U_1 = U_2 = U_m$.

When h_1 is very small as compared to h_2 and (L/k), ($1/h_1$) will be larger. So other two terms in denominator are disregarded. Then $U_1 = h_1$. The numerical value of surface coefficient can be predicted easily.

When fluid pass through each other from the opposite directions, then this arrangement is called counter current or counter flow. In this case the exit temperature of hot fluid is less than that of exit temperature of cold fluid. Therefore a large proportion of heat content of hot fluid is extracted for given entrance temperature of cold fluid. If Δt_1 is nearly constant to Δt_2, then Δt_{av} can be expressed as

$$\Delta t_{av} = \frac{\Delta t_1 + \Delta t_2}{2} \quad \text{(eq 4.32)}$$

For counter current heat flow, heat transfer equation is written as

$$q = UA.\Delta t_{av} \quad \text{(eq 4.33)}$$

4.9 RADIATION

When heat transfer occurs by radiation, then it is called thermal radiation. All matter with a temperature above the absolute zero emits **thermal radiation.** The wavelength of 0.8 to 400 μm are used as radiation source for thermal radiations. The range is 0.8 to 25 μm are used for industrial use. Thermal radiations follow same laws of light such as it travels in straight line and it may be reflected from the surface.

Black body is a body that radiate maximum amount of energy at given temperature. For visible light rays black matte surface approaches a black body. Black surface emit more heat than polished surface. Theoretically an enclosed space with small opening is considered as black body and temperature in that enclosed space should be constant. The total amount of radiation emitted by black body is explained by Stefan-Boltzmann Law. According to this

$$q = bAT^4 \quad \text{(eq 4.34)}$$

where q = energy radiated in one second

A = Area of radiating surface

T = absolute temperature of radiating surface

b = constant. For black body $b = 5.67 \times 10^{-8}$ W/m^2 K^4.

For actual body, the above equation is expressed as

$$q = \varepsilon bAT^4 \quad \text{(eq 4.35)}$$

where

ε = emissivity of actual body.

For black body ε = 1. For actual body ε is less than 1. Emissivity is defined as ratio of energy emitted by actual body to energy emitted by black body.

Absorptivity is fraction of energy absorbed. The substance is considered as black body if ε = α. If Emissivity of black body is one, then Absorptivity must be one.

5 CHAPTER EVAPORATION

Selected Definitions

Evaporation: It is the process by which liquid water goes directly to the vapor phase due to an increase in temperature.

Evaporator: It is an equipment in which liquid is boiled.

Economy of an evaporator: It is expressed as quantity of vapour produced when one unit steam is supplied.

Triple evaporator: It consist of three evaporators.

Jacket: It is defined as casing or envelope with outer pan.

5.1 INTRODUCTION

Evaporation is the process by which liquid water goes directly to the vapor phase due to an increase in temperature. The main objective of evaporation is to get a concentrated product by vaporizing volatile liquid. Evaporators are generally used to carry out the evaporation process. Evaporation is conducted by non volatile solute and volatile solvent to produce thick liquor. Rate of evaporation is controlled by rate of heat transfer.

When heat is applied in solution, the movement of the molecules increases and the molecules present in the surface overcome the surface tension of the liquid and evaporate because the surface molecules have less cohesive force than the others.

Evaporation differs from distillation because in distillation vaporization take place at the boiling point while in evaporation vaporization take place below the boiling point.

5.2 OBJECTIVES OF EVAPORATION

Evaporation is done

1. To get concentrated product
2. To remove water from aqueous solution
3. To evaporate seawater for developing drinking water
4. To get solid free water which is used in boilers for chemical processes.

5.3 APPLICATIONS OF EVAPORATION

1. Evaporation is generally used in pharmaceutical industries, chemical industries for manufacturing of bulk drugs.
2. Evaporation is used in manufacture of galencial preparartions.
3. Evaporation is used in manufacture of biological products (such as insulin)
4. Evaporation is used for preparation of blood products (such as blood plasma and serum).
5. Evaporation is used for preparations of enzymes, hormones and antibiotics
6. Evaporation is used to get demineralized water used for drinking purpose.
7. Evaporation is used to prepare liquid extract or soft extracts.

5.4 FACTORS INFLUENCING EVAPORATION

1. **Temperature :** The evaporation rate directly related to the temperature. As the temperature increases, the rate of evaporation also increases. Because the temperature is rising, the water molecules begin to move faster. As the kinetic energy acquired by the molecules and they escape from the surface to vapour state. Heat is needed to provide the latent heat of vaporization, and in general, the rate of evaporation is controlled by the heat transfer rate. The rate of heat transfer depends on the temperature gradient.
2. **Surface area:** The rate of evaporation is directly proportional to the surface area of the vessel exposed to evaporation.
3. **Agitation:** Agitation is necessary for evaporation.
4. **Vapour pressure:** Liquids with low boiling point evaporate quickly due to high vapour pressure.
5. **Type of product required:** The selection of the method and apparatus to be used for evaporation depends upon type of product required. For example open pan produce liquid or dry concentrate while film evaporator yields liquid concentrate.
6. **Density.** As the density increases, the rate of evaporation decreases.
7. **Time of evaporation:** Exposure to a relatively high temperature for a short time may be less destructive of the active ingredients than a lower temperature with exposure for a longer period. Film evaporators have used a fairly high temperature but the exposure time is very short.
8. **Economic factors:** When selecting the method and apparatus the economic factors are important. Evaporators are designed to give maximum heat transfer to liquid.
9. **Moisture content:** Some drug constituents decompose more rapidly in the presence of moisture, especially at raised temperature. Hence, evaporation should be carried out at a low controlled temperature

Table 5.1 Differences Between Evaporation And Other Heat Process

Evaporation	Other heat process (boiling/ drying)
A process in which a substance changes its state from the liquid state to the gaseous state without boiling	1. **Boiling** process in which a substance changes its state from the liquid state to the gaseous state 2. Drying is typically the word used to describe the removal of water from a substance 3. Distillation include transforming liquid to gas by heating and condensing the liquid.

Evaporation	Other heat process (boiling/ drying)
Evaporation take place at all temperature	1. Boiling take place at a fixed temperature. 2. drying take place at the temperature below its boiling point. 3. In distillation liquid vaporize at the boiling point
Evaporation is a slow process	Boiling, drying and distillation is a quick process.
It take place on the surface of liquid	1. Boiling takes place throughout the liquid 2. Distillation does not occur only at the surface
No bubbles formation take place	On boiling bubbles formation take place
Rate of evaporation increases with decreasing atmospheric pressure	Decrease atmospheric pressure lower boiling point
Evaporation is generally carried out on liquid material	Drying are generally carried out on solid material
Evaporation is not a separation technique	Distillation is also a separation technique

5.5 CLASSIFICATION OF EVAPORATORS

Classification of evaporators

- **Evaporators having heating medium in jacket (Ex. Steam jacketed kettle)**
- **Evaporators having horizontally placed tubes (Ex. Horizontal tube evaporator)**
- **Evaporators having long tube with natural circulation (Ex. Climbing film evaporator)**
- **Evaporators having long tube with forced circulation (ex. Forced circulation evaporator)**
- **Multiple Effect Evaporator**

Figure 5.1: Classification of evaporators

5.6 STEAM JACKETED KETTLE

It is also known as evaporating pan.

Principle

The mechanism involved in this evaporation process is conduction and convection. The material is placed in jacketed kettle. Steam provide heat to a jacketed kettle in which the aqueous extract is placed. The raised temperature increases the tendency of the solvent molecules to escape into the vapors.

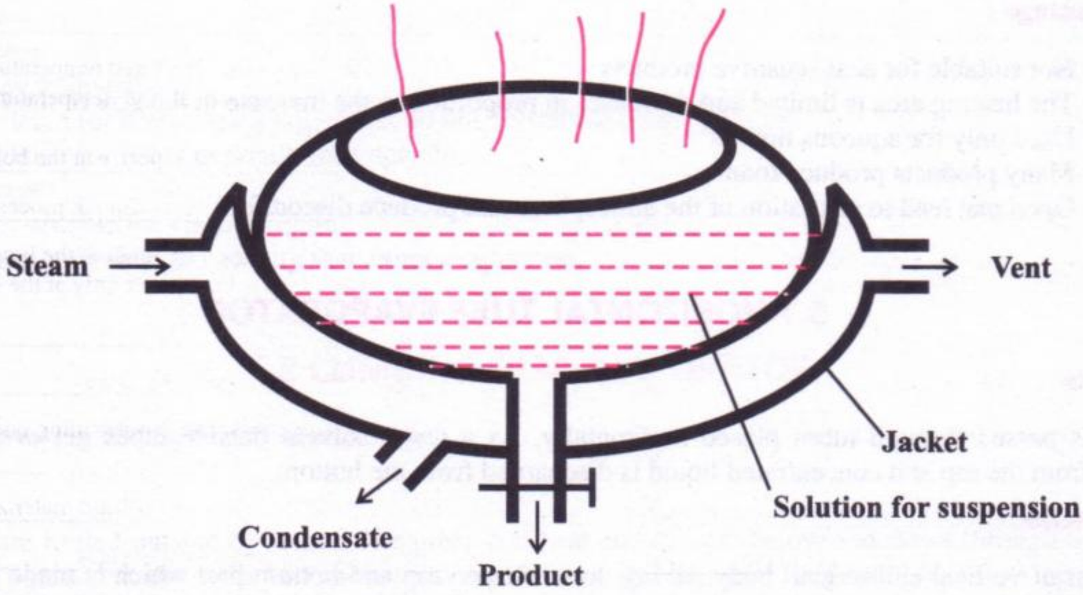


Figure 5.2: steam jacketed kettle

Construction

The apparatus consists of a hemispherical, or shallower pan which is made of copper or stainless steel. Copper is an excellent material for the kettle, because of its good conductivity. The hemispherical shape provide best surface for heating and vaporization. It is surrounded by a jacket with steam inlet. Steam jacket is also attached to condensate outlet and vent for non condensed gases. The kettle is also fitted with outlet at the bottom for discharge of product.

Working

The solution or suspension is placed into the kettle. Steam is allowed to enter through inlet which provide heat to solution or suspension. The condensate leaves through outlet. On small scale kettle is used and also agitation is done manually or mechanically by stirrer. The final product (concentrated product) is collected from the bottom.

Pharmaceutical Applications

1. It is suitable for concentrating aqueous liquids.
2. It is also suitable for concentrating thermo stable liquors.

Advantages

1. Simple in construction
2. Easy to operate
3. Maintenance and installation cost is low
4. Product can be easily removed
5. Used for small scale and large scale operations

Disadvantage

1. Not suitable for heat sensitive products
2. The heating area is limited and decreases in proportion to the increase in the size of the Pan.
3. Used only for aqueous liquids
4. Many products produce foam.
5. Open pan lead to saturation of the atmosphere and produce discomfort.

5.7 HORIZONTAL TUBE EVAPORATOR

Principle

Steam is passed through tubes placed horizontally. As a result solvent outside tubes get evaporated and passed from the top and concentrated liquid is discharged from the bottom.

Construction

It consist of vertical cylindrical body having dome shaped top and bottom part which is made of cast iron. The lower part of cylindrical body is fitted to steam inlet and outlet for condensate. Inside the cylinder horizontal tubes are placed. Horizontal tubes are 6 to 8 in number and made of stainless steel. The lower portion also consist of vent for non condensed gases. Feed inlet is also provided. At the top of the vessel there is one outlet for vapour and concentrated product is discharged from the bottom of the body.

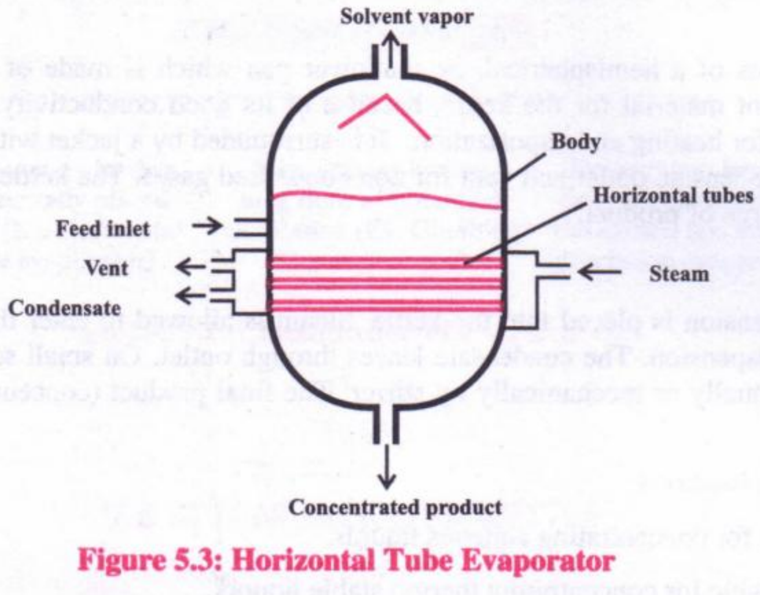


Figure 5.3: Horizontal Tube Evaporator

Working

Feed is introduced through inlet. Steam is also introduced into the body. Therefore tubes get heated. The condensate pass through outlet. The heat is absorbed by the feed and solvent get evaporated. The vapour formed pass through outlet at the top of the body. The process repeat to get concentrated product which is collected from the bottom.

Uses

1. Horizontal tube evaporator is used in pharmaceutical, pulp and paper industry.
2. Also used for making distilled water for boiler feed

Advantages

1. Cheap
2. Easy to install
3. Suitable for non viscous liquid that do not crystallize on evaporation
4. Suitable for batch or continuous operation

Disadvantage

1. Not suitable for viscous liquid
2. They have smaller capacity than other evaporators

5.8 CLIMBING FILM EVAPORATOR

It is also known as **Rising Film Evaporator**

Principle

The tubes are heated outside by steam. The preheated heat enters from below and flows through the heated tubes. The liquid near the walls becomes steam and forms small bubbles. Larger bubbles flow up with slag and strikes deflector. Deflector throws concentrate down.

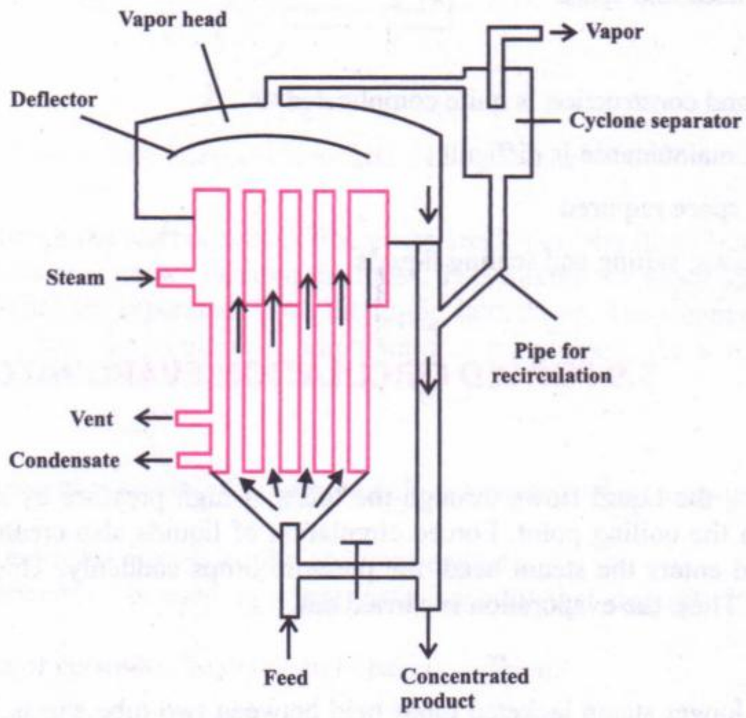


Figure 5.4: Climbing Film Evaporator

Construction:

Heating unit consists of steam jacketed tubes. Long and narrow tubes are held between the two plates. Deflector is placed at the top of the vapour head. There is also the provision of Inlets for steam & feed. Outlets are provided for vapour, concentrated product, non condensed gases & condensate. A cyclone separator is placed at the top of vapour head.

Working

The preheated liquid enters from the bottom. Steam is passed into the unit through the inlet provided. Through the wall, heat is transferred to the liquid. As a result, liquid becomes vapor. Small bubbles are formed that merge or fuse to form large bubbles. The slug of liquid is blown up into the tubes. As a result, the liquid will spread like a film on the walls. This film of liquid vaporizes continuously and finally a concentrated product is obtained that can be collected from the bottom. The vapor eject from the top of the unit.

Uses:

Insulin, liver extracts, vitamins, foaming liquids, corrosive solutions can be concentrated by using Climbing Film Evaportaor.

Advantages:

1. Large area for heat transfer due to large tubes
2. Suitable for heat sensitive materials
3. Used for foam forming liquids
4. Instrument need less space

Disadvantages:

1. Expensive and construction is quite complicated
2. Cleaning & maintenance is difficult
3. Large head space required
4. Not for viscous, salting and scaling liquids

5.9 FORCED CIRCULATION EVAPORATOR

Principle

In forced circulation, the liquid flows through the tubes at high pressure by means of a pump. Therefore, there is elevation in the boiling point. Forced circulation of liquids also creates agitation. When the liquid leaves the tubes and enters the steam head, the pressure drops suddenly. This leads to the flashing of the super heated liquor. Thus, the evaporation is carried out.

Construction

The unit consist of longer steam jacketed tubes held between two tube sheets. Tubes are 2.5 meter long. A pump is used to force liquid to the tubes with high velocity. The pump force liquid through tubes into the flash chamber or vapor head. The flash chamber consist of deflectors. The vapor head is also joined to return pipe.

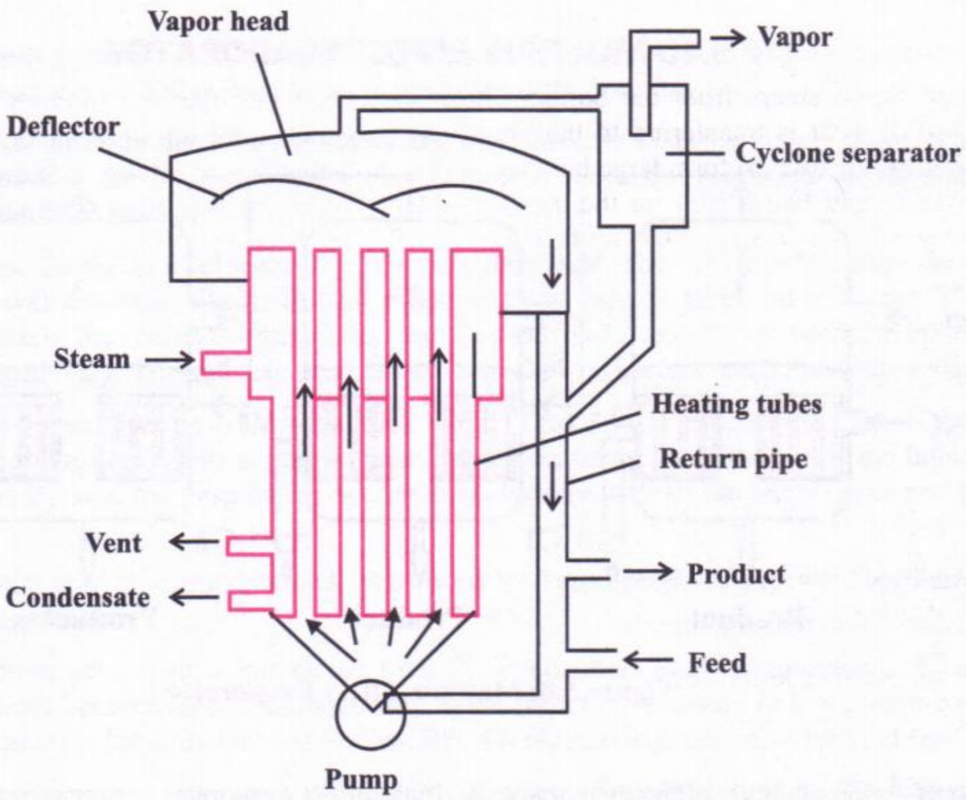


Figure 5.5: Forced Circulation Evaporator

Working

Steam is passed into the unit through the inlet provided. The pump sends the feed (liquid) to the tubes at high velocity. The liquid rises and boils as it passes through the tubes. This mixture of vapor and liquid strikes to the deflector. The vapour and liquid get separated. Then the liquid falls down. The steam enters the cyclone separator and leaves the unit. Thus, the continuous circulation is maintained. As a result concentrated product is formed which is collected.

Uses

1. Forced circulation evaporator is suitable for thermolabile substances when evaporation is conducted under reduced pressure
2. This method is used to get concentrated insulin and liver extracts.
3. Forced circulation evaporator is used to concentrate material that deposit crystalline solid on evaporation
4. Suitable for evaporation of corrosive, foaming and viscous solution.

Advantage

1. There is a rapid liquid movement due to high heat transfer coefficient.
2. Forced circulation does not cause salting, scaling and fouling.
3. It is suitable for the viscous preparation because pumping mechanism is used.

Disadvantage

1. Equipment cost is high due to additional pump requirement
2. Not suitable for salting solutions.

5.10 MULTIPLE EFFECT EVAPORATOR

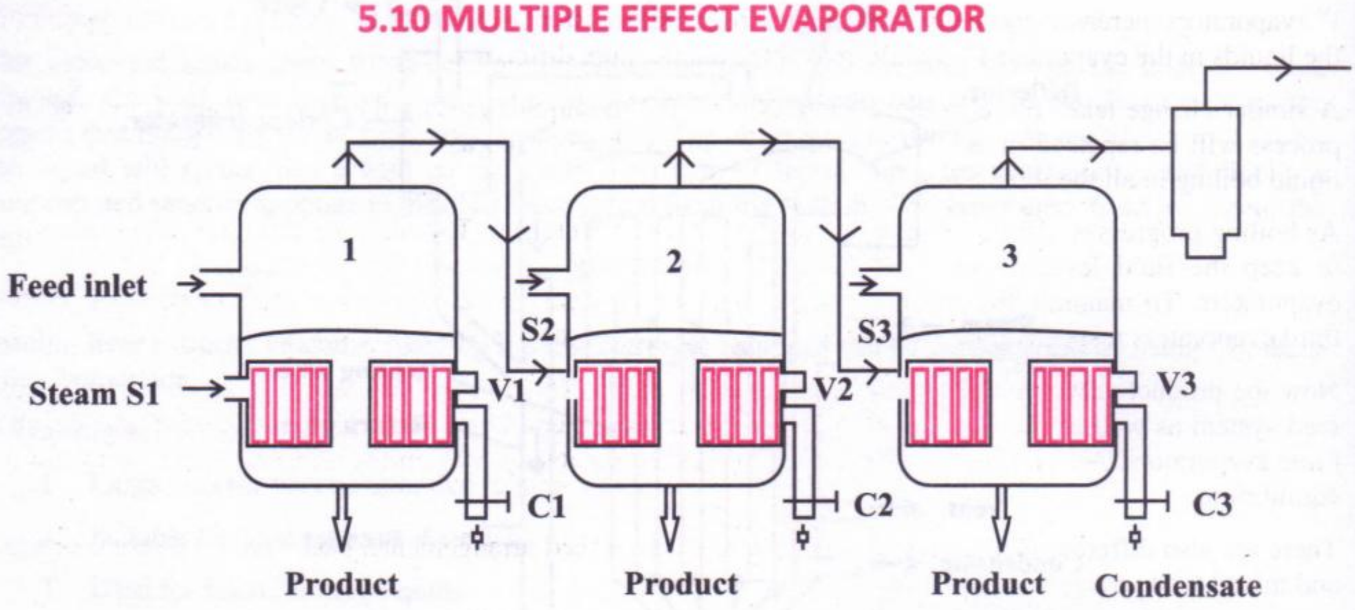


Figure 5.6: Multiple Effect Evaporator

It is the modification of single effect evaporator. A single-effect evaporator wastes energy. The latent heat of the vapor is not used but discarded. However, much of this latent heat can be recovered and reused by employing a multi-effect evaporator.

Construction

It consist of three evaporators therefore it is also called triple evaporator. The vapor from the first evaporator serves as heating medium for the second evaporator. Similarly vapor from the second evaporator serves as a heating medium for the third evaporator. Third evaporator is connected to a vacuum pump.

Working

In this method, the feed (hot liquid solution) is introduced into the three evaporators. Parallel feed arrangement method is used. The vent valves V1, V2 and V3 are kept open. Now, a high vacuum is created by starting the vacuum pump. The steam valves S1 are open through which steam is supplied. The steam first replaces the cold air in the vapor space of the 1st evaporator. When all the cold air is removed, the V1 valves are closed. The condensate valves are also open. The steam supply continues until the desired pressure P_0 is reached in the steam space of the first evaporator. At this pressure, the temperature of the steam is noted t_0. The steam get condensed and the condensate is discharged through the valve C1. Due to the heat transfer, the temperature rises and the liquids reach at the boiling point. During this process, vapor generated. The vapor formed displaces the air in the upper part of the 1st evaporator. After the complete displacement of the air by the vapor in the steam compartments of the second evaporator, the valves V2 is closed.

The vapor of the 1st evaporator transmits its heat to its liquids of the 2nd evaporators and condensed, the condensate is evacuated by the valve C2. These steps continue in the 3rd evaporator also.

As the liquid in the Ist evaporator gains temperature, the temperature difference between the liquids and the vapor decreases, so that the rate of condensation decreases. As a result, the pressure in the vapor space of the

I[st] evaporators increases gradually to P_1 and the rising temperature is noted as t_1, which is the boiling point of the liquids in the evaporator I[st] and decreases the temperature difference (t_0 - t_1).

A similar change takes place in the 2[nd] evaporators and the liquids reach at the boiling point. Similarly, the process will be repeated in the 3[rd] evaporators. Finally three evaporators reaches to steady state with the liquid boiling in all the three bodies.

As boiling progresses, the liquid level in the I[st] evaporator decreases. The feed is fed through the feed valve to keep the fluid level constant. Similarly, the evaporation of liquids takes place in the 2[nd] and 3[rd] evaporators. To maintain the constant liquid level, the feed valves F2 and F3 are used for the second and third evaporators respectively. This process is continued until the evaporators reach the desired viscosity.

Now the product valves are open to collect the thick liquid. Thus, in this evaporator, there is a continuous feed system as well as the continuous supply of steam and a continuous withdrawal of the liquid from the three evaporators. As a result, the evaporators operate continuously with all the temperature and pressure in equilibrium.

There are also different feed arrangements such as forward feed arrangements, backward feed arrangements and mixed feed arrangements .

In forward feed arrangement, feed is introduced from I[st] Evaporators to 2[nd] evaporator to 3[rd] evaporator. Pumping is not required because feed is automatically move from high pressure to low pressure evaporator. This method is also suitable for scale forming liquids. But this method is not suitable for cold feed.

In backward feed arrangement is reverse of forward feed arrangement (i.e from 3[rd] evaporator to 2[nd] evaporator and then to I[st] evaporator). This type of arrangement is suitable for cold feed and viscous preparations. But in this case pumping is required as liquid is moving from low pressure to high pressure evaporator.

In mixed feed arrangement, feed enter into 2[nd] evaporator and then goes to 3[rd] and I[st] evaporators.

Use

This is suitable for scale forming liquids.

Advantages

1. It is suitable for continuous operation.
2. It is economical when compared with single effect evaporator.
3. Product is obtained at lowest temperature.

Disadvantage

1. It is not suitable for cold feed

5.11 ECONOMY OF MULTIPLE EFFECT EVAPORATOR

The economy of an evaporator is expressed as quantity of vapour produced when one unit steam is supplied. This is true if feed is entered or supplied at its boiling point. In this case no more heat is required to raise the temperature. When 1 lb of steam condense in first effect will evaporate 1 lb of water, the vapour of which condensing in second effect, will evaporate 1 lb of water in that effect. Similarly 1lb of vapour liberated in second effect will evaporate 1 lb of water in third effect. As a result liquid undergo vaporization by receiving heat. So there is no loss of heat.

In multiple effect evaporator, the economy equals to

$$\frac{\text{N unit of vapour produced}}{\text{One unit of steam supplied (i.e. One unit of steam produces vapors many times, depending on evaporators connected)}}$$

For example: one unit of steam evaporates 3 units of vapour in case of triple effect evaporator. Therefore economy of multiple effect evaporator is N times to the single effect evaporator.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

1. **Define evaporation**

   Answer- It is the process by which liquid water goes directly to the vapor phase due to an increase in temperature.

2. **Write objective of evaporation**

   Answer- Evaporation is done

   a. To get concentrated solution
   b. To remove water from aqueous solution
   c. To evaporate seawater for developing drinking water
   d. To get solid free water which is used in boilers for chemical processes.

3. **Explain the term Economy of an evaporator.**

   Answer- It is expressed as quantity of vapour produced when one unit steam is supplied.

4. ***Name the Evaporators with long tubes and with natural circulation***

   Answer- Climbing Film Evaporator.

5. **Name the Evaporators with long tubes and with forced circulation**

   Answer- Forced circulation Evaporator

SHORT ANSWER QUESTIONS

1. Write difference between evaporation and other heat process

Evaporation	Other heat process (boiling/ drying)
A process in which a substance changes its state from the liquid state to the gaseous state without boiling	1. **Boiling** process in which a substance changes its state from the liquid state to the gaseous state 2. Drying is typically the word used to describe the removal of water from a substance 3. Distillation include transforming liquid to gas by heating and condensing the liquid.
Evaporation take place at all temperature	1. Boiling take place at a fixed temperature. 2. drying take place at the temperature below its boiling point.

	3. In distillation liquid vaporize at the boiling point
Evaporation is a slow process	Boiling, drying and distillation is a quick process.
It take place on the surface of liquid	1. Boiling takes place throughout the liquid 2. Distillation does not occur only at the surface
No bubbles formation take place	On boiling bubbles formation take place
Rate of evaporation increases with decreasing atmospheric pressure	Decrease atmospheric pressure lower boiling point
Evaporation is generally carried out on liquid material	Drying are generally carried out on solid material
Evaporation is not a separation technique	Distillation is also a separation technique

3. How rate of evaporation affected by temperature?

Answer- The evaporation rate directly related to the temperature. As the temperature increases, the rate of evaporation also increases. Because the temperature is rising, the water molecules begin to move faster. As the kinetic energy acquired by the molecules and they escape from the surface to vapour state. Heat is needed to provide the latent heat of vaporization, and in general, the rate of evaporation is controlled by the heat transfer rate. The rate of heat transfer depends on the temperature gradient.

4. Liquids with low boiling point evaporate quickly. Why?

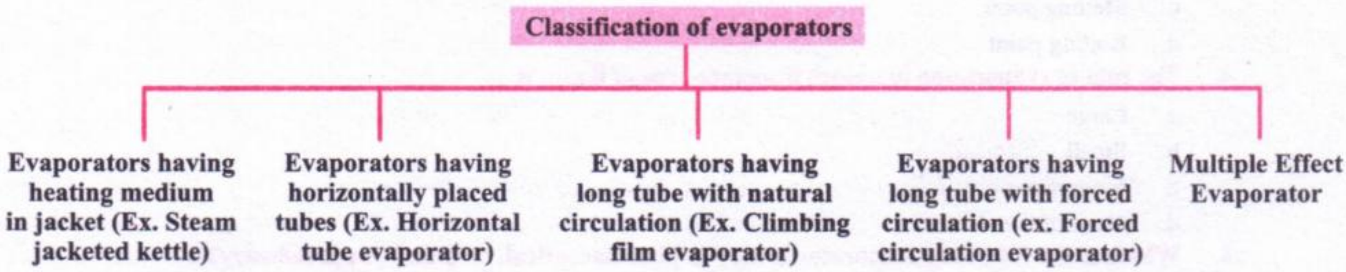
Answer- Due to high vapour pressure, Liquids with low boiling point evaporate quickly. Boiling point and evaporation have an inverse relationship, that is, the higher the boiling point of a substance, the lower is the rate of evaporation.

5. Explain the principle of Forced Circulation Evaporator

Answer- In forced circulation, the liquid flows through the tubes at high pressure by means of a pump. Therefore, there is elevation in the boiling point. Forced circulation of liquids also creates a form of agitation. When the liquid leaves the tubes and enters the steam head, the pressure drops suddenly. This leads to the flashing of the super heated liquor. Thus, the evaporation is carried out.

6. Classify evaporator with example

Answer-



LONG ANSWER QUESTIONS

1. Define evaporation. Explain factors influencing evaporation
(Refer article 5.4)
2. With diagram, explain advantages, disadvantages and uses of steam jacketed kettle
(Refer article 5.6)
3. Describe the principles, construction, working, uses, merits and demerits of horizontal tube evaporator.
(Refer article 5.7)
4. Describe the principles, construction, working, uses, merits and demerits of climbing film evaporator.
(Refer article 5.8)
5. Describe the principles, construction, working, uses, merits and demerits of forced circulation evaporator.
(Refer article 5.9)
6. Explain the working of multiple effect evaporator.
(Refer article 5.10)
7. Write detailed note on
   a. Economy of multiple effect evaporator
   (Refer article 5.11)
   b. Application of evaporation
   (Refer article 5.3)

MULTIPLE CHOICE QUESTIONS

1. Which of the following Statement related to process of evaporation that is incorrect

a. Evaporation occurs at any temperature
b. Evaporation takes place within liquid
c. Evaporation is a slow process
d. No bubbles are formed in liquid during evaporation

2. Which of following factors do not affect rate of evaporation?

a. Temperature of liquid
b. Humidity of surrounding air
c. Depth of liquid
d. Surface of liquid

3. Evaporation take place at

a. All temperature
b. Freezing point
c. Melting point
d. Boiling point

4. The rate of evaporation increases if surface area of liquid is

a. Large
b. Small
c. Moderate
d. None of the above

5. Which of the following evaporator is used in pharmaceutical, pulp and paper industry?

a. Horizontal tube evaporator
b. Steam jacketed kettle
c. Climbing film evaporator
d. Forced circulation evaporator

6. Which of the following evaporator is also known as Rising Film Evaporator

a. Horizontal tube evaporator
b. Steam jacketed kettle
c. Climbing film evaporator
d. Forced circulation evaporator

7. Which of the following feed arrangement is /are used in multiple effect evaporator?

a. Parallel feed arrangement
b. Forward feed arrangement
c. Mixed feed arrangement
d. All of the above

8. Which of the following evaporator is suitable for thermolabile substances when evaporation is conducted under reduced pressure?

a. Forced circulation evaporator
b. Multiple effect evaporator
c. Steam jacketed kettle
d. Both b and c

ANSWERS

1.b 2.c 3.a 4.a 5.a 6.c 7.d 8.a

6 CHAPTER DISTILLATION

Selected Definitions

Distillation: It is defined as the process of separation of the constituents of a mixture by vaporization and further recovering the liquid at other place by condensation.

Distilland: It is the feed liquid in distillation apparatus which is to be distilled

Condensate or distillate: The liquid which is collected by condensation is called condensate.

Distilled water: It is the water in which impurities are removed through distillation.

Reflux: It is the part of condensate which goes back to the column.

Reflux ratio: It is the ratio of reflux to product.

Molecular distillation: It is defined as distillation process in which molecules travels mean free path without coming into collision with one another by applying vacuum and also condensed separately.

Mean free path: It is defined as the average distance travelled by single molecules in a straight line without any collision

Rectification: It is the process of separation between components of the mixture containing miscible volatile liquids having different but close boiling points.

6.1 INTRODUCTION

Distillation can be defined as the process of separation of the constituents of a mixture by vaporization and further recovering the liquid at other place by condensation. The feed liquid in distillation apparatus which is to be distilled is called distill and while liquid collected by condensation is called condensate or distillate. Distillation is used to separate volatile components from non volatile components or to separates a mixture of liquids with different boiling points. Distillation is also used to purify liquid mixtures.

Distillation differs from evaporation and drying. In distillation, condensation vapor is required as product while in evaporation the concentrated liquid residue is final product and in drying, dried solid residue is used as product.

6.2 APPLICATIONS

Distillation is most widely used in pharmaceutical practice. The various applications are

1. Distillation method is used for preparation of distilled water
2. Steam distillation is used for separation of volatile oil from vegetable drugs such as cloves and eucalyptus oils
3. Azeotropic distillation is used to get absolute alcohol
4. The process is also used for recovery of solvents from crude drugs extract for the preparation of galencials.
5. For purification of organic solvents, distillation is used.
6. In petroleum industry, using flash distillation method, the crude oil is separated into different fractions.
7. Molecular distillation methods are used to purify different organic compounds.
8. Distillation methods are used to estimate alcohol content in dosage form such as elixirs

6.3 CLASSIFICATION OF DISTILLATION METHODS

These distillation methods are used on laboratory scale as well as on industrial scale

1. Simple distillation
2. Flash distillation
3. Fractional distillation
4. Distillation under reduced pressure
5. Steam distillation &
6. Molecular distillation

6.4 SIMPLE DISTILLATION OR DIFFERENTIAL DISTILLATION

In this process vapor is removed from the system as soon as it is formed and condensed. Simple distillation is preferred for purification and separation of liquids having high volatility. The Rayleigh Equation is useful in the analysis of simple distillation.

$$\text{In}\left[\frac{L_1}{L_2}\right] = \int_{x_2}^{x_1} \frac{1}{(y-x)} dx \qquad \textbf{(6.1)}$$

Where

L_1 and L_2 are the total number of moles of the liquid in still before and after distillation.

x_1 and x_2 are the mole fraction of more volatile component in L_1 and L_2 respectively

x and y are obtained by equilibrium diagram. The plot of x vs 1/y-x is drawn to get integrated value by estimating area under curve between limits x_1 and x_2

Apparatus for distillation

It consist of distillation flask or still in which liquid which is to be distilled is boiled. A condenser where vapors are condensed into liquid. Water is circulated through the jacket of condenser. The condenser is attached to receiver by adapter. Receiver is used to collect liquid. A thermometer is also inserted into the cork and attached to the flask. The whole unit is made of glass.

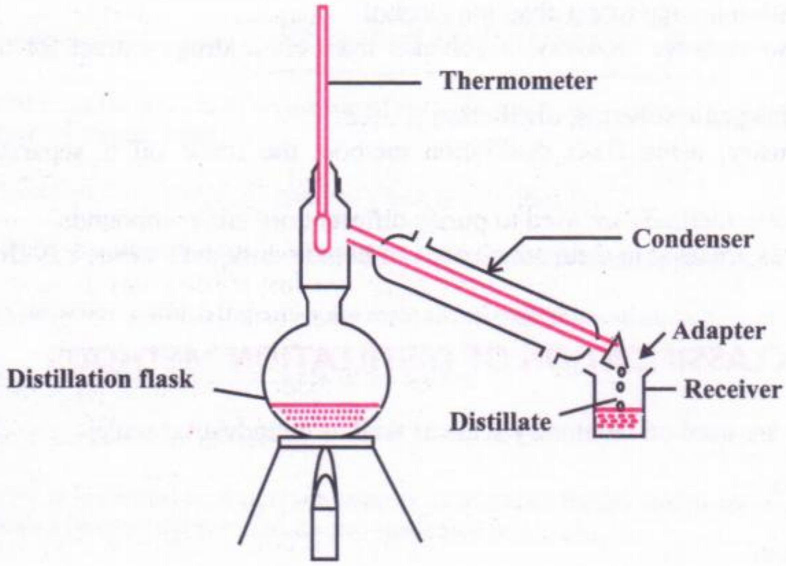


Figure 6.1: Apparatus for simple distillation

The liquid is filled into the flask upto one half to two third of its volume. There may be chances of bumping which is avoided by placing small porcelain piece or pumice stone before distillation. The pumice stone should never be added during distillation or in superheated liquid, it may produce sudden splashing. At laboratory scale, the water bath is maintained at the temperature below 100^0C for distilling liquid with boiling point below 80^0. For inflammable liquids heating mentle are preferred. The liquid starts to boil after some time. At this time the temperature of distillate is observed by thermometer. This temperature is equals to the boiling point of the liquid. As a result vapours start to rise up and pass through condenser. Here vapour is condensed and liquid is collected into the receiver flask. The process is continued.

On large scale still is made of stainless steel or copper. In this case steam is used as heating medium. The steam is circulated into the jacket around the vessel. The thermometer is attached to the still to check temperature of boiling liquid. The still is attached to condenser and to receiver. The metal condenser such as double pipe heat exchangers or tubular heat exchangers are used on large scale.

Applications of simple distillation in pharmacy

1. This is used for preparation of distilled water and water for injection.
2. This process is used to prepare many volatile oils and aromatic water. For example Spirit of nitrous ether and Aromatic Spirit of Ammonia
3. This process is also used to separate non-volatile solid from volatile liquids such as alcohol and ether.

6.5 PREPARATION OF PURIFIED WATER AND WATER FOR INJECTION BP BY DISTILLATION

Natural water is not safe for pharmaceutical purpose because it contain bacteria, dissolved impurities and dissolved gases. Distilled water is the water in which impurities are removed through distillation. Distillation involves boiling the water and then condensing the steam into a clean container. Distilled water is also used in brewing, sugar and starch manufacturing industries. Freshly distilled water is also used for manufacturing of sterile water for injection.

6.5.1 Distilled water still

Today wide range of stills are available in different designs and capacity. These stills can also operated continuously. On small scale metal or neutral glass stills are used. But it is necessary to discard the first and the last portion during processing. The dissolved gases are more volatile than water as they escape in the first portion of the distillate, therefore, must be rejected. Similarly, the last portion may contain volatile portion of the dissolved solid substances, so discarded. The source water usually must be pretreated by one or a combination of following treatment such as Chemical softening, filtration, deionization, carbon absorption, or reverse osmosis purification. The gases such as carbon dioxidein source water should be removed. It contaminate the distillate. Any soluble product should also be avoided. Contamination of distillate by pyrogen should also be avoided.

The distillation unit consist of boiler which is made of cast iron. The baffles and the condenser tubes that comes into contact with product are made of stainless steel or monel metal. At the top there is also provision of removal of gases in water.

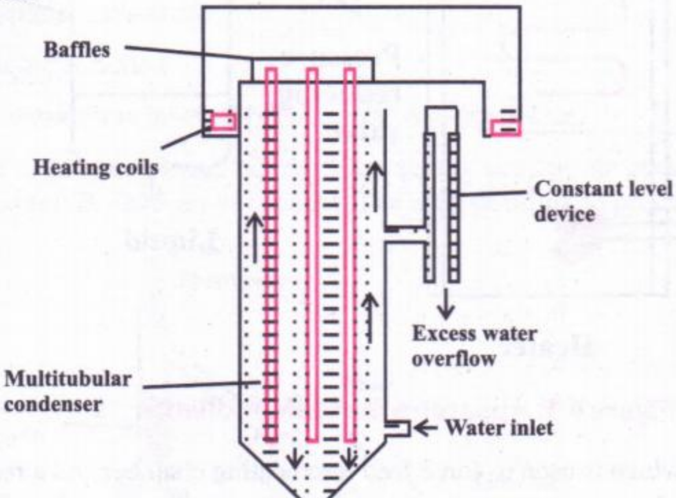


Figure 6.2: Distillation unit for preparation of water for injection

The source water from the tap enters the still through the inlet, which rises in the jacket attached with the number of tubes. The excess water goes through the exit. Some of the hot water at 90 and 95^{0}C enters the boiler through a narrow opening. The water level is maintained in the boiler up to the overflow level. The water is boiled in the boiler by means of heating coils. During heating, the dissolved gases in the condenser can escape through a small opening and only the steam escapes into the condensing tubes. Since dissolved gases are more volatile than water, they escape into the first part of the distillate and must be rejected. Similarly, the last part may contain a volatile part of the solids dissolved in tap water, hence discarded.

6.6 FLASH DISTILLATION OR EQUILIBRIUM DISTILLATION

This is a one-step operation where a liquid is partially vaporized, the vapors are in equilibrium with the residual liquid and the resulting vapors and liquid are separated. This method is used only when the difference between the volatilities of two components are very large.

Principle

Flash distillation is a special operation in distillation, where a liquid mixture is heated and fed with a constant flow into a distillation equipment. The resulting vapor and liquid phases enter into an equilibrium chamber and are drained separately. During the operation, the total pressure and temperature of the system, as well as the compositions of the two phases in the equilibrium remains constant with time.

Apparatus

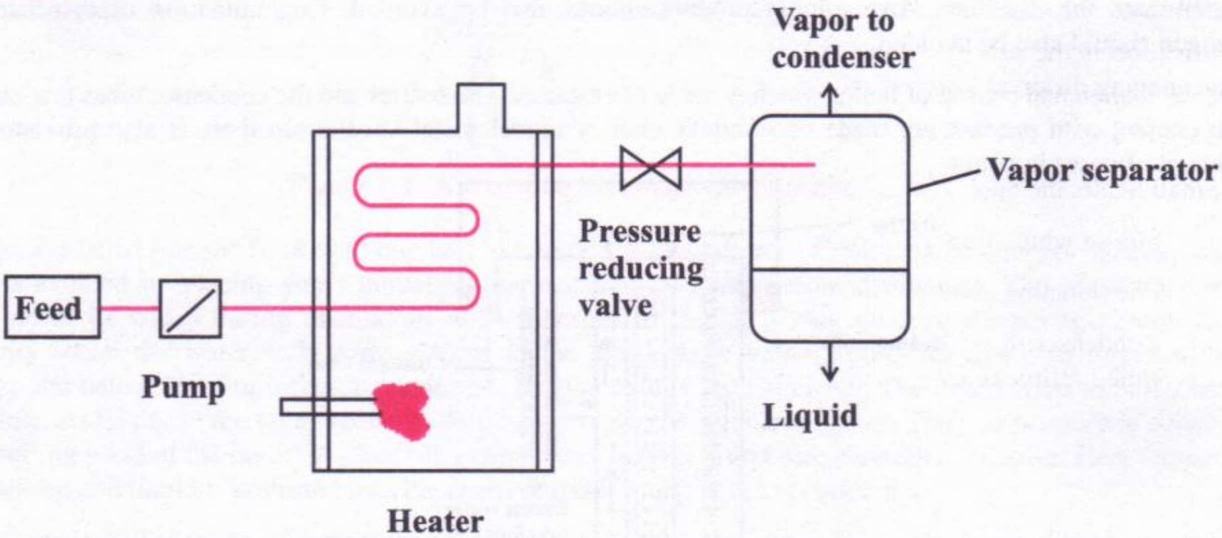


Figure 6.3: Apparatus for flash distillation

The apparatus consist of pump which is used to force feed into heating chamber. As a result feed gets heated. The other end of pipe is attached to vapor separator through pressure reducing valve. Due to pressure drop, hot liquid flashes. The sudden vaporisation cause cooling. The individual vapor phase molecule of high boiling fraction get condensed and low boiling fraction stay as vapor. After some time vapor and liquid phase separate and achieve equilibrium. The apparatus also has provision of vapor outlet at top and liquid outlet at bottom. The liquid is collected from bottom of the separator. At the end of the process, the vapor will be in equilibrium with liquid.

Use

1. Flash distillation is used for components with large relative volatility, or for the separation of components based on the vapour–liquid equilibrium.
2. Flash distillation is most commonly used in petroleum refining industries.

Advantages

1. It is a Continuous process

Disadvantages

1. Not suitable for two component system
2. Not effective in cases where nearly pure components are needed.

6.7 FRACTIONAL DISTILLATION OR RECTIFICATION

Fractional distillation differs from simple distillation because in simple distillation vapour pass through condenser and condensate collected into receiver while in fractional distillation vapour pass through fractionating columns where partial condensation of vapors occur and a part of condensing vapour goes to the still.

Rectification is the process of separation between components of the mixture containing miscible volatile liquids having different but close boiling points.

Construction

On Small Scale, the apparatus consist of

a. Still in which liquid is boiled.
b. Fractionating column: It is inserted between still and condenser.
c. Condenser: It is used to condense vapors. Some part of condensate goes back to the column which is called reflux and rest is obtained as product. The ratio of reflux to product is called reflux ratio.

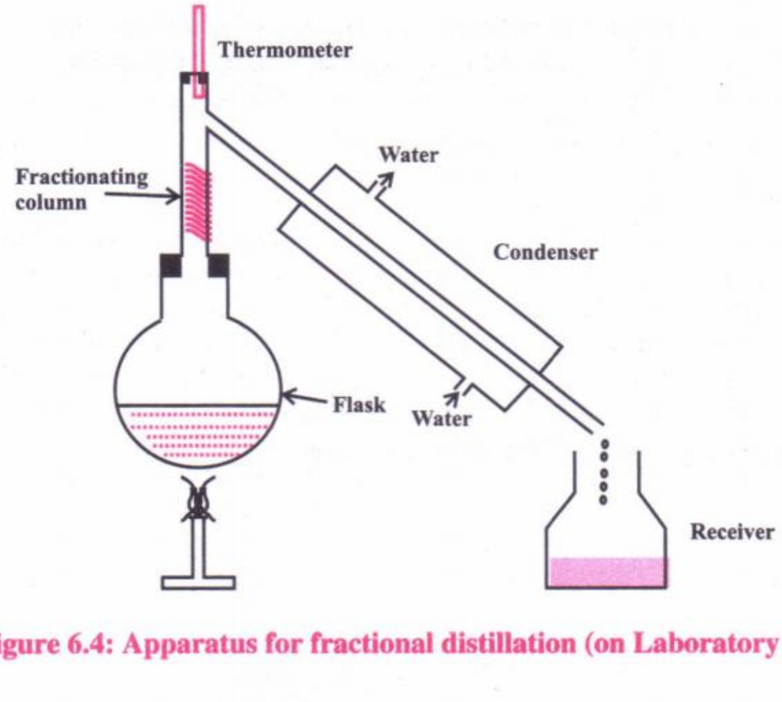


Figure 6.4: Apparatus for fractional distillation (on Laboratory scale)

On large scale, provision is made to supply heat at the bottom of column. At the top of column, a condenser is attached. The fractionating column has large area for providing sufficient flow condition. The top of the column is cooler than the bottom, so that the liquid stream becomes progressively hotter as it descends and the vapor stream becomes progressively cooler as it rises.

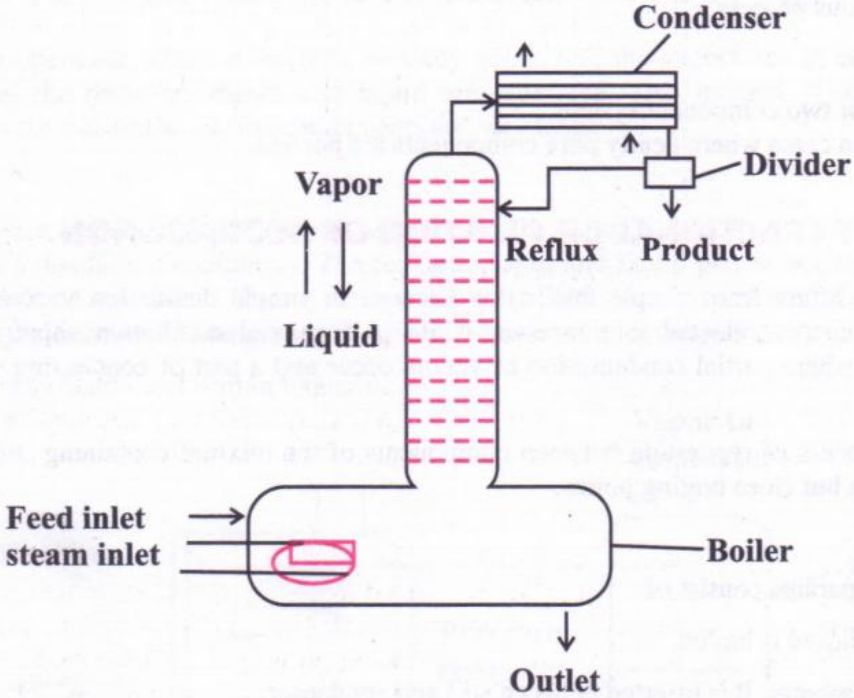


Figure 6.5: Apparatus for fractional distillation (on Large scale)

The efficiency of fractionating column is measured by number of theoretical plates. Smaller the boiling point difference, greater the number of theoretical plates for efficient separation. The heat input to still should also be controlled otherwise packing will remain wet if it is low.

There are different varieties of equipments for rectification

A. Plate column: It is divided into two types.

(i) Bubble cap column

(ii) Sieve-plate column

B. Packed column

A. Plate column:

(1) Bubble cap column is widely used in large distillation plants.

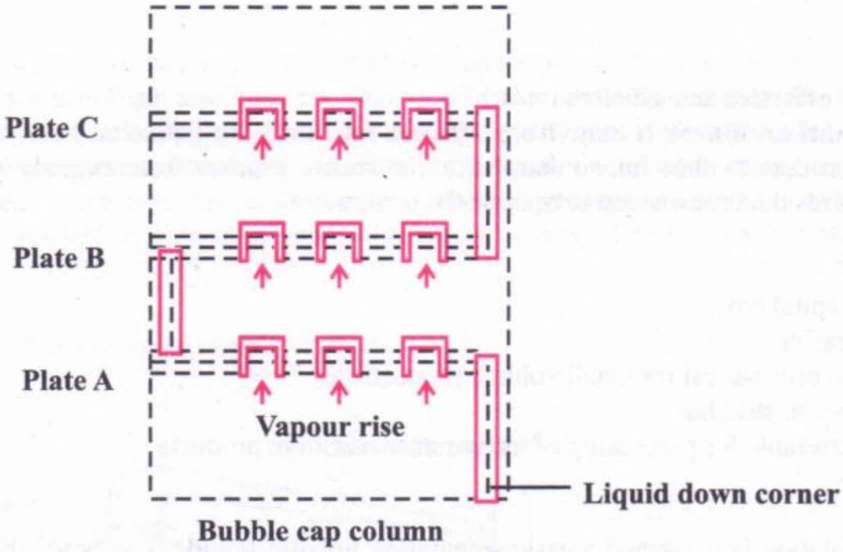


Figure 6.6: Construction of bubble cap column for fractional distillation

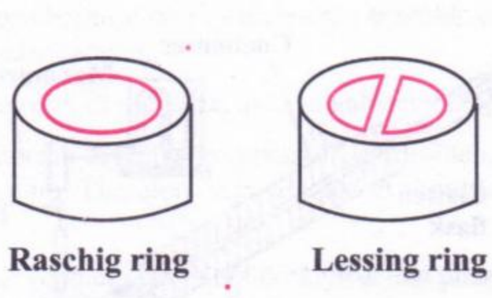
The column is divided into sections by means of a series of *horizontal plates*. Each plate carries a number of *caps* that is secured by bolt with the plate. The edge of the cap is *serrated* or the sides may be *slotted.* Vapor rises from the plate A. This vapor pass through liquid on plate B and partially condensed. The process of condensation and vaporisation continues at plate C.

(2) Sieve plate columns

All the constructions are same as bubble cap columns. Instead of bubble cap plates, flat plates with a large number of relatively small perforations, drilled in them are used. These perforations are usually 3/16 to ¼ inch in diameter. The pressure and velocity of the vapour rising up in the column through these holes and prevent downflow. Now a days Turbo-grid plates are used which consist of number of horizontal bars with narrow slots between them.

B. Packed column

The column is entirely filled with some sorts of material that offers a large surface area supposedly wetted by the liquid. Raschig rings are popular. A *Raschig ring* is a hollow cylinder whose length is equal to its diameter. This may be made of metal, stone ware, ceramics, carbon, plastics, or other materials. Packed columns can be used for corrosive materials. *Berl Saddles* are also used widely. *Lessing Ring* is modified Raschig rings



Advantages

1. Highly effective and efficient
2. Fractional distillation is easy to use. Modern fractional distillation columns have been equipped with microprocessors that fully control the distillation process from beginning to end. Automization minimizes the time needed to operate the equipment.

Disadvantages

1. High capital cost
2. Not flexible
3. It is not economical for small volume productions
4. Not easy to sterilize
5. Not preferable for processing of temperature-sensitive products

Uses

Fractional distillation is a method used in separating volatile liquids. Fractional distillation has been used traditionally in the separation of mixtures and purification of solvents, chemicals and other naturally occurring material. Fractional distillation has found widespread use in oil refineries.

6.8 DISTILLATION UNDER REDUCED PRESSURE OR VACUUM DISTILLATION

In this distillation occur at a temperature below its boiling point by vacuum. Vacuum distillation is preferred when liquids have high boiling point at atmospheric pressure or solutions contain thermolabile substances. Vacuum pumps and sunction pumps are used to reduce pressure on liquid surface.

Principle: The liquid boils when its vapor pressure is equal to the atmospheric pressure. Liquids, which are decomposed at their boiling point at atmospheric pressure, can be distilled at a much lower temperature than their boiling point if the pressure is reduced to the surface of the liquid. Boiling under reduced pressure will also increase the rate of distillation.

Construction and working:

Distillation under reduced pressure (At laboratory scale)

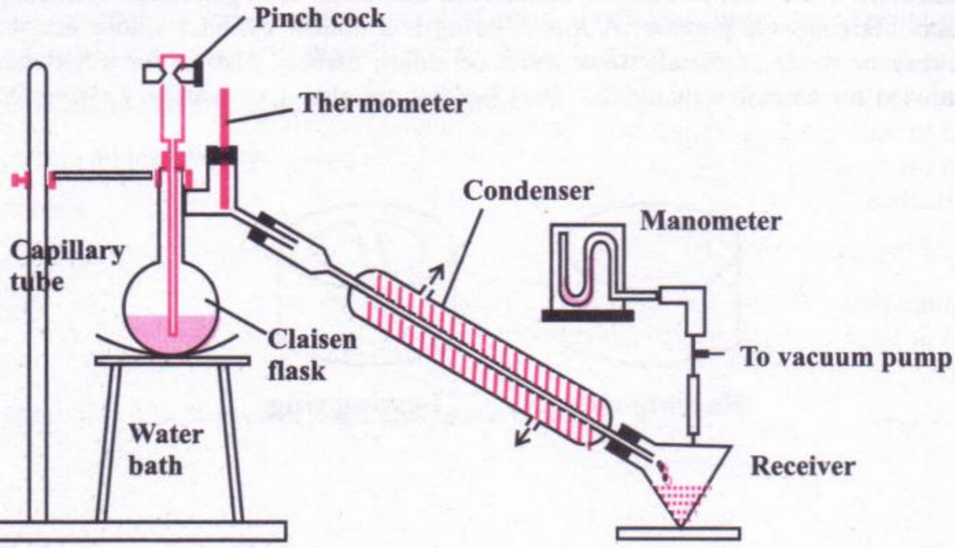


Figure 6.7: Distillation under reduced pressure (at laboratory scale)

The liquid to be distilled is put into flask upto one half to two third of its volume. A porcelain piece is added to prevent bumping. The Claisen flask also have provision of Capillary tube. A thermometer is also inserted in the flask. Water bath is used as heating medium. The required vacuum is applied and contents are heated gradually. Due to rise in temperature liquid get converted into vapors due to vacuum. The claisen flask is attached to receiver through condenser. These vapors pass through condenser. Collect the condensate in the receiver. The receiver is attached to a vacuum pump to reduce pressure. The pressure is measured with the help of a manometer.

Distillation under reduced pressure (At industrial scale)

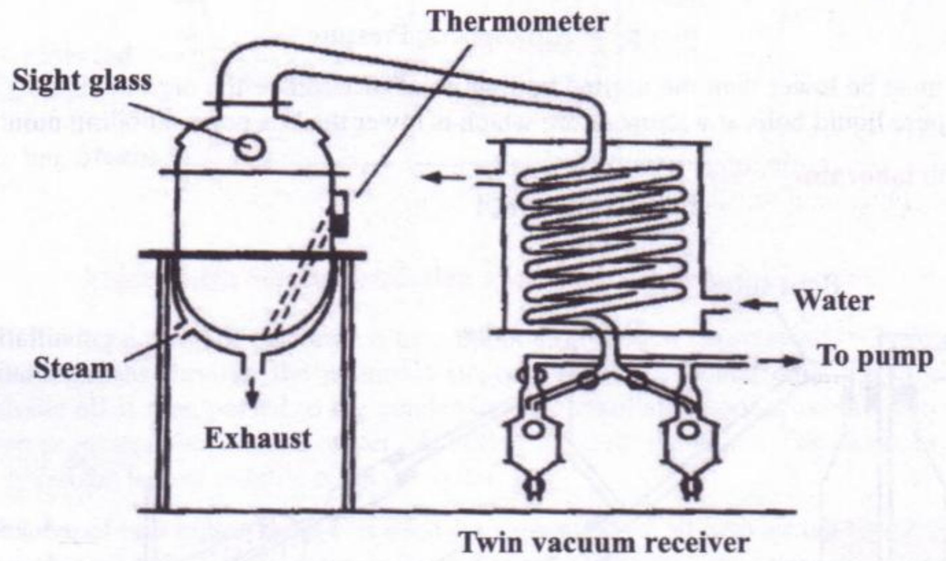


Figure 6.8: Distillation under reduced pressure (at industrial scale)

The vacuum jacket still is made of stainless steel. The still is attached to air vent, a drainpipe at bottom and also to condenser. The liquid to be distilled is attached through pipe with tap. The other end of pipe is attached to liquid reservoir. A thermometer is also inserted into still. Vacuum pump is also attached which generate vacuum. Through steam liquid is gradually heated. Due to rise in temperature liquid get converted into vapors due to vacuum. These vapors pass through condenser. Collect the condensate in the receiver. Here distillation process continues because two receivers are attached so that distillate is collected from one while other is attached to still under vacuum.

Use: This process is used for recovery of menstrua used in galencial preparations

Advantages: Some preparations such as enzymes, vitamins, glycoside and alkaloids undergo decomposition when processed at high temperature. Therefore their extraction should be done at lower temperature under reduced pressure.

Disadvantage: Foaming is major problem in case of biological and plant extracts.

6.9 STEAM DISTILLATION

In steam distillation impure compounds are distilled with the help of steam. This method is applicable to solids as well as liquids. For purification by steam distillation, an impure compound should not decompose at the steam temperature, should have a fairly high vapour pressure at 373 K, should be insoluble in water and the impurities present should be non-volatile.

Principle

Mixture of immiscible liquids begin to boil when the sum of their vapour pressure is equal to atmospheric pressure. Let p_1 represent the vapour pressure of water and p_2 the vapour pressure of the organic liquid. In steam distillation the liquid boils at a temperature at which

$$p_1 + p_2 = \text{Atmospheric Pressure}$$

This temperature must be lower than the normal boiling point of water or the organic liquid. Thus in steam distillation, the impure liquid boils at a temperature which is lower than its normal boiling point.

Apparatus used on laboratory scale

Construction

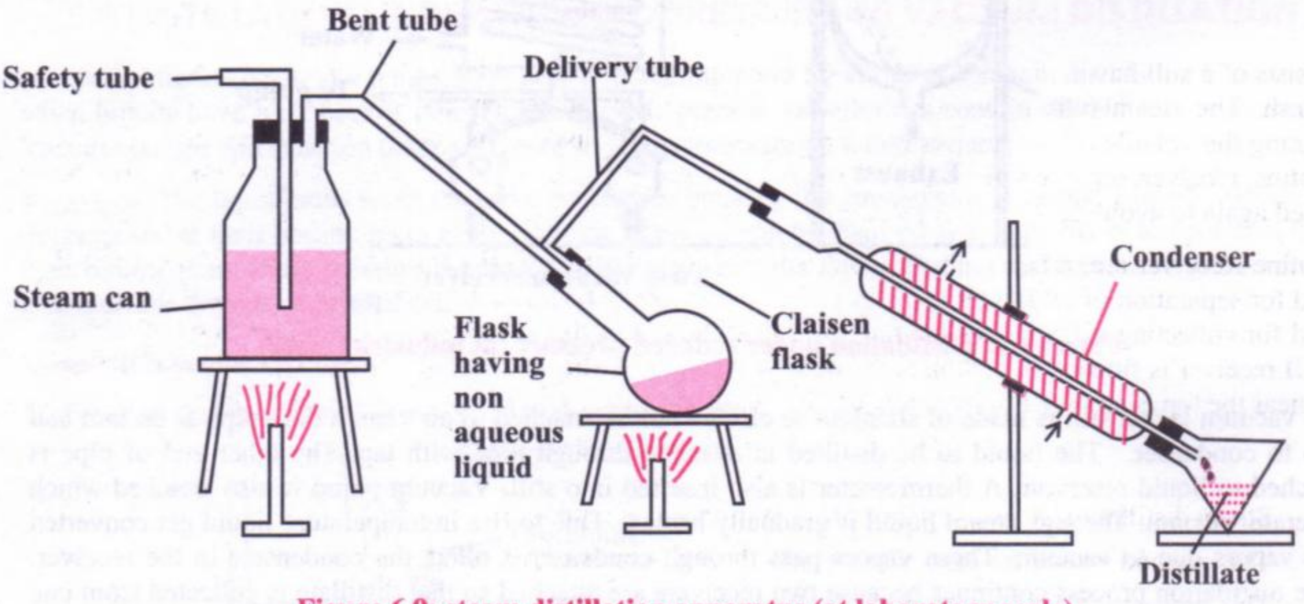


Figure 6.9: steam distillation apparatus (at laboratory scale)

It consist of steam can with two holes. Through one hole safety tube passes to relieve pressure if high pressure generated. Through other hole bent tube is passed whose other end is attached to flask having non aqueous liquid. There is also provision to heat steam can and flask. A delivery tube is also attached to flask and condenser. The condenser is attached to receiver.

Working

Steam can is filled with water. The non aqueous liquid is placed into flask and a small quantity of water is added. The flask is then heated gently. Now steam is bubbled through the contents in the flask. The vapours of the compound mix up with steam and escape into the condenser. The condensate thus obtained is a mixture of water and the non aqueous liquid which can be separated.

Apparatus used on industrial scale

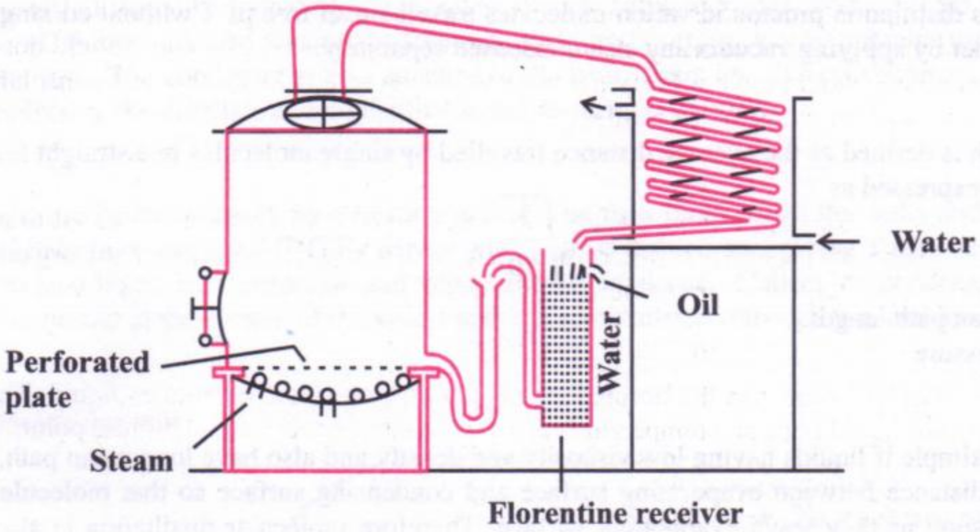


Figure 6.10: Steam distillation apparatus (at industrial scale)

It consists of a still having a mesh or perforation near the bottom. Steam is produced by boiling water below the mesh. The steam passes through the materials (to be extracted) packed over the mesh. The vapour containing the volatile oil is then passed to the condenser. The distillate is collected in Florentine receivers. Florentine receiver separates the oil and water according to their densities. The aqueous phase can be recycled again to avoid the loss of volatile oil in the water.

Florentine Receiver are of two types: Type-I is used for separation of oil heavier than water. While Type-II is used for separation of oil lighter than water. In Type-I receiver, the tap fitted near the bottom of the vessel is used for collecting oil, whereas the tap fitted near the top of the vessel is used for water to overflow. In Type-II receiver is fitted with siphon at the bottom that works when it gets filled with water whereas the tap fitted near the top is an outlet for the flow of oil.

Use:

1. Steam distillation is used for separation of immiscible liquids
2. This method is used for extraction of volatile oils such as clove, eucalyptus.
3. This process is used for preparation of some aromatic water e.g. concentrated rose water

Advantage

1. Steam distillation is useful for extracting most fats, oils and waxes. This process works well for types of substances that do not mix with water, which are known as immiscible substances.
2. Steam distillation is used for oil extraction and also used in the fragrance and essential oil industry

Disadvantage

Steam distillation has the disadvantage of having a higher initial cost for investment in the equipment.

6.10 MOLECULAR DISTILLATION OR EVAPORATIVE DISTILLATION

It is defined as distillation process in which molecules travels mean free path without coming into collision with one another by applying vacuum and also condensed separately.

Principle

Mean free path is defined as the average distance travelled by single molecules in a straight line without any collision. It is expressed as

$$\lambda = \eta\sqrt{\frac{3}{p\rho}} \qquad (6.2)$$

Where λ = mean path length
p = vapour pressure
ρ = density
η = viscosity

Distillation is simple if liquids having low viscosity and density and also have long mean path. There should be minimum distance between evaporating surface and condensing surface so that molecule pass through condenser as soon as they leave evaporating surface. Therefore molecular distillation is also called **short path distillation**. The intermolecular distance should be high which can be achieved by very high vacuum (0.1 to 1.0 pascal)

Apparatus

Falling film Molecular still or wiped film Molecular still

Principle

The liquid film on heated surface under high vacuum produce vapors and then each molecule condensed individually and distillate is collected.

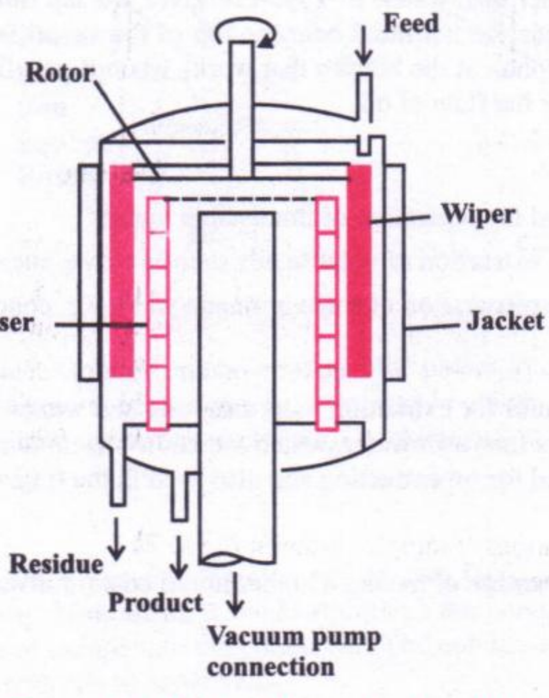


Figure 6.11: Falling film molecular still

Construction

It consist of vessel (1 meter in diameter) and jacket is provided around vessel. Wiper is also attached to the wall of the vessel. Wipers are also attached to rotating head through rotor. Vacuum pumps are connected by a large diameter pipe. The condenser is also attached to the wall. There are also provision are made for feed (at top) and collecting the distillate and undistilled liquid residue (at bottom)

Working

The vessel walls are heated suitably by a heating jacket. The feed flows down the walls and is spread to a film by the polytetrafluoroethylene (PTFE) wipers which move about 3 m/s giving a film velocity of about 1.5 m/s. Due to heat liquid film evaporate and vapors hit the condenser. Collect the condensate as product. The residue is collected at the bottom of the vessel and it is re-circulated (through the feed line).

Centrifugal Molecular still

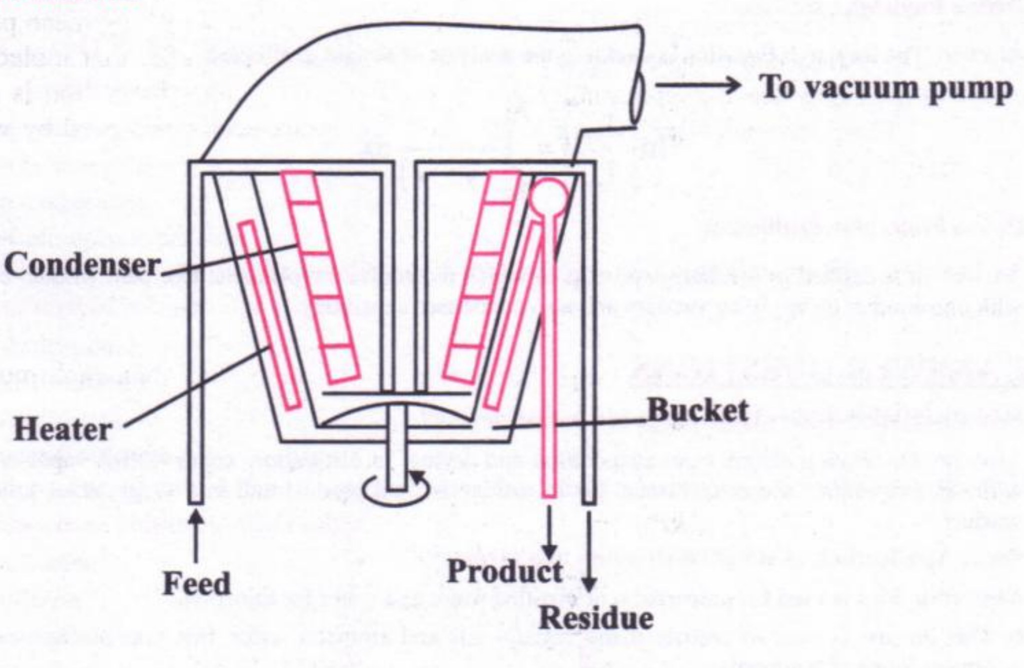


Figure 6.12: Centrifugal molecular still

The feed is introduced into centre of a bucket-shaped vessel (1 to 1.5 m in diameter) that rotates at high speed (by centrifugal action). The film of liquid that is formed moves outwards over the surface of the vessel to the residue-collection pipe. The vessel is heated by radiant heaters. Condensers and a collection device are located close to the inner surface of the rotor. Therefore condensate is collected into other vessel while residue is collected at bottom of vessel which is recirculated through feed pipe for further distillation.

Use

1. For separation of vitamins (example Vitamin A and E)
2. For purification of chemicals
3. For purification of oils

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

1. **Define Distillation**

   Answer- It is defined as the process of separation of the constituents of a mixture by vaporization and further recovering the liquid at other place by condensation.

2. **What do you mean by Mean free path?**

   Answer- It is defined as the average distance travelled by single molecules in a straight line without any collision

3. **What is the difference between distilland and distillate?**

   Answer- The feed liquid in distillation apparatus which is to be distilled is called distilland while liquid collected by condensation is called condensate or distillate.

4. **Define Rayleigh Equation**

   Answer- The Rayleigh Equation is useful in the analysis of simple distillation

$$\ln\left[\frac{L_1}{L_2}\right] = \int_{x_2}^{x_1} \frac{1}{(y-x)}dx$$

5. **Define Molecular distillation.**

   Answer- It is defined as distillation process in which molecules travels mean free path without coming into collision with one another by applying vacuum and also condensed separately.

SHORT ANSWER QUESTIONS

1. **How distillation differs from evaporation and drying?**

   Answer- Distillation differs from evaporation and drying. In distillation, condensation vapor is required as product while in evaporation the concentrated liquid residue is final product and in drying, dried solid residue is used as product.

2. **Write Applications of simple distillation in pharmacy.**

   Answer- a. This is used for preparation of distilled water and water for injection.

   b. This process is used to prepare many volatile oils and aromatic water. For example Spirit of nitrous ether and Aromatic Spirit of Ammonia

   c. This process is also used to separate non-volatile solid from volatile liquids such as alcohol and ether.

3. **Why distilled water is preferred in pharmaceutical industries?**

   Answer- Natural water is not safe for pharmaceutical purpose because it contain bacteria, dissolved impurities and dissolved gases. Distilled water is water in which impurities are removed through distillation. Distillation involves boiling the water and then condensing the steam into a clean container. Freshly distilled water is also used for manufacturing of sterile water for injection.

4. **How Fractional distillation differs from simple distillation?**

   Answer- Fractional distillation differs from simple distillation because in simple distillation vapour pass through condenser and condensate collected into receiver while in fractional distillation vapour pass through fractionating columns where partial condensation of vapors occur and a part of condensing vapour goes to the still.

5. **Why molecular distillation is also called short path distillation?**

   Answer- The minimum distance between evaporating surface and condensing surface is less and therefore molecule pass through condenser as soon as they leave evaporating surface. Therefore molecular distillation is also called short path distillation.

LONG ANSWER QUESTIONS

1. Describe the construction and working of apparatus used in simple distillation process.
   (Refer article 6.4)
2. Describe in detail about the distillation unit used for preparation of water for injection
   (Refer article 6.5)
3. Explain the principle and apparatus used for flash distillation
   (Refer article 6.6)
4. Explain construction and working of apparatus used for fractional distillation on laboratory and large scale
   (Refer article 6.7)
5. Write detailed note on vacuum distillation
   (Refer article 6.8)
6. Explain principles, construction, working, uses, merits and demerits of steam distillation process (on laboratory and large scale)
   (Refer article 6.9)
7. Write down the theory of molecular distillation. How is molecular distillation is carried out?
   (Refer article 6.10)

MULTIPLE CHOICE QUESTIONS

1. Vacuum distillation occur at

a. Temperature below its boiling point
b. High boiling point
c. High temperature
d. High atmospheric pressure

2. When the difference between the volatilities of two components is very large, then which of the following distillation method is used

a. Flash distillation
b. Vacuum distillation
c. Steam distillation
d. Molecular distillation

3. The process of separation between components of the mixture containing miscible volatile liquids having different but close boiling points is called

a. Rectification
b. Distillation
c. Evaporation
d. Condensation

4. The enzymes, vitamins, glycoside and alkaloids are extracted by

a. Steam distillation
b. Distillation under reduced pressure
c. Flash distillation
d. Vacuum distillation

5. Porcelain piece is added into distillation flask before distillation because

a. To avoid chances of bumping
b. to avoid overheating
c. to get uniform mixing
d. to raise the level of liquid in distillation flask

6. In distillation, distillate is

a. Dilute solution
b. liquid which is collected by condensation
c. concentrated solution
d. feed liquid in distillation apparatus

7. If solutions contain thermolabile substances, then which of the following distillation method is preferred?

a. Vacuum distillation
b. Fractional distillation
c. Simple distillation
d. Steam distillation

8. Which equation is useful in the analysis of simple distillation?

a. Rayleigh Equation
b. Haigen Poiseuille's equation
c. Bernoulli's equation
d. Mier's theory

9. In fractional distillation, a large surface area for condensation is provided through

a. still
b. thermometer
c. a fractionating column
d. reflux condenser

10. Which of the following distillation process is also called evaporative distillation

a. Molecular distillation
b. Flash distillation
c. Steam distillation
d. Fractionating distillation

ANSWERS

1.a 2.a 3.a 4.b 5.a 6.b 7.a 8.a 9.c 10.a

7 CHAPTER DRYING

Selected Definitions

Drying: It can be defined as an process in which the liquid, generally water, present in a wet solid is removed by application of heat and finally a liquid free solid product is obtained.

Bound Water: It is the moisture content of a substance that exerts a equilibrium vapor pressure lower than that of the pure liquid at same temperature.

Unbound water: It is the moisture content of a substance that exerts a equilibrium vapor pressure equal to that of the pure liquid at same temperature.

Free Moisture: It is the moisture content of the solid in excess of the equilibrium moisture content

Moisture content: It is measured by ratio of weight of dry sample to ratio of weight of water in sample

Equilibrium Moisture Content (EMC): It is the moisture content of the solid when in equilibrium with the given partial pressure of vapor in the gas phase.

Critical Moisture Content (CMC): The point at which decrease in drying rate start.

Fluidized State: It is the state in which the granules are suspended in the air stream and rise from the bottom.

Isothermal Desorption : It is the process of reducing the residual moisture content to optimum values when drying is continued at warmer temperature.

Desorption: If solid contains more moisture than EMC, then solid will continuously lose water until EMC is reached.

Sorption: If solid contains less moisture than EMC, then solid will continuously absorb water until EMC is reached.

7.1 INTRODUCTION

Drying can be defined as an process in which the liquid, generally water, present in a wet solid is removed by application of heat and finally a liquid free solid product is obtained. Drying is often necessary in various industrial operations to remove moisture from a wet solid. There are different ways to remove liquid. In general, drying is accomplished by thermal techniques and thus involves the application of heat. Non – thermal drying processes such as squeezing wetted sponge, adsorption by desiccant (desiccation) and extraction are also used. For example: Organic liquids or gases are dried by passing them through bed of silica gel or activated alumina which act as adsorbents.

Table 7.1 The term evaporation is different from drying.

Drying	Evaporation
Dry solid product is obtained	Final product is either concentrated solution, suspension or wet slurry.
Water is removed at the temperature below the boiling point of water	Here water vapour is removed at its boiling point
Carrier gases such as air is used to remove water	No gas is used
Small amount of water removed from solid	It include removal of large amount of water

The drying processes and equipment can be categorized according to several criteria, including the nature of the material and the method of heat supply and the method of operation. There are some factors such as temperature of inlet and exhaust air, volume of air, quantity of material, period of drying or drying time that also influence process of drying.

7.2 APPLICATIONS

In manufacturing of bulk drugs, the last stage of processing is drying.

1. If the bulk drug ingredients are not stable in liquid or frozen form, lyophilization is necessary. Lyophilization enables longer shelf life and makes easier transport of the product.
2. For manufacturing of bulk drug or for large scale production of synthetic drugs , drying is essential to get free flowing materials. For example. Dried aluminium hydroxide, spray dried lactose.
3. It is necessary to dry fresh plants such as belladonna leaves, nux vomica, etc., before subjecting them to size reduction.
4. Drying is necessary to avoid deterioration of crude drugs of animal & vegetable origin, synthetic & semi synthetic drugs, aspirin & penicillin's tablets that undergo chemical decomposition process.
5. Drying is necessary to avoid deterioration of blood products, skin & tissue that undergo microbial decomposition. They are dried by special process to maintain their shelf life for longer period of time.
6. During production of tablets, granules are dried to improve flow property as well as compression.
7. Viscous and sticky material are dried to improve flow property.
8. Some material such as milk, coffee extract are dried to convert them into instant soluble power form.
9. Drying is necessary to make material light weight.
10. Removal of moisture significantly decreases rate of chemical reactions, chances of microbial attack or enzymatic actions and thus improves stability.

7.3 MECHANISM OF DRYING PROCESS

Drying not only means the elimination of moisture, but during the process it is essential to preserve the physical structure and appearance. It is a complicated process. Drying involves two process. First one, is Heat Transfer where heat is generated within the solid & flows to exterior surface. And second is Mass Transfer which involves movement of the moisture to the surface of the solid & its subsequent evaporation from the surface.

Water in wet solid mass either present in bound form or in unbound form. Moisture content of a substance that exerts a equilibrium vapor pressure lower than that of the pure liquid at same temperature is called *bound water.* Substances containing bound water are often called *hygroscopic substances.* Moisture content of a substance that exerts a equilibrium vapor pressure equal to that of the pure liquid at same temperature is called *Unbound water.* Thus, in a non hygroscopic material, all the liquid is unbound water. The moisture content of the solid in excess of the equilibrium moisture content is called free moisture. The moisture content is measured by ratio of weight of water in sample to weight of dry sample. It is expressed in percentage

$$\% \text{ Moisture content} = \frac{\text{Weight of water in sample}}{\text{Weight of dry sample}} \times 100 \qquad (7.1)$$

7.3.1 Equilibrium relationship

The moisture content of the solid when in equilibrium with the given partial pressure of vapor in the gas phase is called the Equilibrium Moisture Content (EMC). If solid contains more moisture than EMC, then solid will continuously lose water until EMC is reached. This process is called *desorption.* If solid contains less moisture than EMC, then solid will continuously absorb water until EMC is reached. This process is called *sorption.* EMC of solid is constant for given temperature of humidity of air. For air of zero humidity, EMC of all material is zero. With increase in air temperature, the EMC of solids decreases.

In case of Non porous insoluble solid like talc , EMC is zero. While in case of fibrous substances EMC value are high. EMC values for porous solids are much higher.

The EMC of material can be determined by putting sample in dessicator which are maintained at known relative humidity. The sample from each dessicator is collected and weighed at particular interval until a constant weight is achieved. The final moisture content is EMC.

The EMC data are useful in analysis of drying operations and particularly in predicting final moisture contents. By this over drying can be prevented.

7.3.2 Rate Relationships

Drying of solids follow two drying zones, known as the constant-rate period and the falling-rate period. During the constant-rate drying period, the moisture vaporised per unit time per unit area of drying surface remains constant. While in *falling rate drying period* the amount of moisture vaporised per unit time per unit area of drying surface decreases continuously. The two zones are distinguished by a break point called the critical moisture content where the moisture content at which the constant rate drying period ends and the falling rate drying period starts.

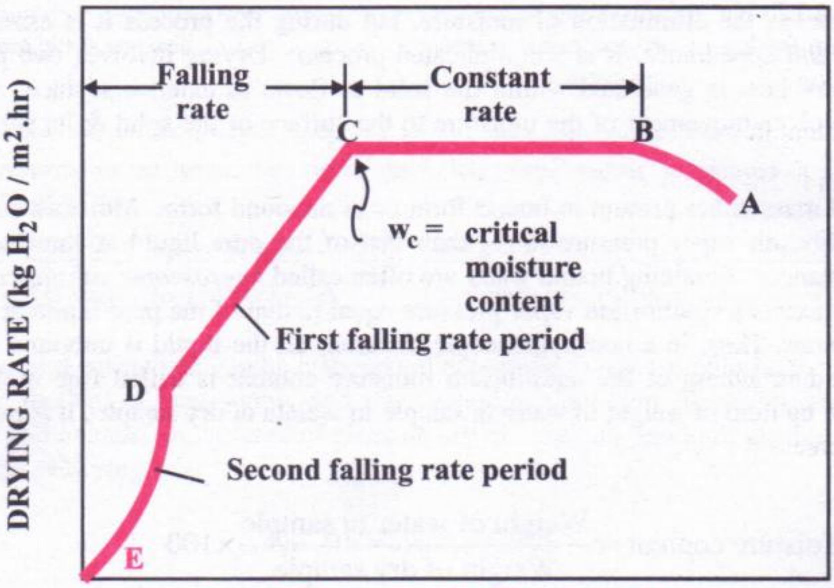


Figure 7.1: Typical drying rate curve

Point B represents equilibrium temperature conditions of the product surface. The Curve consist of Section BC is known as the *constant rate periods*, represents removal of unbound water from the product. The section CD representing first falling rate period which is also known as Period of Unsaturated surface drying and section DE representing second falling rate period. The first falling drying rate occurs when wetted spots in the surface continually decline until the surface is dried (Point D). Second falling rate period begins at point D when the surface is completely dry. The point C at which decrease in drying rate start is referred to as the critical moisture content (CMC).

7.3.4 Rate Of Drying

The rate of drying of a sample can be measured by the following calculation

$$\text{Drying Rate} = \frac{\text{Weight of water in sample (kg)}}{\text{Time (h)} \times \text{Weight of dry solid (kg)}} \quad (7.2)$$

7.3.5 Loss on Drying

It can be calculated by

$$\text{Loss ondrying (\%)} = \frac{\text{Mass of water in sample (kg)}}{\text{Total mass of wet sample (kg)}} \times 100 \quad (7.3)$$

Solved Problems

Exercise 7.1: When 120 Kg of moist drug granule sample obtain its equilibrium moisture content and it was found that it contain 94 Kg of dry material. What will be the equilibrium moisture content of that sample under given condition?

Answer- Water content in moist granulation= 120-94 = 26 Kg

EMC of granulation is 26/ 94 = 0.27 Kg per Kg of dry granulation

7.4 CLASSIFICATION OF DRYERS

Drying equipments are classified on the basis of their operating features. It can be classified as batch or continuous. In case of batch dryer the material is loaded in the drying equipment for a given period of time, whereas, in case of continuous mode the material is continuously added to the dryer. In few cases vacuum may be used to decrease the drying temperature.

Classification of dryers

- **Static Bed Dryer (Ex. Tray Dryer, Freeze Dryer)**
- **Moving Bed Dryer (Ex. Drum Dryer)**
- **Fluidised Bed Dryer**
- **Vacuum Dryer**
- **Pneumatic Dryer (Ex. Spray Dryer)**

7.5 TRAY DRYER

Principle: It is the example of Static bed dryer. In this process, there is no relative movement among the solid particles being dried. It is operated in batch process. This type of dryer operates by passing hot air over the surface of a wet solid that spread over trays arranged in racks and due to forced convection moisture is removed.

Construction: It consist of chamber whose wall is insulated by thick glasswool or suitable heat insulating material. Inside the chamber there are various trays on which wet materials are placed. The number of trays depend on the size of chamber. For laboratory purpose, minimum 3 trays are required. There should be appropriate distance between upper, middle and lower tray. The dryer is also attached to provision of fresh air inlet and air outlet. The fan in dryer is used to circulate air over the material placed in trays. Heater is also provided inside to facilitate uniform heating. The door of the heater is explosion proof and is locked with the help of spring loaded ball latches with suitable pressure. Door lips are having Neoprene rubber gasket to prevent leakages.

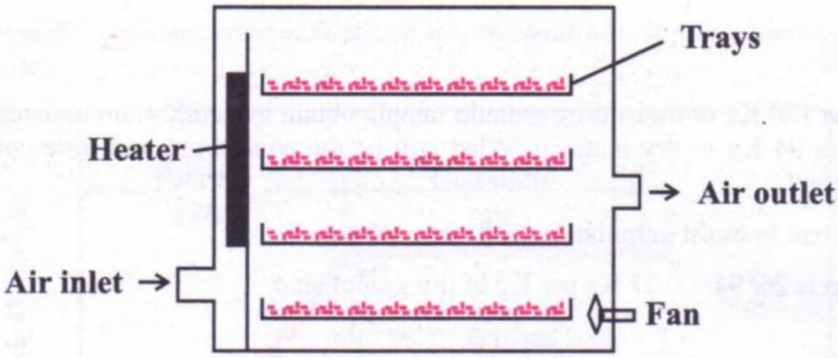


Figure 7.2: Tray dryer

Working: Wet material are spread into trays and placed into the chamber. The doors are closed. The air is introduced through inlet and through heater air heated up. Hot air is circulated by fan over the tray. There should be uniform air flow otherwise proper drying will not be achieved. *Even b*affles are used to distribute the air uniformly over the trays. Some moist air is continuously vented through outlet. The fresh air enters through the inlet. The water evaporate from the interior of the solid due to hot air. At the end, trays are removed from chamber and dried material is collected.

Advantages:

1. Tray Dryer is the most conventional dryer used very widely and still being used where the moisture content is more and where the product has to be dried at low temperature for long hours.
2. It is a batch process and can also be used where quantity of material is less.
3. In the tray dryers the handling of the materials can be done without losses.
4. The batch sizes in the pharmaceutical industry are relatively small 250 kg or less per batch compared with the chemical industry 1000 kg or more per hour.
5. Valuable products can also handled effectively.

Disadvantages

1. Not suitable for oxidisable and thermolabile substances.
2. The process takes long time.
3. The process is expensive to operate

Pharmaceutical Applications

1. Tray dryer is used in the drying of the sticky materials.
2. Tray dryers are used in the drying of the granular mass or crystalline materials.
3. Plastic substances can be dried by the tray dryers.
4. Wet mass preparations, precipitates and pastes can be dried in a tray dryer.
5. In the tray dryers the crude drugs, chemicals, powders and tablet granules are also dried and shows free flowing of the materials by picking up the water.
6. Some types of equipments can also be dried in the tray dryers.

7.6 DRUM DRYER OR ROLLER DRYER

Principle:

The drum dryer is an equipment used to convert the solutions and suspensions into the solids. The main purpose is to spread the liquid to a large surface area so that drying can occur rapidly.

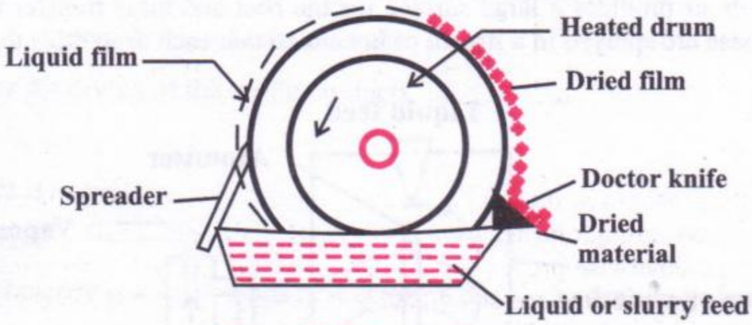


Figure 7.3: Drum dryer

Construction

It consists of hollow steel drum of about 0.75-1.5 m in diameter and 2-4 m in length. It is heated internally, usually by steam, and rotated on its longitudinal axis. The external surface of drum is polished. Liquid or slurry is placed as feed in a pan. The drum is partially dipped in pan. The spreader is used to spread liquid film evenly on roller. The rotation of the drum adjusted so that all of the liquid is fully vaporized. The drum is rotated continuously. The dried deposit or material can be scrapped off with the help of Doctor knife. The dried material is collected in storage bin.

Working:

As drum rotates, the liquid material get adhere to external surface of drum. The liquid is spread as film onto the surface. The drying of the material is done by the process of steam when passed in to the drum. By the mechanism of the conduction the heat get transferred in to the drum and drying process takes place. The materials is completely dried during the whole process during its revolutions. The dried materials is scrapped by the knife and that falls in to the bin.

Advantages

1. Drying take place in less time.
2. It is suitable for thermosensitives drugs.
3. It occupies less space.
4. In order to reduce the temperature of drying the drum can be enclosed in a vacuum chamber.
5. Rapid drying takes place due to rapid heat and mass transfer.

Disadvantages

1. Maintenance cost is high.
2. Skilled operators are essential to control thickness of the film.
3. It is not suitable for less solubility products.
4. The operating conditions are critical. Therefore it is necessary to introduce careful control on feed rate, film thickness, speed of drum rotation and drum temperature

Pharmaceutical Applications

1. Drum dryer is used for drying of solutions, slurries and suspensions

2. Milk products, starch products, ferrous salts, suspensions of zinc oxide, suspensions of the kaolin, yeast, pigments, malt extracts, antibiotics, glandular extracts, insecticides, DDT, calcium and barium carbonates are dried by this method.

7.7 SPRAY DRYER

Principle: The spray dryer provides a large surface for the heat and mass transfer by atomizing the liquid into small droplets. These are sprayed in a stream of hot air, so that each drop dries to get a solid particle.

Construction

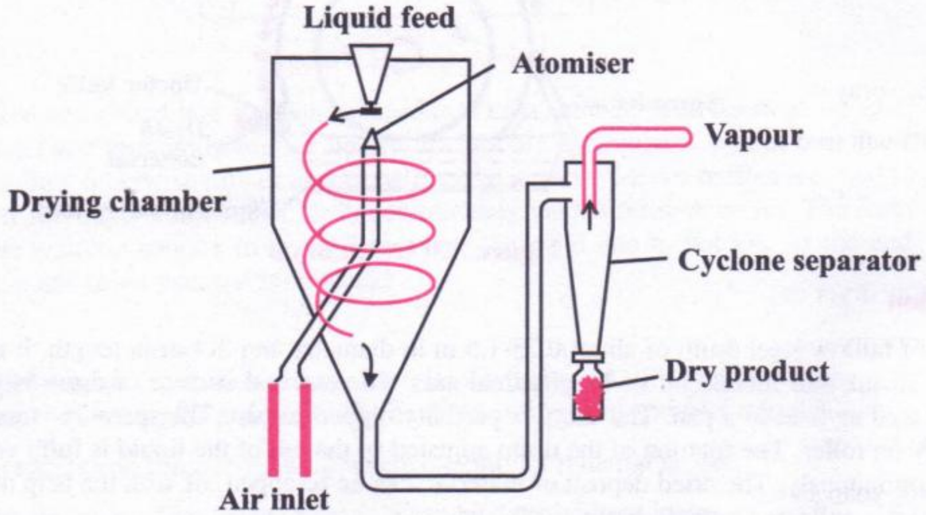


Figure 7.4: spray dryer

It consist of drying chamber having conical base. It is made of stainless steel. The inlet for hot air is also provided at bottom and another inlet for spray disk atomizer at the top. Atomization may be achieved by means of single-fluid or two-fluid nozzles. The drying chamber is connected to cyclone separator. The dry product is collected from the bottom of cyclone separator

Working

The spray-drying process can be divided into four sections

- atomization of the fluid,
- mixing of the droplets
- drying,
- removal and collection of the dry particles

The feed entered the drying chamber through the atomizer. Jet atomiser and Rotary atomiser are used. Jet atomiser get easily blocked resulting in variation of the droplets size. Rotary atomiser are preferred to avoid this problems. Hot air passes through the inlet. The air temperature should be adjusted in such a way that the droplet dries completely before reaching the wall of the drying chamber. The residence time of a droplet in the dryer is only a few seconds (5–30 s). The particle should not be overheated. The bottom of drying chamber is connected to cyclone separator. In cyclone separator, the centrifugal force throw out the dried particles to the bottom and dried particle are collected in a bin. The vapors are removed from the top.

Advantages

1. The process of drying completes within 3 to 30 seconds.
2. Less labour costs required as it is continuous process.
3. Uniform and controlled size product can be obtained.
4. The product obtained has high bulk density and show excellent solubility.
5. The solutions or suspensions can be dried easily
6. It is suitable for the drying of the sterile products.

Disadvantages

1. The spray dryer is expensive.
2. Difficult to operate.
3. The thermal efficiency is low, as much heat is lost in the discharged gases.

Pharmaceutical Applications

1. Spray dryer can be used for drying both solution or suspension.
2. Spray dryer are very useful for the drying of heat sensitive substances.
3. Citric acid, borax, sodium phosphate, hexamine, gelatine and extracts are dried by a this method.
4. The suspensions of starch, barium sulphate and calcium phosphate are also dried by the spray dryer.
5. Milk, soap and detergents are also dried by a spray dryer.
6. Spray dryer are used compulsorily if the quantity of the materials to be dried is large and the products is hygroscopic or undergoes chemical decomposition.
7. Some of the products that are dried using the spray dryer are acacia, adrenaline, bacitracin, blood, boric acid, calcium sulphate, coffee extract, dextran, fruit juices, ferrous sulphate, pepsin, pancreatin, plasma, serum, soaps, sodium phosphate, starch, sulphur, vaccines vitamins, yeast etc.

7.8 FLUIDIZED BED DRYER

Principle

In the fluidized-bed dryer, hot air is passed through a perforated bottom of the container containing granules to be dried. The granules are suspended in the air stream and rise from the bottom. This condition is called a fluidized state. Hot air surrounds each granule to dry it completely. Therefore, the materials or granules are dried uniformly.

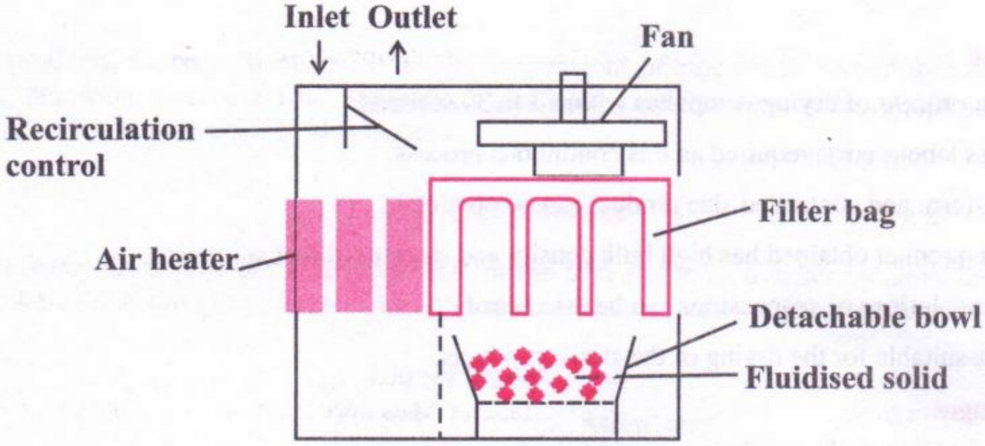


Figure 7.5: Fluidized bed dryer

Construction

The fluidized bed dryer consists of a steel shell of cylindrical or rectangular cross section. A detachable bowl which has perforated bottom is placed on the bottom of the dryer. It is used to load and unload the materials. The bowl is used to place the materials to be dried. A fan is mounted on the top to circulate hot air. The fresh air inlet, the pre-filter and the heat exchanger are connected in series to heat the air to the required temperatures. The temperature of the hot air and the exhaust air are monitored. The bag filters are placed on top of the drying container for the recovery of the fines. The air flow is adjusted by means of the recirculation control. The fabric bags are provided to prevent the passage of the fine particles.

Working

The wet granules to be dried are placed in a detachable bowl. The bowl is inserted in the dryer. Fresh air can pass through a pre-filter, which is then heated when passing through a heat exchanger. Hot air flows through the bottom of the bowl. At the same time, the fan starts to rotate. The air speed increases gradually. When the velocity of the air is greater than the sedimentation rate of the granules, the granules remain partially suspended in the gas stream.

After a specific times, a pressure point is reached in which the friction drag on the particles is equal to the force of gravity. The granules rise in the container due to the high gas velocity of 1.5 to 7.5 m per minute and then fall back. This condition is said to be fluidised state. The gas surrounds each granule to dry them completely. The air comes out of the dryer passing through the filters in the bag. The entrained particles remain adhered to the interior of the surface of the bags. Periodically, the bags are shaken to remove entrained particles.

The residence time for drying is approximately 40 min. The materials are sometimes left in the dryer to reach room temperature. The bowl is removed for unloading. The final product is free flowing.

Advantages

1. It takes less time to complete drying as compared to other dryer.
2. Drying is achieved at constant rate.
3. Handling time is also short

4. It is available in different sizes with the different drying capacity
5. The equipment is simple and less labour costs required.
6. More thermal efficiency.
7. Drying capacity is more than other dryer.
8. It facilitates the drying of thermolabile substances since the contact time for drying is short.
9. It is batch type or continuous type process

Disadvantages

1. Many organic powders develop electrostatic charges during drying. To avoid this efficient electrical grounding of the dryer is essential.
2. Chances of attrition of some materials resulting in the production of fines.

Pharmaceutical Applications

1. It is used for the drying of the granules in the production of the tablets.
2. It is used for coating of granules.

7.9 VACUUM DRYER

Principle

In vacuum dryer, the materials are dried by vacuum. Due to vacuum, there is decrease in pressure. Therefore water boils at a lower temperature and then the evaporation of water takes place faster.

Construction

It consists of a heavy steam jacketed container made of cast iron. The closed chamber consists of shelves that are used to place metal trays consisting of material. The shelves provide a large area for heat conduction. The chamber is so strong to withstand under vacuum. The oven can be closed by a door. The oven is connected through a condenser and liquid receiver to a vacuum pump.

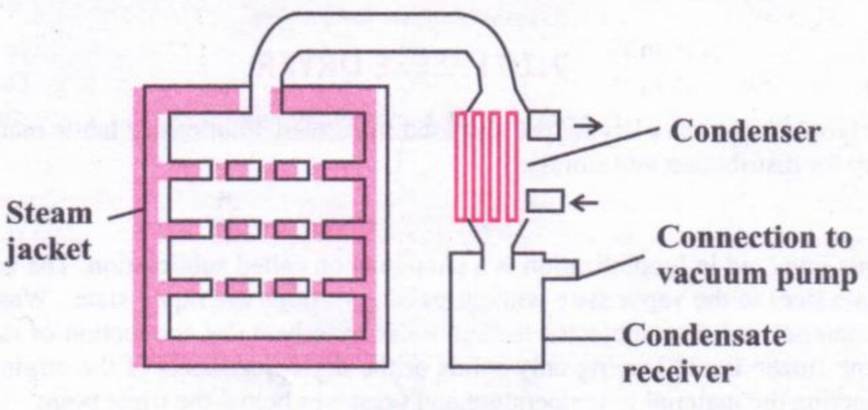


Figure 7.6: Vacuum Dryer

Working

The trays that are present in the dryer are used to dry the materials that are placed on the shelves and the pressure is reduced to 30 to 60 kps by the vacuum pump. The door closes firmly and steam passes through the jacket space and the shelves. So the heat transfer is carried out by the conduction mechanism. When evaporating under vacuum, the water is evaporated from the material at 25 - 30^{0}C. The vapor goes to the condenser. After drying the vacuum line is disconnected. Then the materials are collected from the trays.

Advantages

1. Material handling is easy.
2. Hollow shelves which are electrically heated can be used.
3. It provides large surface area. So the heat can be easily transfer throughout the body of the dryer and fast drying action takes place.
4. Hot water can be supplied throughout the dryer, which helps in the drying process at the desired temperature

Disadvantages

1. Dryer is a batch type process .
2. It has low efficiency.
3. It is more expensive.
4. Labour cost is too high.
5. Need high maintenance.
6. There is a danger of over heating due to vacuum.

Pharmaceutical Applications

Vacuum dryer can be used for the drying of the heat sensitive materials, dusty materials, hygroscopic materials, toxic materials , feed materials containing the solvents, drugs which are required as porous end products and for friable dry extracts.

7.10 FREEZE DRYER

Freeze drying or lyophilisation is a drying process used to convert solutions of labile materials into solids of sufficient stability for distribution and storage.

Principle

The main principle involved in lyophilization is a phenomenon called sublimation. The water passes directly from the solid state (ice) to the vapor state without passing through the liquid state. Water is removed from the frozen state material and then subjected to high vacuum to heat (by conduction or radiation or by both) so that the sublime frozen liquid leaving only solids or the dry components of the original liquid. Drying is achieved by subjecting the material to temperature and pressures below the triple point.

Construction

The freeze dryer consist of drying chamber in which shelves are used to place the material. Heat supply is in the form of radiation source by using heating coils. The condenser is also attached. Condenser consist of large surface cooled by solid carbon dioxide slurred with acetone or ethanol. The condenser surface should be cleaned properly. The purpose of the condenser is to attract the vapors being sublimed off of the product. Because the condenser is maintained at a lower energy level relative to the product ice, the vapors condense and turn back into solid form (ice) in the condenser. In shelf freeze dryers, the condenser can be located inside the product chamber (internal condenser) or in a separate chamber (external condenser) connected to the product chamber by a vapor port. The distance between subliming surface and condenser should be less than mean path of molecules. Because this increases the rate of drying. The vacuum pump is also connected which cause evaporative cooling. The vacuum system consists of a separate vacuum pump connected to an airtight condenser and attached product chamber.

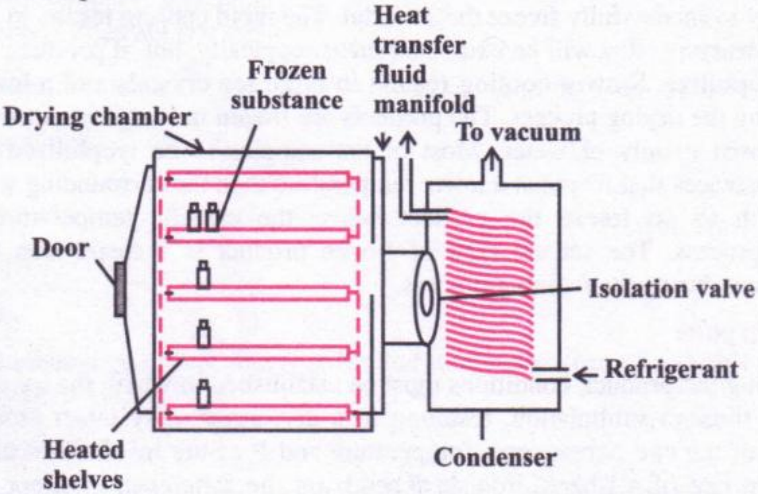


Figure 7.7: Freeze dryer

Working

The following steps are involved in the working of freeze dryer

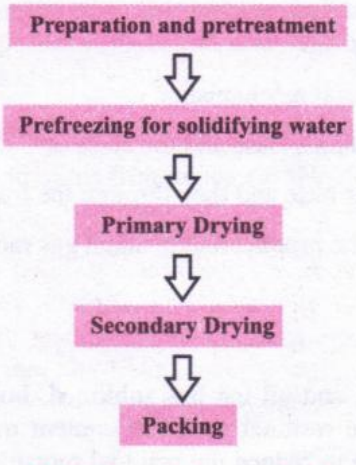


Figure 7.8: Steps in freeze drying process

1. Pretreatment:

It includes any method of treatment of the product before freezing. This may include the concentrating the product, the revision of the formulation (ie, the addition of components to increase stability and / or improve processing), decreasing a high vapor pressure solvent or increase the surface area. Pretreatment methods include: freezing concentration, solution phase concentration, formulation to preserve the appearance of the product, formulation to stabilize reactive products, formulation to increase the surface area and decreasing high vapor pressure solvent.

2. Prefreezing:

The product should be frozen at a temperature low enough to solidify completely. Since freeze-drying is a change in the state from the solid phase to the gas phase, the material to be freeze-dried must first be adequately pre-frozen. The pre-freezing method and the final temperature of the frozen product can affect the ability to successfully freeze the material. The rapid cooling results in small ice crystals, useful for preserving structures that will be examined microscopically, but it produce a product that is more difficult to lyophilize. Slower cooling results in large ice crystals and a less restrictive channel in the matrix during the drying process. The products are frozen in two ways, most of the products that are lyophilized consist mainly of water. Most of the samples to be lyophilized are eutectic, which are mixtures of substances that freeze at a lower temperature than the surrounding water. It is very important in lyophilization to pre-freeze the product below the eutectic temperature before beginning the lyophilization process. The second type of frozen product is a suspension that is subjected to the formation of glass during the freezing process.

3. Primary drying:

After pre-freezing the product, conditions must be established in which the ice can be removed from the frozen product through sublimation, resulting in a dry, structurally intact product. This requires very careful control of the two parameters: Temperature and Pressure involved in the lyophilization system. The sublimation rate of a frozen product depends on the difference in vapor pressure of the product compared to the vapor pressure of the ice collector. The molecules migrate from the high pressure sample to a lower pressure area. As the vapor pressure is related to the temperature, it is necessary that the temperature of the product is warmer than the temperature of the cold trap (ice collector). The temperature at which a product is lyophilized is balanced between the temperature that maintains the frozen integrity of the product and the temperature that maximizes the vapor pressure of the product. This balance is key to optimum drying.

Heat enters the products by one of several mechanisms: -

1. By direct contact between the container base and the shelf or
2. By conduction across the container base and then through the frozen mass to the drying front or
3. By gaseous convection between the product and residual gas molecules in the chamber or
4. By radiation.

4. Secondary drying

After primary freeze-drying is complete, and all ice has sublimed, bound moisture is still present in the product. The product appears dry, but the residual moisture content may be as high as 7-8%. Continued drying is necessary at warmer temperature to reduce the residual moisture content to optimum values. This process is called 'Isothermal Desorption'. Secondary drying is usually carried out for approximately 1/3 or 1/2 the time required for primary drying.

5. Packing

By replacing vacuum with inert gas, bottles and vials are closed.

Advantage

1. This is suitable for drying heat sensitive products
2. Freeze-dried product is porous and easy to be rehydrated and instantly dissolved.
3. Drying takes place at very low temperatures, so that enzyme action is inhibited and chemical decomposition , particularly hydrolysis, is minimized .
4. Denaturation of protein does not occur.
5. Loss of volatile material is less.
6. Sterility can be maintained.

Disadvantage

1. The process is very slow
2. Expensive process.
3. It is not a general method of drying, but it is limited to certain types of valuable products that can not be dried by any other means.
4. The period of drying is high .
5. The product is prone to oxidation, due to the high porosity and large surface area. Therefore, the product must be vacuum packed or with an inert gas or in container

Pharmaceutical Applications

1. It is used in production of injection, solution and suspension. It is also used for production of blood plasma and its fractionated products, bacterial and viral cultures, antibiotics and plant extracts , steroids, vitamins and enzymes.
2. Food items like mushrooms, prawns, meat products can be dried by this method
3. Coffee and tea concentrates and citrus fruit juices are also dried by this method.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

1. **Define Drying**

   Answer- It can be defined as an process in which the liquid, generally water, present in a wet solid is removed by application of heat and finally a liquid free solid product is obtained.

2. **Define Unbound water.**

   Answer- It is the moisture content of a substance that exerts a equilibrium vapor pressure equal to that of the pure liquid at same temperature.

3. **What is Equilibrium Moisture Content (EMC)?**

   Answer- It is the moisture content of the solid when in equilibrium with the given partial pressure of vapor in the gas phase.

4. **How Moisture content is measured?**

   Answer- It is measured by ratio of weight of dry sample to ratio of weight of water in sample

5. **Define Bound Water**

   Answer- It is the moisture content of a substance that exerts a equilibrium vapor pressure lower than that of the pure liquid at same temperature.

SHORT ANSWER QUESTIONS

1. **Write difference between drying and evaporation**

   Answer- The term evaporation is different from drying.

Drying	Evaporation
Dry solid product is obtained	Final product is either concentrated solution, suspension or wet slurry.
Water is removed at the temperature below the boiling point of water	Here water vapour is removed at its boiling point
Carrier gases such as air is used to remove water	No gas is used
Small amount of water removed from solid	It include removal of large amount of water

2. **What are desorption and sorption?**

   Answer- If solid contains more moisture than EMC, then solid will continuously lose water until EMC is reached. This process is called *desorption*. If solid contains less moisture than EMC, then solid will continuously absorb water until EMC is reached. This process is called *sorption*.

3. How Equilibrium Moisture Content is determined? What is the importance of EMC data?

Answer- The EMC of material can be determined by putting sample in dessicator which are maintained at known relative humidity. The sample from each dessicator is collected and weighed at particular interval until a constant weight is achieved. The final moisture content is EMC. The EMC data are useful in analysis of drying operations and particularly in predicting final moisture contents. By this over drying can be prevented.

4. How to measure Rate Of Drying?

Answer- The rate of drying of a sample can be measured by the following calculation

$$\text{Drying Rate} = \frac{\text{Weight of water in sample (kg)}}{\text{Time (h)} \times \text{Weight of dry solid (kg)}}$$

5. How to measure Loss on drying?
Answer-

$$\text{Loss ondrying (\%)} = \frac{\text{Mass of water in sample (kg)}}{\text{Total mass of wet sample (kg)}} \times 100$$

LONG ANSWER QUESTIONS

1. Explain mechanism of drying process. Also explain drying rate curve.
   (Refer article 7.3)
2. Describe principles, construction, working, uses, merits and demerits of Tray dryer
   (Refer article 7.5)
3. Describe principles, construction, working, uses, merits and demerits of Drum dryer
   (Refer article 7.6)
4. Describe principles, construction, working, uses, merits and demerits of Spray dryer
   (Refer article 7.7)
5. Describe principles, construction, working, uses, merits and demerits of Fluidized Bed Dryer
   (Refer article 7.8)
6. Describe principles, construction, working, uses, merits and demerits of Vacuum Dryer
   (Refer article 7.9)
7. Describe principles, construction, working, uses, merits and demerits of Freeze Dryer
   (Refer article 7.10)
8. Write detailed note on
   A. Application of drying
      (Refer article 7.2)
   B. Steps involved in freeze drying process
      (Refer article 7.10)

MULTIPLE CHOICE QUESTIONS

1. **The process in which the liquid, generally water, present in a wet solid is removed by application of heat is called**
   a. Drying
   b. Evaporation
   c. Crystallization
   d. Dehumidification
2. **Substances containing bound water are called**
   a. hygroscopic substances
   b. Non hygrscopic substances
   c. Efflorescent substance
   d. Deliquescent substance
3. **Which of the following is also known as Roller dryer?**
   a. Tray dryer
   b. Drum dryer
   c. Freeze dryer
   d. Fluidized bed dryer
4. **Which of the following is used for drying of food items like mushrooms, prawns, meat products**
   a. Tray dryer
   b. Spray dyer
   c. Roller dryer
   d. Freeze dryer
5. **In which of the following dryer, atomizers are used**
   a. Tray dryer
   b. Spray dyer
   c. Roller dryer
   d. Freeze dryer
6. **Which of the following is example of static bed dryer**
   a. Tray dryer
   b. Drum dryer
   c. Roller dryer
   d. Spray dryer
7. **Which of the following dryer is is used for coating of granules**
   a. Tray dryer
   b. Drum dryer
   c. Fluidized bed dryer
   d. Spray dryer

8

CHAPTER

MIXING

Selected Definitions

Mixing: It is defined as a process in which two or more components within a system are converted into one mass or mixture.

Ideal Mixing: It is the process in which different materials are thoroughly combined to produce homogenous product.

Positive Mixtures: These are prepared by mixing two miscible liquids.

Negative Mixtures: These mixtures are prepared by mixing insoluble solids in a vehicle in case of suspension or by mixing two immiscible liquids in case of emulsion.

Neutral Mixtures: Some products such as Pastes, ointments etc do not mix spontaneously but after mixing they do not separate out easily.

Convective Mixing: These are the mixing in which the groups of particles move from one position to another. It is also referred to as macromixing.

Shear Mixing: In this mixing, shearing forces are created within the mass of the material by the use of a stirring arm or a burst of air.

Diffusive Mixing: During this mixing, gravitational forces cause the upper layers of materials to slip and random motion of the individual particles takes place on newly developed surfaces. This is also sometimes known as micromixing.

Miscible liquids: These liquids mix with each other in all proportion.

Partially miscible liquids: These liquids mix with each other at specific proportion.

Immiscible liquids: They are not miscible.

Bulk transport: It is the movement of large portion of material from one location to another location.

Turbulent Mixing: In this, mixing is due to turbulence. Turbulence is a function of velocity gradient between two adjacent layers of a liquid.

Laminar Mixing / Streamline Mixing: This type of mixing occur when two dissimilar liquids are mixed through a laminar flow, the shear that is generated stretches the interface between them.

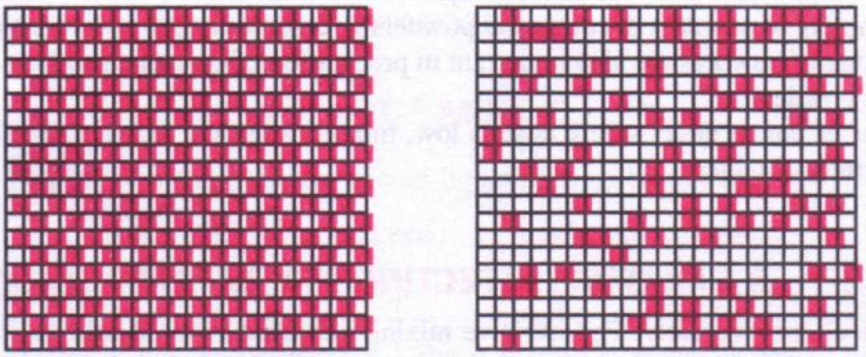
Molecular Diffusion: It is mixing at the molecular level is the diffusion resulting from the thermal movement of the molecules.

Propellers: These are mechanical device that are used to mix liquid materials by using blades.

Homogenizer: They are used to convert coarse emulsion to fine emulsion.

8.1 INTRODUCTION

Mixing is defined as a process in which two or more components within a system are converted into one mass or mixture. **Ideal Mixing** indicates that different materials are thoroughly combined to produce homogenous product. **Random Mixing**is probability of finding same proportions of component in the entire mixture. **Ordered Mixing** yields the closest situation of the perfect mix and it is achieved by use of mechanical, adhesion or coating force.



(a) (b)

Figure 8.1 : (a) Ideal Mixing (b) Random Mixing

The term Mixing and Blending are often used interchangeably but technically they are slight different. Blending means to mix or intermingle smoothly or inseparably.

8.2 TYPES OF MIXTURES

Mixtures can be classified as

a. **Positive Mixtures:** These are prepared by mixing two miscible liquids. These type of mixtures are easy to prepare.
b. **Negative Mixtures:** These mixtures are prepared by mixing insoluble solids in a vehicle in case of suspension or by mixing two immiscible liquids in case of emulsion. These mixture require high degree of energy or external force.
c. **Neutral Mixtures:** Some products such as Pastes, ointments etc do not mix spontaneously but after mixing they do not separate out easily. These are called neutral mixtures.

8.3 OBJECTIVES OF MIXING

Mixing can be done for the following reasons.

1. Mixing is a critical process. The quality of final product depends upon the nature of mixing. Improper Mixing lead to non homogeneous products.
2. Proper Mixing lead to decrease batch cycle times and operational cost.
3. To increase the dissolution or diffusion rate

8.4 APPLICATIONS

Mixing is one of the common pharmaceutical operation. There are few examples of large scale Mixing in Pharmacy which are in practice:

a. Mixing is an intermediate step in production of tablet or capsule. Mixing of powders in different proportion prior to granulation or tabletting
b. Dry mixing of materials for direct compression into tablets.
c. Dry mixing of powders & composite powders in capsules and insufflations respectively.
d. Blending of powders are also important in preparation of cosmetic products such as facial powder or dental powder
e. In case of potent drugs where dose is low, mixing is critical factor. Otherwise it will affect content uniformity of tablet.

8.5 FACTORS AFFECTING MIXING OPERATION

1. **Nature of the product:** For effective mixing particle surface should be smooth. Rough surface of one or more components lead to increase chances of entry of active substance into the pores of another ingredient and further affect mixing.
2. **Particle size:** It is easier to mix powders of same particle size. Variation in particle size lead to improper mixing. Increasing the difference in particle size will lead to segregation (size separation), since small particles can fall through the voids between the larger particles
3. **Particle shape:** The particle should be spherical in shape to achieve uniform mixing.
4. **Particle charge:** Some particles due to electrostatic charges exert attractive force which lead to separation.
5. **Proportion of Material:** It is easy to mix powders if available in equal quantities. But to mix small quantities of powders with large quantities of ingredients is difficult process.
6. **Relative density:** If the components have a different density, the denser material will sink through lighter material, the effect of which will depend on the relative positions of the material in the mixer.
7. **Viscosity:** The mixing is also affected by the viscosity. An increase in viscosity reduces the extent of mixing. More viscous particles cause poor mixing.
8. **Surface tension of liquids:** The surface tension of the liquid is also an important factor affecting the mixing. High surface tension reduces the extent of mixing.
9. **Temperature:** The temperature also affects the mixing because the viscosity changes with the change of temperature
10. **Mixer volume:** The volume of the mixin g also affects the mixing phenomena. The blender volume should be such that overfilling should not be done as it decreases the mixing efficiency
11. **Agitator type:** The shape, size, location and type of agitator also affect the degree of mixing achieved and the time required to mix specific components.
12. **Speed / rpm of the impeller:** The speed of the impeller affects the homogeneity of the mixing. As mixing at less rpm is more homogeneous than at a higher rpm.
13. **Mixing time:** The mixing time is also very important for appropriate mixing. There is always an optimal mixing time for the specific conditions in which the mixing is taken place.

8.6 EVALUATION OF DEGREE OF MIXING

The degree of mixing is evaluated by comparing standard deviation of sample under investigation (S_I) with estimated standard deviation of sample from fully random mix (S_R). It is expressed by Lacey.

$$\text{Mixing Index (M)} = S_R / S_I \quad (8.1)$$

Higher the value of mixing index, greater will be homogeneity.

8.7 TYPE OF MIXING

Mixing are of different types Solid-solid Mixing, Liquid-liquid Mixing, Solid-Liquid Mixing

Table 8.1 Difference between solid and liquid mixing

Solid Mixing	Liquid Mixing
In this two or more substances are intermingled by continuous movement of particles.	This is achieved by mixing element of suitable shape to act as impeller to produce appropriate flow pattern in mixing vessel
This is used for mixing of dry powders	This is used in preparation of emulsion, suspension and mixtures
Large sample size is required	Small sample size is sufficient
High power required for mixing	Less power required for mixing

8.8 SOLID-SOLID MIXING

Material having similar physical properties will be easier to form a uniform blend or mixture compared to the difference in properties. It is more difficult to achieve a good mixing of particulate solids of different sizes and densities. material density, particle size and distribution, wettability, stickiness, particle shape / roughness are the physical properties that affect mixing process. The mechanism involved in solid solid mixing are

Convective Mixing, in which the groups of particles move from one position to another. It is also referred to as macromixing.

Shear Mixing In this, shearing forces are created within the mass of the material by the use of a stirring arm or a burst of air.

Diffusive Mixing: During this mixing, gravitational forces cause the upper layers of materials to slip and random motion of the individual particles takes place on newly developed surfaces. This is also sometimes known as micromixing.

8.9 EQUIPMENTS

A wide variety of equipments are used for mixing powders on industrial scale. During mixing of powder, a few points should be considered so that proper mixing can be achieved. The mixer should have sufficient space for mixing. It should not be Overfilled. It reduces efficacy of mixing. The shearing force should be sufficient so that aggregation can be prevented. The forces used should not cause breakage of particles. The selection of appropriate mechanism is more important and also there should be optimum time for mixing.

Some Mixing equipments are discussed below

8.10 DOUBLE CONE BLENDER

Principle: The mixing occur due to tumbling motion.

Construction: All parts of equipments including mixing tank and blades are made of stainless steel. The equipment consist of two cones joined as cylindrical section which are rotated about an axis on the shaft. The conical shape at both ends allows uniform mixing and easy discharge.

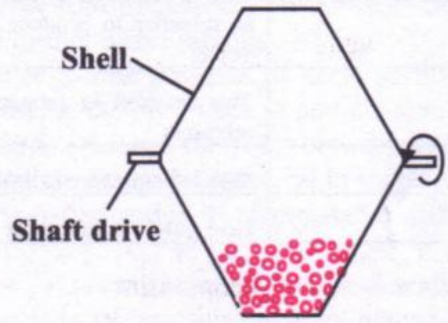


Figure 8.2: Construction of Double Cone Blender

Working: The powder is filled up to two third of volume of blender to ensure proper mixing. The rate of rotation should be 30-100 revolutions per minute. On rotation mixing occur due to tumbling motion. The product can be discharged from the bottom of the equipment. The mixing tank can be slanted freely at the angle of 0° to 360° degrees for discharging and cleaning purpose.

Advantages:

1. Easy to maintain and clean
2. There are no chances of clogging of material into corners
3. Large amount can be handled easily
4. It is efficient for mixing powders of different densities
5. Wear on equipment is little

Disadvantages:

1. Not suitable for fine particles
2. Not suitable for particles with greater particle size difference due to less shear

Pharmaceutical Application

1. Double Cone Blender is an efficient and versatile equipment for the homogeneous mixing of dry powders and granules. Dry powder mixing for tablets and capsule formulations.
2. It can be used for pharmaceutical, food, chemical and cosmetic products etc.

8.11 TWIN SHELL BLENDER OR V CONE BLENDER

Principle: The mixing occur due to tumbling motion.

Figure 8.3: Construction Of Twin shell blender

Construction

It consists of a totally enclosed V shaped vessel which prevent any foreign particle to enter into chamber. It is made of either stainless steel or transparent plastic. It consists of horizontal shaft rotated about an axis causing the particles within the mixer to tumble over each other onto the mixture surface. The charging of material into the V-Blender is through either of the two ends. Batches from 20 kg to 1 tonne can be loaded for mixing depending upon the size of equipment.

Working

The material is loaded into the blender. The recommended fill-up volume for the V-Blender is 50 to 60% of the total blender volume. On rotation, a tumbling motion occurs. When the V-Blender tumbles, the material divides and recombines continuously. The repetitive converging and diverging movement between the material and the blender results homogenous blending. The product is collected from the bottom of V. Normal blend times are typically in the range of 5 to 15 minutes depending on the properties of material to be blended.

Blender speed can also be key to mixing efficiency. At low speeds, shear forces are less. Although higher mixing speeds provide more shear, this can lead to greater dust resulting from the segregation of fines. There is also a critical speed which, if approached, will considerably reduce the mixing efficiency. As revolutions per minute increase, the centrifugal forces at the extreme points of the blender will exceed the gravitational forces required for mixing. As a result, the powder must tend to gravitate toward the outer walls of the blender casing. As the size of the blender increases, the rotational speed generally decreases in proportion to the peripheral speed of the blender extreme. V-Blenders are designed to operate between 50% and 80% of the critical speed.

Advantages

1. V-Blenders are therefore preferred when precise blend formulations are required.
2. They are also well suited for applications where some ingredients may be as low as five percent of the total blend size.
3. Particle size reduction and attrition are minimized due to the lack of moving blades. Therefore, it can be used for fragile materials
4. Loading and unloading of material is easy
5. The absence of shaft projection reduce chances of product contamination.
6. Easy to clean

Disadvantage

1. They require high headroom for installation and operation.
2. They are not suitable for blending particles of different sizes and densities. There are chances of segregation of these particles at the time of discharge.

Pharmaceutical Applications

1. V blenders are used for dry mixing. It provide efficient blending in short time.
2. This blender is often used for pharmaceuticals. But not suited for very soft powders or granules.
3. V-Blenders are generally used for the Food products, Milk powder, Dry flavors, Pesticides and Herbicides, Animal feed, Spice blends, Baby foods and Cosmetics

8.12 V-BLENDER WITH INTENSIFIER BAR OR AGITATOR BLADES

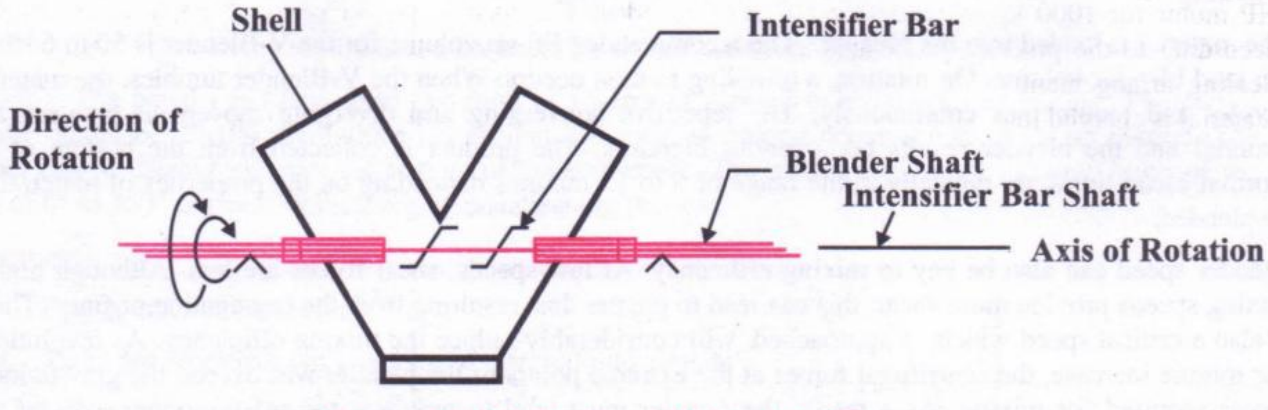


Figure 8.4 : V-Blender with Intensifier Bar

The general construction and operation are the same as those of the V cone blender. In addition, V-Blender can be equipped with high speed intensifier bars (or agitator blades) with spray pipes for addition of liquid. The Intensifiers may be provided for the disintegration of agglomerates which are formed during wet mixing.

Advantages:

1. Suitable for both dry and wet mixing.
2. Suitable for mixing of fines and particle compositions.
3. Suitable for mixing of cohesive powders.

Disadvantages:

1. Undesirable attrition of particles.
2. Sealing problems of the shaft of the Intensifier bar.
3. Cleaning issues

8.13 RIBBON BLENDER

Principle

The mechanism of mixing is shear which is transferred by moving blades.

Construction

A ribbon blender consists of a U-shaped horizontal trough or shell containing a helical double-ribbon agitator that rotates inside. The shaft of the agitator is positioned in the center of the trough on which the helical ribbons (also called spirals) are welded. Since the ribbon stirrer consists of a set of internal and external helical ribbons, it is also called a "double" helical ribbon agitator. The counteracting blades are provided for high shear as well as for breaking of lumps or aggregates. The ribbon blenders are powered by a drive system consisting of a motor, a gearbox and couplings. They are generally powered by 10 HP to 15 HP motor for 1000 kg of product mass to be blended. The specific power ranges from 3 to 12 kW / m^3 according to the products to be mixed. The area where the shaft exits the container is envisaged with a Sealing arrangement to ensure that the material does not move from the container to the outside. The material is charged into the mixer usually by feed hoppers. It is also equipped with bottom discharge spout.

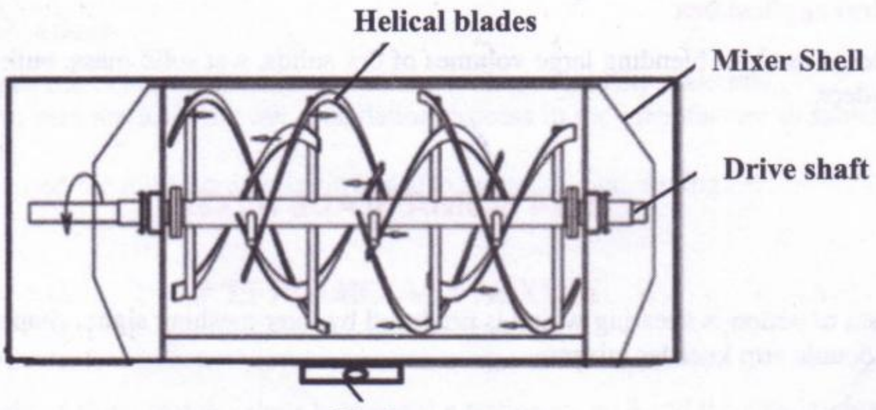


Figure 8.5: construction of Ribbon Blender

Working

The materials to be blended are loaded into the blender, typically filling it between 40 and 70 percent of the total volume of the container. Ribbons are allowed to rotate with the help of the drive system. During the blending operation, one blade slowly moves the solids in one direction and the other moves them rapidly in the opposite direction. As a result, the homogeneous blending is achieved in a short time. The mixing is generally carried out in 15 to 20 minutes. After blending, the material is discharged from a discharge spout located at the bottom of the trough.

Particle size and bulk density have the strongest influence on the mixing efficiency of the ribbon mixer. Ingredients having a similar particle size and bulk densities tend to mix faster than the ingredients with a variation of these attributes.

Advantages

1. Ribbon blender can be operated in both batch and continuous modes.
2. High shear by baffles cause break down of aggregates
3. Less headspace requirement

Disadvantages

1. It is practically difficult to obtain 100% discharge in the ribbon blender.
2. Higher clearance between the external periphery of the outer ribbon and the container may result in unmixed or dead spots.
3. The movement of ribbons near the vessel walls due to high shear and compression can damage fragile materials and cause attrition.

Variant

An alternate design of the ribbon agitator is the paddle agitator which can handle a fragile material. The paddle agitator is composed of both forward and reverse paddles in place of the ribbon. The paddles are positioned to move the material in opposing lateral directions as well as in a radial direction. The paddle design is generally used when friable materials are mixed, and when batches as small as 15% of the total capacity are going to be blended into the blender

Pharmaceutical applications

Ribbon blender is used for blending large volumes of dry solids, wet solid mass, bulk drugs, chemicals, and cosmetic powders.

8.14 SIGMA BLADE MIXER

Principle

The mechanism of action is shearing which is produced by inter meshing sigma shaped blades. It belongs to the family of double arm kneader mixers.

Construction

It consist of two mixing blades, which shapes resemble the Greek letter sigma ($\sum$) , are fitted horizontally in each trough of bowl. The clearance between the blades and the vessel walls is low (~2 mm). The low clearances produces high shear.

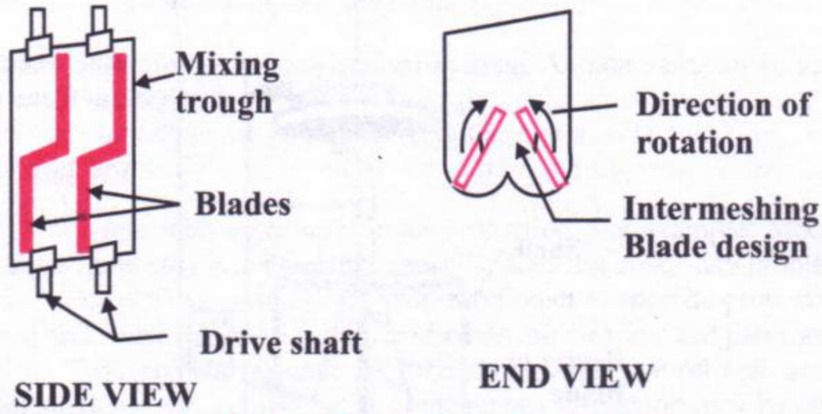


Figure 8.6: Construction of Sigma Blade Mixer

Working

The powders (40 to 65 percent of the mixer's total volumetric capacity) are introduced from the top of the trough. The entire process is carried out in a closed enclosure because the dust can be released. The blades move at a different speed using the drive system. that includes motor, gear reducer, couplings, gears, bearings and seals. The material moves up and down and shear occurs between the blades and the wall of the trough. The equipment is also attached to the perforated blades to break lumps and aggregates. The discharge of the material is either by tilting the mixing vessel, through bottom discharge valve, or through a discharge screw.The homogeneous mixture is obtained in 10 to 30 minutes. Mixing homogeneity up to 99%.

Advantages

1. During mixing, minimum dead space is created.
2. lumps and aggregates broken by perforated blades
3. Loss of volatile solvent during mixing can be prevented by closing the chamber.

Disadvantages

1. The power consumption in double arm kneader mixer is very high compared to other types of mixers and can range from 45 to 75 kW/m^3 of mix material
2. Both blades rotate at same speed.

Pharmaceutical Applications

1. The sigma blade mixer is a commonly used mixer for high viscosity materials.
2. Sigma blade mixers are used for wet granulation process in the manufacture of tablets, pill masses and ointments.
3. It is primarily used for solid-liquid mixing and also for solid-solid mixing.

8.15 PLANETARY MIXERS

Principle

It works on the principle of shear that develops between the stationary wall and the rotating blade. The blade is also used to reduce the size. The planetary blades rotates on their own axis while they travel around the centre of the mixing bowl which ensures complete and effective mixing.

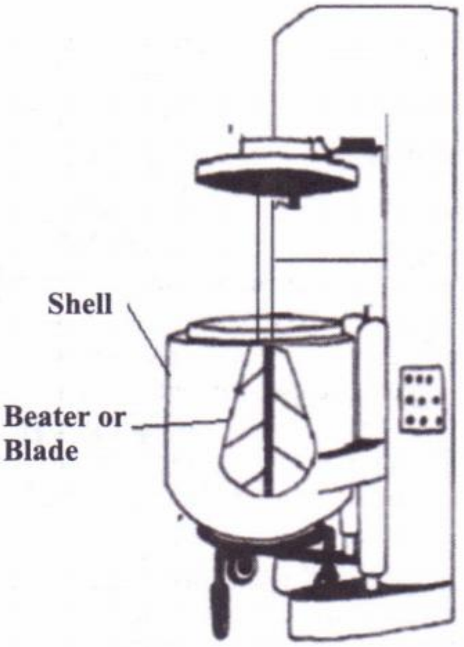


Figure 8.7: Planetary Mixers

Construction

It consists of a vertical cylindrical shell or bowl that can be removed. The shell or bowl is covered and may be provided with nozzles, a liquid spray arrangement or viewing ports. The material can be loaded into the mixer either through the nozzles on the top cover, or directly loaded into the mixer bowl. The mixer has two blades that rotate on their own axes when they orbit the mixing container on a common axis. The mixing blade is mounted at the top of the shell. The drive system consists of a motor and a gearbox that drives the planetary head. Each planetary blade is generally driven by gears that rotate due to the movement of the planetary head.

Working

The material to be mixed is loaded into mixing bowl or shell. The blades rotate on their own axis when they orbit the mixing bowl on a common axis. Therefore there is no dead spot in the mixing and high shear is applied for mixing. After mixing, the material is discharged through a bottom valve, or by manual scooping of the material from the bowl.

Advantages

1. Simple construction, operation, and relatively lower cost
2. No dead spot in the mixing
3. Rotation speed of blades can be varied
4. Used for wet granulation process
5. High mixing efficiency

Disadvantage

1. Require high power
2. Heat build up within powder mix

8.16 LIQUID-LIQUID MIXING

Liquid liquid Mixing require shear to form homogenous system. As compared to solid- liquid mixing , Liquid- liquid mixing is simple in operation.

8.16.1 Type of liquid Mixture

1. **Miscible liquids:** They mix with each other in all proportion. For example: Mixture of ethanol in water. Their mixing is quite easy and this type of mixing does not create any problem.
2. **Partially miscible liquids:** These liquids mix with each other at specific proportion. For example: Mixture of P-cresol and water . Their miscibility based on temperature and pressure.
3. **Immiscible liquids:** They are not miscible. For example: Vegetable oil and water mixture. They form heterogenous mixtures e.g. emulsions. A homogenous dispersion may be obtained by adding emulsifying agents.

8.16.2 Mechanism of mixing

The mechanism of liquid mixing are

1. **Bulk transport:** It is the movement of large portion of material from one location to another location. The movement is done by rotating blades or paddles.
2. **Turbulent Mixing**: In this, mixing is due to turbulence. Turbulence is a function of velocity gradient between two adjacent layers of a liquid. In turbulent flow there is random fluctuation in fluid velocity at a given point within the system. The turbulent flow can be easily visualized as a composite of eddies of different sizes. An eddy is defined as a part of the fluid moving as a unit in a direction often contrary to that of the general flow.
3. **Laminar Mixing / Streamline Mixing:** When two dissimilar liquids are mixed through a laminar flow, the shear that is generated stretches the interface between them. In this mechanism the layers folds on themselves. As a result the number of layers, and therefore the interfacial area between them, increases exponentially with time.
4. **Molecular Diffusion:** The mechanism responsible for mixing at the molecular level is the diffusion resulting from the thermal movement of the molecules. The process is described in terms of Fick's law of diffusion:

$$\frac{D_m}{dt} = -DA\frac{dc}{dx} \tag{8.2}$$

Where, Dm/dt is the rate of transport of mass across an interface.
A is the area
dc/dx is the concentration gradient across the interface
D is diffusion coefficient

8.16.3 Flow Pattern during mixing

The movement of the liquid at any point in the vessel will have three velocity components

1. **Radial components,** act in a direction vertical to the impeller shaft.
2. **Longitudinal component,** act parallel to the impeller shaft.

3. **Tangential component**, act in a direction that is a tangent to the circle of rotation round the impeller shaft

8.17 MIXING EQUIPMENTS

Mixing devices are known as impellers. Impellers operate using a combination of radial, axial and tangential flow Three main type of impellers are: Propellers, Turbines and Paddles.

8.18 PROPELLERS

Propellers are the mechanical device that are used to mix liquid materials by using blades. A three bladed design is generally used for liquids.

The mixing is done by mixing a immisible liquid with the other miscible liquid to form the real solutions. These mixers work primarily on shear forces using different types of blades.

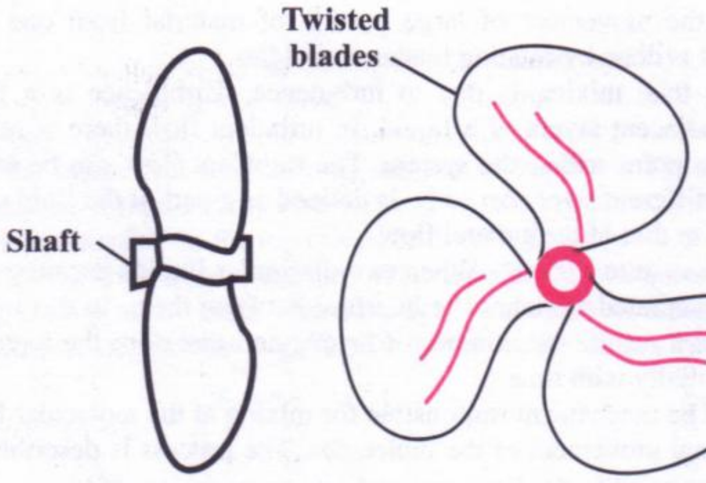


Figure 8.8: Three bladed design

Propeller Mixer

PRINCIPLE

The propeller mixer mainly works on the principle of shearing force.

Construction

It consist of vessel and propeller. A propeller has angled blades, which cause the fluid to circulate in both an axial and a radial direction. Size of propeller is small and may increase upto 0.5 meters depending upon the size of tank. Small size propellers can rotate upto 8000 rpm

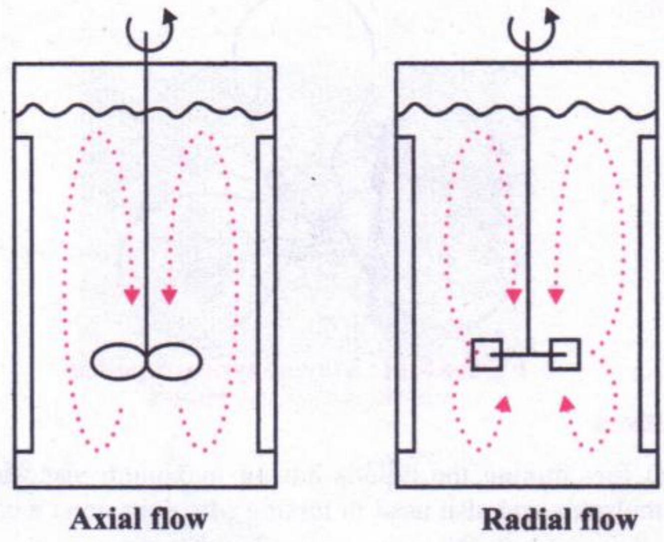


Figure 8.9: Flow pattern during mixing

Working

A vortex forms when the centrifugal force imparted to the liquid by the propeller blades causes it to back up around the sides of the vessel and create a depression at the shaft. As the speed of rotation is increased air may be sucked into the fluid by the formation of a vortex this cause frothing and possible oxidation. Another method of suppressing a vortex is to fit vertical baffles into the vessel.

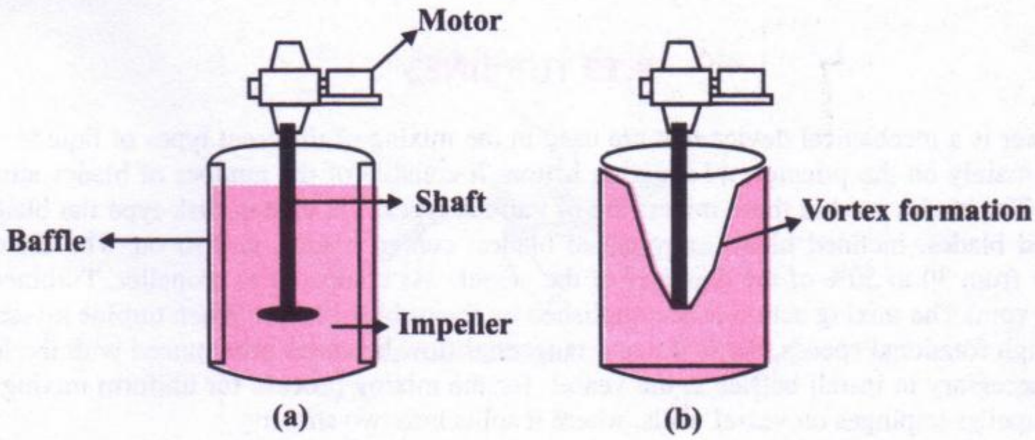


Figure 8.10 (a) Baffled tank with no vortex formation and

(b) unbaffled tank having vortex formation

Installation of ***Vertical Propeller*** reduce the vortex to considerable extent. Vertical propeller mixer consist of three blades (4 ft long).

Horizontal or inclined propeller or marine propeller are also used on side-entry mixers. They are mounted with the impeller shaft inclined at an angle to the vessel axis to improve the process results. They provide good blending capability in small batches of low to medium viscosity.

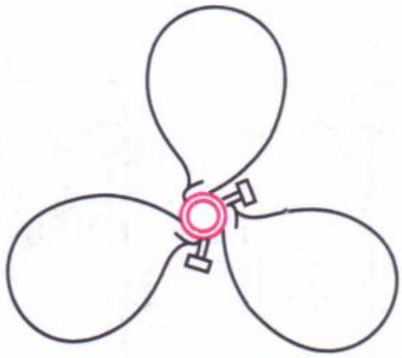


Figure 8.11: Marine type propeller

Pharmaceutical Applications

The propeller mixer used for mixing the liquids having maximum viscosity of 2.0 **Pascal**-second, for mixing of low visocity emulsions and also used in mixing of suspensions with particles size upto 0.1 to 0.5 mm.

Advantages

Propellers are effective when high mixing capacity is required.

Disadvantages

1. Propellers are not effective for liquids having viscosity greater than 5.0Pascal second
2. Equipment Cost is high

8.19 TURBINES

A turbine mixer is a mechanical device that are used in the mixing of different types of liquids. The turbine mixer works mainly on the principle of shearing action. It consists of the number of blades attached to the circular disk. The blades used in these mixers are of various types: flat blades, disk-type flat blades, inclined blades, curved blades, inclined blades, arrowhead blades, curved blades, and so on. The diameter of the turbine varies from 30 to 50% of the diameter of the vessel. As compared to propeller, Turbines rotate at a lower speed (rpm).The mixing action is accomplished by the turbine blades. When turbine mixers operate at sufficiently high rotational speeds, the radial and tangential flow becomes pronounced with the formation of vortex. It is necessary to install baffles in the vessel for the mixing process for uniform mixing. The radial flow of the impeller impinges on vessel walls, where it splits into two streams.

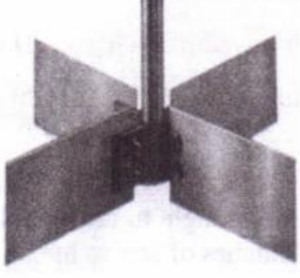


Figure 8.12 Straight Blade turbine

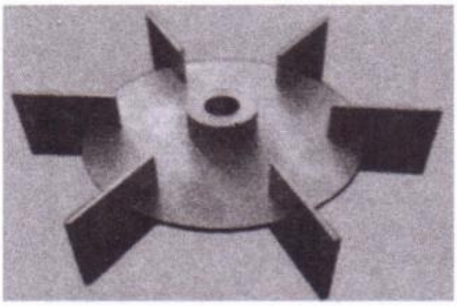


Figure 8.13 Disc turbine

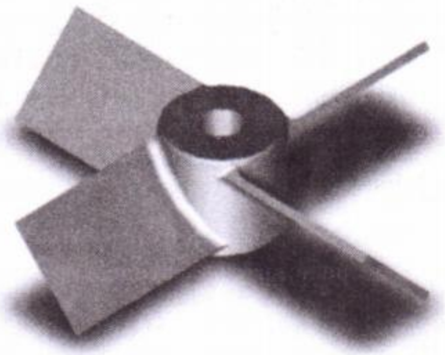


Figure 8.14 Pitched blade turbine

Figure 8.15 Curved vane turbine

Uses

A turbine mixer suitable for viscous fluids (having viscosity 7.0 pascal-second), Turbines are also used for thin paste and emulsification. Turbines can also used to handle slurries with 60% solids. Turbines are mainly used for semisolid materials.

Advantage

Turbines give greater shearing forces than propellers

8.20 PADDLES

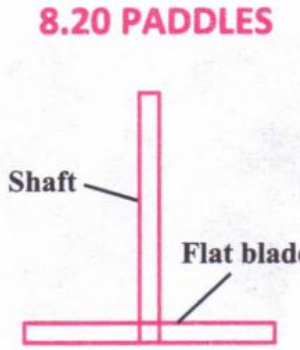


Figure 8.16 Paddle

Paddle consist of two long flat blades attached vertically to shaft. It rotates at low speed. Paddles mixer are suitable to mix viscous liquids or semisolids. A variety of paddle mixer are available depending upon nature and viscosity of product. Blades used in this mixer are dished or hemispherical in shape. Paddles push liquid radially and tangentially. There is no axial movement of flow during mixing. The diameter of paddle is 50-80% of inside diameter of vessel.

Advantages

1. Vortex formation is not possible.
2. It has low speed.
3. Mixing efficiency is better.
4. No dead spots and deposited solids.

Disadvantages

In case of suspension mixing is poor. Therefore baffled tanks are required

8.21 SILVERSON EMULSIFIER

Two immiscible liquids are mixed to prepare an emulsion is widely used in pharmacy. The equipment used for preparation of emulsion is known as **emulsifier. Homogenizer** are used to convert coarse emulsion to fine emulsion.

Principle

The sliverson homogenizer works on the principle that the large globules in a coarse emulsion are broken into smaller globule by intense shearing forces and turbulence by high speed rotors.

Construction

It consists of a emulsifier head. The emulsifier head consist of a number of turbines blades. The blades are surrounded by mesh which is enclosed by cover having perforations. The blades are rotated by using the electric motor fitted at the top. There is also one shaft whose one end is connected to motor and other end is connected to head.

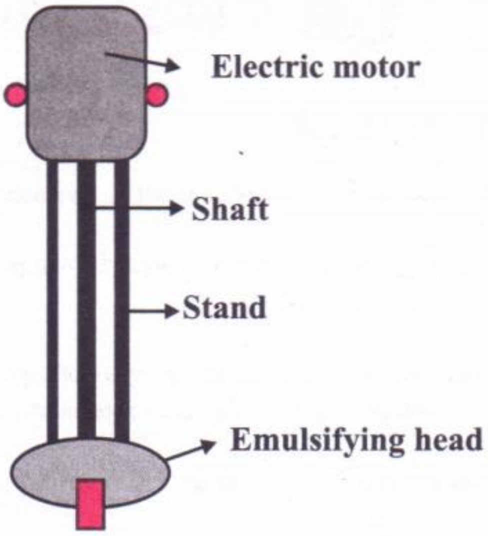


Figure 8.17: Construction Of Silverson Emulsifier

Working

The emulsifier head is dipped into the vessel containing immiscible liquids. When the motor is started, shaft rotates the head. Therefore turbines blades also rotate at very high speed. The liquids are sucked through the fine hole. Centrifugal force expel content through mesh and then to cover and subjects them to mechanical shear. This is followed by intense hydraulic shear. The oil is reduced into the globules quickly resulting in a homogeneous, uniform product. Then fine emulsion emerge through opening of cover. As a result bigger globule rapidly break into smaller globules.

Pharmaceutical Applications

1. Silverson Mixer Homogenizers are fast and efficient. They are used to get a fine droplet or particle size (2 - 5 microns).
2. Process efficiency is good.
3. Low operating cost.
4. It is used for preparation of creams, ointments, pharmaceutical suspensions and emulsions of fine particle size.

Disadvantage

1. Chances of choking of pores of mesh.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

Q1. Define Mixing

Answer- It is defined as a process in which two or more components within a system are converted into one mass or mixture.

Q2. Define Convective Mixing.

Answer- These are the mixing in which the groups of particles move from one position to another. It is also referred to as macromixing.

Q3. What are Diffusive Mixing?

Answer- During this mixing, gravitational forces cause the upper layers of materials to slip and random motion of the individual particles takes place on newly developed surfaces. This is also sometimes known as micromixing.

Q4. Define Laminar Mixing.

Answer- This type of mixing occur when two dissimilar liquids are mixed through a laminar flow, the shear that is generated stretches the interface between them.

Q5. What are Propellers?

Answer- These are mechanical device that are used to mix liquid materials by using blades.

SHORT ANSWER QUESTIONS

Q1. The Mixing is carried out in a closed enclosure, Why?

Answer- Mixing is carried out in closed enclosure to avoid release of the dust. And the loss of volatile solvent during mixing can also be prevented by closing the chamber.

Q2. Write disadvantage of double cone blender.

Answer- It is not suitable for fine particles and also not suitable for particles with greater particle size difference due to less shear.

Q3. How degree of mixing is evaluated?

Answer- The degree of mixing is evaluated by comparing standard deviation of sample under investigation (S_I) with estimated standard deviation of sample from fully random mix (S_R)

$$\text{Mixing Index (M)} = S_R / S_I$$

Q4. How V blender Works?

Answer- The material is loaded into the blender. On rotation, a tumbling motion occurs. When the V-Blender tumbles, the material divides and recombines continuously. The repetitive converging and diverging movement between the material and the blender results homogenous blending.

Q5. What are the uses of propeller mixer?

Answer- Propeller mixer are used for mixing the liquids having maximum viscosity of 2.0 Pascal-second, for mixing of low visocity emulsions and also used in mixing of suspensions with particles size upto 0.1 to 0.5 mm maximum with a drying residue of 10%

LONG ANSWER QUESTIONS

1. Define Mixing Index. Write the differences between solid and liquid mixing
   (Refer article 8.7)
2. Describe Principles, Construction, Working, uses, Merits and Demerits of twin shell blender.
   (Refer article 8.11)
3. Describe Principles, Construction, Working, uses, Merits and Demerits of ribbon blender.
   (Refer article 8.13)

4. Describe Principles, Construction, Working, uses, Merits and Demerits of Sigma blade mixer.
   (Refer article 8.14)
5. Define mixing. Describe the factors affecting mixing operations.
   (Refer article 8.1,4.5)
6. Describe Principles, Construction, Working, uses, Merits and Demerits of Silverson Emulsifier.
   (Refer article 8.21)
7. Write short note on
   a. Turbines
      (Refer article 8.19)
   b. Paddles
      (Refer article 8.20)
8. Write short note on
   a. Propellers
      (Refer article 8.18)
   b. Application of mixing
      (Refer article 8.4)

MULTIPLE CHOICE QUESTIONS

1. Which of the following is not the mechanism involved in solid solid mixing?

a. Convective
b. Shear
c. Diffusive
d. Bulk transport

2. Which of the following is suitable mixing equipment for two immiscible liquids

a. Silverson emulsifier
b. Double cone blender
c. Ribbon blender
d. twin shell blender

3. Vortex formation take place

a. In unbaffled tanks
b. At high impeller speed
c. When blades in turbines are arranged perpendicular to central shaft
d. All of the above

4. Which of the following is also known as V Cone Blender?

a. Twin shell blender
b. Double cone blender
c. Ribbon blender
d. Colloid mill

5. Which of the following is example of static mixer

a. Ribbon blender
b. V cone blender
c. Double cone blender
d. Silverson emulsifier

6. In sigma blade Mixer, the clearance between the blades and the vessel walls is

a. Low
b. High
c. Moderate
d. None of the above

7. Silverson mixer is used for preparation of :

a. lotion
b. Emulsion
c. Elixirs
d. Suspension

8. Which of the following rate is observed during mixing of solids?

a. First order law
b. zero order law
c. Second order law
d. Third order law

9. The movement of large portion of material from one location to another location is called

a. Bulk transport
b. Diffusion
c. Agitation
d. Convection

10. Higher the value of mixing index, greater will ___________

a. Homogenity
b. Solubility
c. Viscosity
d. Density

ANSWERS

1.d 2.a 3.d 4.a 5.a 6.a 7.b 8.a 9.a 10.a

9 CHAPTER FILTRATION

Selected Definitions

Filtration: It is defined as a solid liquid separation process in which solids are separated from suspension by passing through a porous medium that accumulate the solids, but allows the passage of fluids.

Slurry: It is the suspension of solid and liquid which is to be filtered.

Filter medium: It is the porous medium used to filter the solution.

Filter cake: It is defined as the accumulated solids on filter medium.

Filtrate: It is the clear liquid which pass through the filter.

Clarification: It is the separation process in which the amount of solid in liquid is not more than 1 % w/v.

Rate of filtration: It is defined as volume of filtrate collected in unit time.

Poiseuille's equation- This equation states that the flow of the filtrate under pressure through capillaries is laminar

Permeability: It is defined as flow rate of liquid having unit viscosity across unit area of cake and unit thickness under pressure difference of unity.

Filter aids: These are inert powders added to the liquid be filtered and increase the porosity and cake permeability.

Surface filtration: It is the process of removal of material suspended in a liquid by means of sieving.

Membrane Filtration: It is a separation process that uses a semipermeable membrane.

Bubble point pressure: It is the minimum pressure which is required to force the liquid out of the capillary.

9.1 INTRODUCTION

Filtration can be defined as a solid liquid separation process in which solids are separated from suspension by passing through a porous medium that accumulate the solids, but allows the passage of fluids. The suspension of solid and liquid which is to be filtered is known as **slurry.** The porous medium used to filter the solution is known as **filter medium**. The accumulated solids referred as **filter cake.** The clear liquid passing through the filter is **filtrate.** The term **clarification** is used when amount of solid in liquid is not more than 1 % w/v. **Rate of filtration** is defined as volume of filtrate collected in unit time.

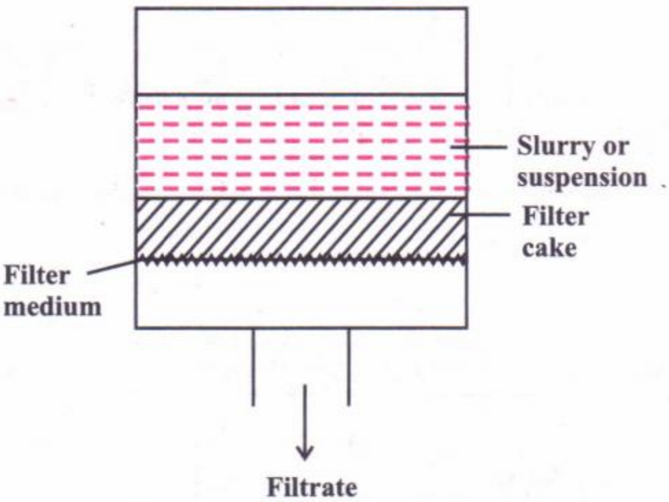


Figure 9.1: Filtration process

9.2 APPLICATION OF FILTRATION

1. During manufacturing of sterile products, it is necessary to remove smallest particle. Therefore, air is filtered through HEPA filters (high efficiency particulate air filters) to get sterile air.
2. The solution, suspension, eye drops, elixirs etc. should be free from suspended solids. Filtration is major step during production of such formulations.
3. Filtration methods are used in home to clarify potable water
4. Filtration is necessary to separate substances of different chemical composition
5. On industrial scale filtration is used for dewaxing of oils.
6. Filtration technique is used to treat sewage and waste water treatment.

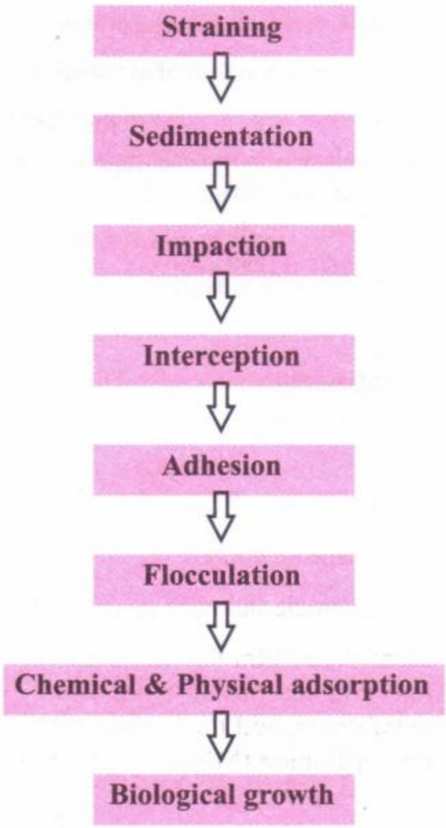


Figure 9.2: Steps involved in mechanism of filtration

9.3 MECHANISM OF FILTRATION

The filtration process involves several mechanisms. It has been identified that the straining is the main mechanism that is operative in the elimination of solids in suspension during the filtration. Other mechanisms that include impaction, interception and adhesion, etc.

1. **Straining:** The particles which are larger than the pore space of the filtering medium are strained out mechanically. While particles smaller than the pore space are trapped within the filter.
2. **Sedimentation:** The particles within the filter settle on the filtering medium.
3. **Impaction:** Heavy particles do not follow streamlines flow.
4. **Interception:** The particles are removed during contact with the surface of the filter medium
5. **Adhesion:** The particles adhere to the surface of the filter medium as they pass
6. **Flocculation:** It occur within the interstices of the filter medium.
7. **Chemical Adsorption (i.e. Bonding, chemical interaction) and Physical adsorption (i.e. Electrostatic force, van der wall force):** Once a particle has come into contact with the surface of the filter medium or with other particles, one of these mechanisms, chemical or physical adsorption or both may occur.
8. **Biological growth:** The biological growth inside the filter reduces the pore volume and improves the removal of particles with any of the previous removal mechanisms

9.4 TYPE OF FILTRATION

Based on the mechanism, the filtration is classified as

1. **Depth filtration:** In this method, the removal of suspended material from the liquid suspension is performed by passing the liquid through a filter bed composed of granular or compressible filter medium. The material used for filter bed are packed bed of sand, anthracite, or other granular media. Solids (particles) get attached with gradient density structure to the media by adsorption or by physical restriction. This method is used in the treatment of surface waters for potable water supply.
2. **Surface filtration:** Surface filtration involves the removal of material suspended in a liquid by means of sieving. In this method, the liquid passes through a thin septum (ie, filter material). Materials that have been used as a filter septum include woven wire cloths, cloth fabrics of different fabrics and a variety of synthetic materials
3. **Membrane Filtration:** Membrane filtration is a separation process that uses a semi permeable membrane. It consist of two parts:

(a) permeate containing the material that passes through the membranes, and

(b) retentate include species being left behind.

Membrane filtration can also be classified in terms of the size range of the permeating species, the rejection mechanisms, the driving forces employed, the chemical structure and composition of the membranes, and the geometry of the construction. The most important types of membrane filtration are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and Reverse osmosis (RO).

9.5 THEORIES OF FILTRATION

The fluid passes through the filter medium, which offers resistance to its passage, under the influence of a force that is the pressure difference across the filter.

$$\text{rate of filtration} = \frac{\text{driving force}}{\text{resistance}} \quad (9.1)$$

There are different theories of filtration

Poiseuille's equation- If flow of the filtrate under pressure through capillaries is laminar, then Poiseuille's equation could be used

$$V = \frac{\pi \Delta P r^4}{8 L \eta} \quad (9.2)$$

Where V = rate of flow

ΔP = pressure difference across the filter

r = radius of capillary in filter bed

L = thickness of filter cake

η = viscosity of filtrate

Darcy's law

When fluid flow through a porous material, such as the filter cake, then the flow rate relates to pressure drop causing that flow and this process is described by **Darcy's law**

$$V = \frac{K A \Delta P}{\eta L} \quad (9.3)$$

Where

K = permeability coefficient of cake

A = surface area of porous bed

ΔP = pressure difference across the filter

L = thickness of filter cake

η = viscosity of filtrate

Permeability is defined as flow rate of liquid having unit viscosity across unit area of cake and unit thickness under pressure difference of unity. The SI unit of permeability is m^2.

Kozeny Carman Equation

Darcy equation is further modified by Kozeny – Carman. The Kozney- Carman equation is used for filtration is expressed as

$$V = \frac{A}{\eta S^2} \times \frac{\Delta P}{KL} \times \frac{\varepsilon^3}{(1-\varepsilon)^2} \quad (9.4)$$

Where

K = Kozeny constant

A = surface area of bed

ΔP = pressure difference across the filter

L = thickness of filter cake

η = viscosity of filtrate

ε = Porosity of cake or bed

S = specific surface area of particles consist of cake

For random packing of incompressible bed, Kozeny constant is generally considered as 5. A 10 % in porosity cause 3 fold changes in V (rate of flow). Kozney Carman equation is not applicable in actual condition where the depth of granular bed in less than actual length of path traversed by fluid, since actual flow path is sinuous instead of straight throughout the bed.

9.6 FACTORS INFLUENCING FILTRATION

1. **Area of filter surface:** According to Darcy's equation the rate of filtration is directly proportional to surface area of filter medium while according to Kozeny-Carman equation rate of flow of filtrate is inversely proportional to specific surface of filter bed. Therefore rate of flow can be enhanced by using large filters. For example in rotary drum filter, the continuous removal of filter cake provide infinite area of filtration.
2. **Permeability coefficient (k):** As thickness of cake increase, the rate of filtration will decrease. The permeability coefficient depends on characteristic of cake such as porosity, compressibility and specific surface area.
3. **Pressure drop:** The rate of filtration is proportional to the pressure difference across both the filter medium and filter cake. The pressure drop can be achieved by

(a) Maintaining a head of slurry above the filter medium. The pressure developed will depend on the density of the slurry.

(b) The pressure below the filter medium can be reduced below atmospheric pressure by connecting the filter receiver to a vacuum pump and developing a pressure difference across the filter.

(c) Pumping the slurry into the filter under pressure.

4. **Viscosity of Filtrate :** An increase in the viscosity of the filtrate will increase the flow resistance. The filtration rate is inversely proportional to the viscosity of the fluid. This problem can be overcome by two methods: (a) The filtration rate can be increased by raising the temperature of the

slurry. However, it is not practical for thermolabile materials and also for volatile filtrate. (b) Dilution is another approach, but the rate must be doubled.

5. **Thickness of the filter cake :** The rate of flow of the filtrate through the filter cake is inversely proportional to the thickness of the cake. The preliminary decanting is used to reduce the amount of solids.

9.7 FILTER AIDS

Filter aids are inert powders added to the liquid be filtered and increase the porosity and cake permeability. The purpose of the filter aid is to prevent blockage of the medium and to form an open porous cake, thereby reducing the flow resistance of the filtrate.

Filter aids are used in two ways:

- As a precoat layer to protect the filter medium and improves the clarity of the filtrate
- As body feed to enhance flow rates

Filter aids such as diatomaceous earth, perlite and cellulose allow liquid to pass through while retaining the haze-causing particles. Diatomaceous earth (DE) or Kieselghur is the skeleton of ancient diatoms. They are extracted from the ancient seabed, processed and classified to produce different types of filtration aids. DE is the most commonly used filter aid. However, the crystalline type DE is a suspect carcinogen and inhalation should be avoided during handling. There are different qualities of commercial DE. A finer grade can be used to increase the clarity of the filtrate. The smaller the particle size of the filter aid results lower filtration rate. Perlite is another important mineral filter aid.

Diatomaceous earth and perlite are silica based minerals. There are several other special materials used as filter aids, including asbestos, cellulose, agricultural fibers, saw dust, rice hull ash, paper fibers etc. Decolourising clay and activated carbon with kieselghur act as filter aid for clarifying aqueous solutions as well oils.

Good filter aids are light and chemically inert. They form high porosity filter cakes that allow high initial flow of liquid, provide pore spaces to trap and contain filterable solids and leave a high percentage of channels remaining open for flow. Dicalite diatomite, perlite and cellulose filter aids meet these criteria. They are available in a variety of grades to meet the requirement of removing solids from any application.

The main disadvantage of filter aid is that sometime active constituent also get adsorbed on filter aid.

9.8 FILTER MEDIA

The surface on which the solids are deposited in a filter is called "filter media". The filter medium must be capable of supplying clear filtrate at an adequate production rate. There should be no loss of filter media during backwash. It must withstand mechanical stresses without breaking or compressing. Use narrow-size filter media for good porosity and long filter run. There must be no chemical or physical interactions with the components of the filtrate. It must retain the solids without clogging at the beginning of the filtration. Filter media should have ability to discharge cake easily. Sterile filtration imposes a special requirement since the pore size should not exceed the dimension of bacteria or spores.

Filter media are made of

(a) Woven filters such as Wire screening (e.g. stainless steel) and fabrics of cotton, wool, nylon. Stainless steel is more durable. It is resistant to plugging and can be easily cleaned. Nylon is superior for pharmaceutical use. Cotton is preferred in case of cake filtration because it is light in weight , cheap and easily available.

(b) **Non- woven fibrous filters**: These include materials in which fabrics are joined to form a porous network. They are discarded after single use.

(c) Filter paper is a common filter medium. They are used for retention of very fine solids. They have controlled porosity, limited absorption characteristics, and low cost. They are also available in various thickness and strength

(d) Filter sheets and filter clothes are also available in various porosity grades.

(e) **Porous plates:** These include perforated metal or rubber plates, natural porous materials such as stone, porcelain or ceramics, and sintered glass.

(f) **Membrane filters:** They are useful in the preparation of sterile solutions. These filters are made by casting of various esters of cellulose, or from nylon, Teflon, polyvinyl chloride.

During filtration solids get deposited on filter medium. Due to this thickness of cake increased while rate of filtration decreases. In this case filter cake is removed and filtration is restarted.

9.9 CLASSIFICATION OF FILTRATION EQUIPMENT

Classification of Filtration Equipment

- **Pressure filter**
  - **1. Plate and frame filter press**
  - **2. Meta filter**
- **Vacuum filter**
  - **1. Filter leaf**
- **Rotary Drum filter**
- **Cartridge filter**
- **Membrane filter**
- **Seitz filter**

9.10 PLATE AND FRAME FILTER PRESS

Principle

This is the simplest type of pressure filter. The slurry enters the frame by pressure and flows through the filter medium. The filtrate is collected on the plates and sent to the outlet. A number of frames and plates are used so that the surface area increases and, therefore, large volumes of slurry can be treated simultaneously with or without washing.

Construction

It consists of plates and frames arranged alternatively and supported on a pair of rails. The plate is a solid piece having a ribbed surface. The plate consist of an outlet. The frame is hollow and provides space for the filter cake. Frame of varying thickness are also available. The frame consists of an open space inside where the slurry reservoir is held for filtration and an inlet for receiving the slurry. The cloth as filter medium is placed between plate and frame. The filter cloth have holes and act as gasket. Plate, filter medium, frame, filter medium and plate are arranged in the sequence and clamped to a supporting structure. By this alternate arrangement of frame and filter, the chamber form in which the cake will be deposited. The plate and frame are square or rectangular and made of cast iron, stainless steel, nickel, aluminum, monel, wood, hard rubber or plastic (polypropylene).

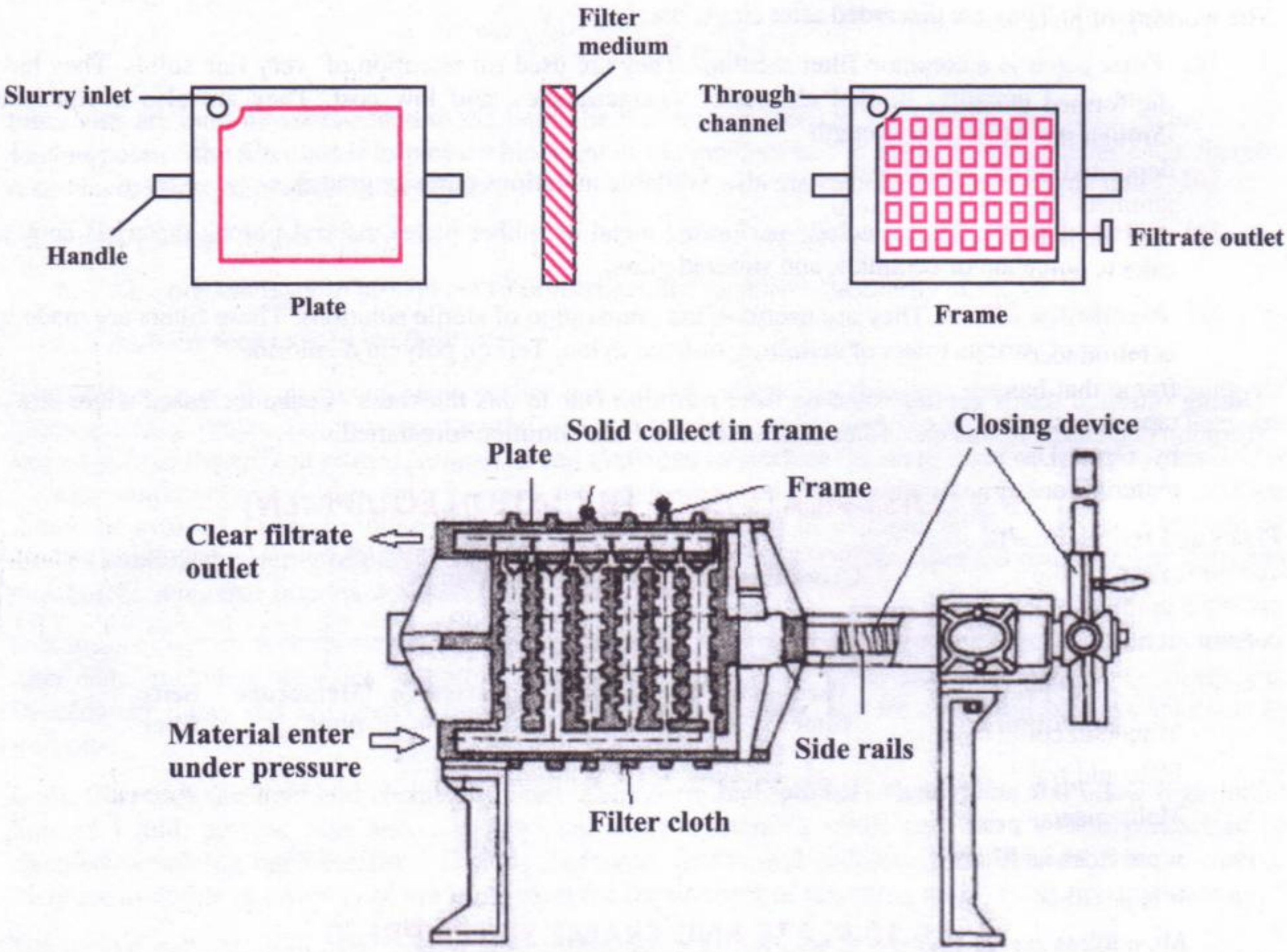


Figure 9.3: Plate and frame filter press

Working

The plate and frame assemblies are designed in two types, namely,

(i) non - washing type and

(ii) washing type.

(1) **Non-washing type:** In this type, the plates and frames have one hole at the upper corners. The holes in the plate are not connected to inside. But the holes on the frame open inside the frame. The holes in the plates and frames align to form a continuous channel through which the slurry is fed.

(2) **Washing type:** When the cake is washed thoroughly with washing liquid or when there is contamination, then washing type plate frame filter press is used. Two different types of plates are used. For the identification of the plates and frames, outside button systems are there. For example: There are one button on Plate. While Frame have two buttons and Wash plate have three buttons. The arrangement of the Plate frame and wash-plate is always in the order of 1-2-3-2-1 button.

The working of plate and frame filter press is explained in two steps

1. **Filtration process**: The slurry to be filtered is pumped through the channel or feed inlet. It runs on the formed chamber and fills the chamber completely. The filtrate passes through the cloth, runs through the faces of the plates and finally leaves the filter through discharged cocks. The solids are deposited on the filter cloth. After some time chamber is fully charged, then the press is said to be jammed. To remove the soluble impurities from the cake wash, liquid is introduced into the press, then air is blown to remove the residual liquid from it. The press is then dismantled and the solids cake is removed or scrapped from each plate and dropped to a conveyor or storage bin.
2. **Washing process**: In the simple washing, the outlet of the washing plates is closed. The wash liquor is introduced through the feed channel. The water passes through the filter cloth and then enters the frame that has the deposited cake. After washing the cake, the water comes out through the outlet taps. It is suitable when the cake is uniform and permeable. Filtrate is discharged by two ways either by Open Discharged or Close Discharged. The close technique is used when toxic or volatile materials are to be filtered.

Plates and frames may be made of various metals to provide resistance from corrosion or to prevent metallic contamination of the product. The plate is ranging from 100 x 100 mm to 1500 x 1750 mm. Operating pressure upto 700 kPa are common. The press may be operated upto 7 MPa by using suitable material of construction.

Advantages:-

a. Simple in construction.
b. Plate and frame filter presses provide the lowest cost of filtration per unit of fluid processed
c. Maintenance cost is low.
d. It provides large filtering area per unit for floor space occupied.
e. It is possible to alter the capacity.
f. Most joints are external, so leakage is easily detected.
g. Flexibility.
h. Proper washing of cake is possible.

Disadvantages:-

a. Labour requirement is very high.
b. Life of Filter cloth is relatively short.
c. Not suitable to get high output. It is suitable for slurries containing less than 5% solids.
d. Problem of leakage of equipment.

Uses:

a. Plate and frame filter press is widely used in food industry, mining industry, pharmaceutical industry, chemical industry, waste water treatment.

b. In pharmaceutical industry- Enzymes, amino acids, antibiotics, pharmaceutical intermediates, bulk drugs, medicine, blood products, antibiotics (chlortetracycline, erythromycin, spiramycin, Jinggangmeisu, Midecamycin, tetracycline, berberine, oxytetracycline), calcium phytate, Chinese inositol, growth derived sand, organic phosphorus, glucoamylase are filtered by this press.

c. The filter sheets made of asbestos and cellulose are capable of retaining bacteria, so that sterile filtrate can be obtained provided that all the filter press and the filter medium have been previously sterilized. For this purpose, steam passes through the assembled unit for sterilization.

d. For the filtration of viscous liquids, heating and cooling coils are attached in the press.

e. Filter presses are used in a huge variety of different applications, from dewatering of mineral mining slurries to blood plasma purification.

f. At the same time, filter press technology is suitable for ultrafine coal dewatering as well as filtrate recovery in coal preparation plants.

9.11 META FILTERS OR EDGE FILTER

Principle

It is a type of pressure filter. Pressure filters feed the product to the filter at a higher pressure than would be derived from gravity alone. This is the most common type of filter used in the processing of pharmaceutical products. The metafilter works as a strainer or filter for the separation of particles. The metal rings with number of semicircular projections are arranged as a nest. Therefore channels are formed at the edges. This channel offers resistance to the flow of solids (forced particles). The clear liquid is collected into a receiver from the top.

Construction

Metafilters consist of metal rings. These rings are made of stainless steel. They are approximately 15 mm in internal diameter, 22 mm in outer diameter and 0.8 mm in thickness. These rings have several semicircular projections on one surface. The metafilter consists of a grooved drainage rod on which a series of metal rings are packed. The height of the projections and the shape of the ring section are such that when the rings are packed together in the same way upwards, and tightened on the drainage rod with a nut, narrowing channels are formed from approximately 250 μm down to 25 μm.

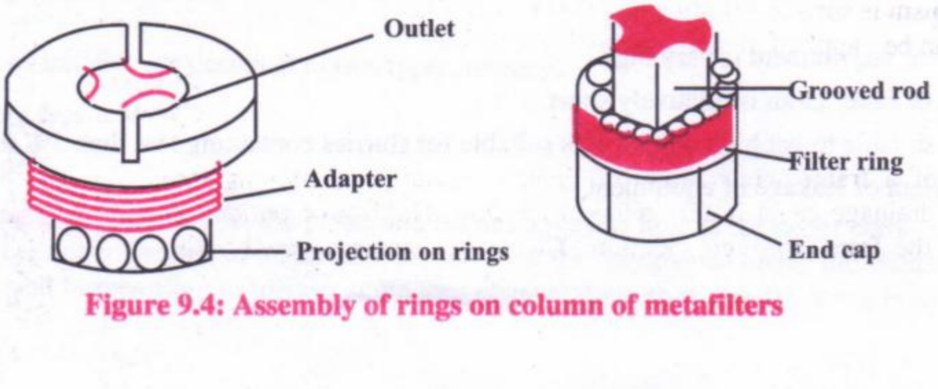


Figure 9.4: Assembly of rings on column of metafilters

Working

These metafilters are mounted in a container and can be operated by pumping slurry under pressure or, occasionally, by applying reduced pressure on the outlet side. The slurry passes through the channels formed at the edges between the rings. The clear liquid is raised and collected from the outlet to the receiver. In this way, the metafilter can be used as a strainer for coarse particles, but for finer particles a bed of a suitable material like kieselguhr is first formed. The packs of ring, therefore, essentially serves as a base on which the true filter medium is admitted.

Stacked-disc filter are also designed which is very robust device. It consists of a number of rings which are assembled on a grooved rod. The assembled stacks are placed in a pressure vessel which can be sterilized if necessary. During use, the filtrate passes between the discs and is removed through the grooves. Solids are deposited on the filter coating. Operation is continued until the resistance becomes too high. The solids are removed from the rings by applying back pressure via the fluted rods. There is no filter cloth and the bed is easily replaced, labour cost are low.

Advantages: -

a. It can be used at high strength and pressure with no danger of bursting the filter medium.

b. It is economical filter. As there is no filter medium as such , the running cost is low.

c. It can be made non corrosive material and avoid contamination with most sensitive product.

d. By selecting the appropriate material to form the filter bed, it is possible to filter very fine particles. Removal of the cake is effected effectively by back flushing with water, further cleaning is necessary.

Uses

a. These filters are used for clarification and polishing of beverages and pharmaceutical suspension having low solid content.

b. Suitable for viscous liquids.

c. Suitable for corrosive substance.

d. It is used in clarification of syrups, and products such as insulin liquors.

9.12 FILTER LEAF

Principle

The mechanism is surface filtration and acts as a strainer.
Vacuum can be applied to increase the filtration rate.

Construction

It consists of a frame which may be circular, square, and rectangular shape. The drainage canal is surrounded by frame. The filtrate outlet is attached to the frame through sunction. The entire unit is covered with filter cloth.

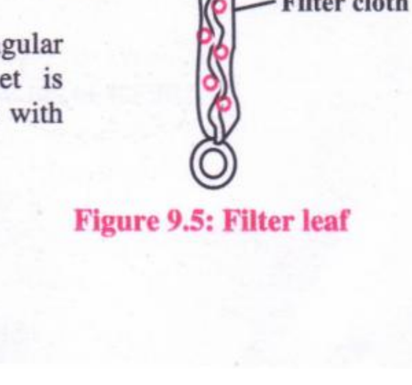


Figure 9.5: Filter leaf

Working

The whole assembly is placed inside a container of slurry. The vacuum is connected to outlet.. The slurry passes through the filter cloth. Solids accumulate on the cloth. Filtrate enter the drainage canal and passes through the outlet. The cake is washed by immersing the filter in a container of water. The air is passed in the opposite direction which facilitate removal of cake.

Uses

Leaf filters are suitable for handling flammable, toxic and corrosive materials as they are autoclaved and designed for hazardous environments when high pressure and safe operation are required. The leaf filters are satisfactory if the solids content of the slurry is not too high, i.e., about 5% of the slurry.

Advantages :-

1. It require minimum floor space.
2. Labor cost is also not so much high.
3. High Washing efficiency
4. Filtration area can be enhanced by attaching number of leaves in parallel.
5. It provide high filtrate clarity.
6. Cake can be easily dislodged and washed.

Disadvantages:-

The maximum concentration of slurry that can be filtered is only 5%w/v.

Variant

Sweetland filter is variant of filter leaf. An alternative method is to enclose the filter leaf in a special cylindrical vessel into which the slurry is pumped under pressure. The upper part of the cylinder is fixed. Lower part can be swung away. The cake is removed by compressed air.

Different assemblies of leaf filter such as Moore Filter and Kelly filter are also available which provide large surface area.

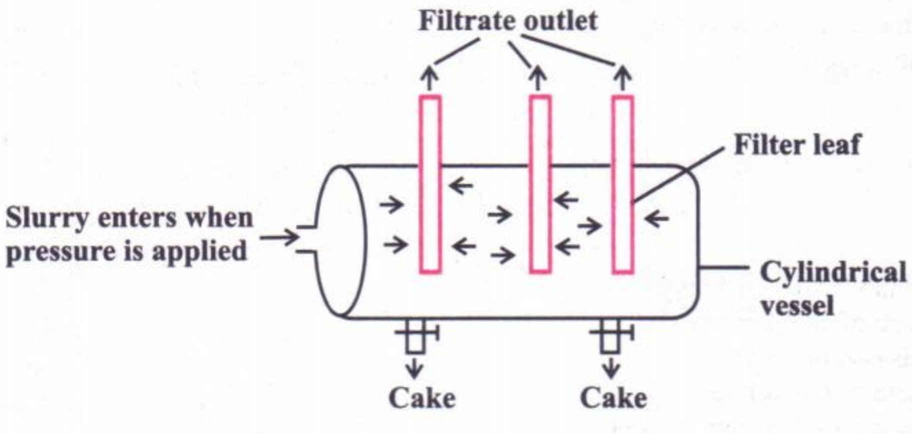


Figure 9.6: Sweetland filter

9.13 CARTRIDGE FILTER

Principle: The principle behind this filter is that water is pushed through thin porous membrane in which pre-filter and membrane filter are combined in to the single unit. As a result the particles are retained on the surface.

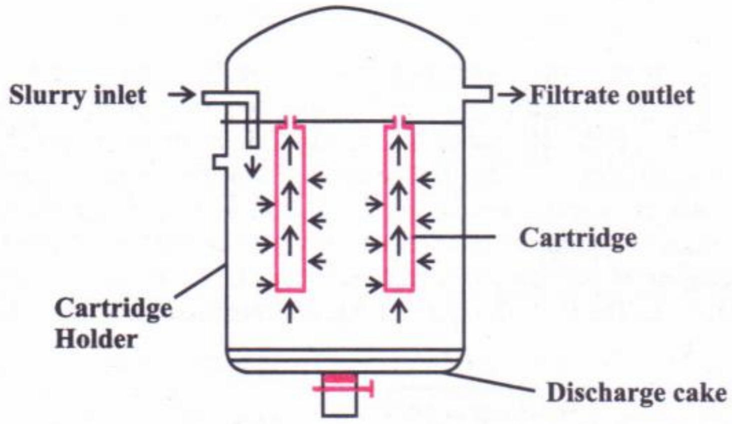


Figure 9.7: Cartridge filter

Construction

It consist of cylindrical configuration having disposable filter media which are made of plastic or metal. The filter consist of cartridges one of which act as prefilter while another one act as actual filter for filtration. The cartridges are enclosed in holder. There is also provision for slurry inlet and filtrate outlet. At the bottom discharge cake is collected which is removed from bottom.

Working

The slurry is pumped into the cartridge holder through the inlet. It passes through cartridge filter. The filtration occurs due to mechanism of straining. The particles get attached to the surface while the clear liquid passes to the center. The filtrate moves up and collected through the outlet.

Uses

Cartridge filter is used for preparation of sterile solutions such as preparation used for parenteral and ophthalmic. Cartridge filter is also used in water treatment plant.

Advantages

1. This is suitable for sterile operations
2. Less chance of contaminations
3. Ease in disassembling.
4. Filter media can be reused.
5. Cartridges with self cleaning devices are advantageous.
6. Cartridge are not brittle, when they are dry.
7. They are used in line continuous filtration which reduces handling of solutions.

Disadvantage

1. The cost of disposable elements neutralize the labor saving cost.

9.14 ROTARY DRUM FILTER

Principle:

The slurry is filtered on rotating drum surface by applying vacuum.

Construction

It consist of hollow horizontal metal drum which is 1 to 20 ft long. The drum rotates at the speed of less than one rpm. The face of the drum is divided into circumferential sectors each forming a separate vacuum cell. The internal piping is used to attach each sector to center of drum through rotating valve. The valve has certain filters adjustable blocks. A valve with a bridge setting controls the sequence of the cycle so that each sector is subjected to vacuum, blow and a dead zone. This helps in discharging of cake. The slurry is placed into the tank. Agitator is used to maintain uniformity of slurry. Filter cloth is attached to the face of the drum by inserting special caulking ropes into the grooved strips. The cloth ends are attached to clippers. The filter cloth is used to retains the cake. The multifilament strings are threaded across the entire cloth width. Sprays are attached to wash the cake.

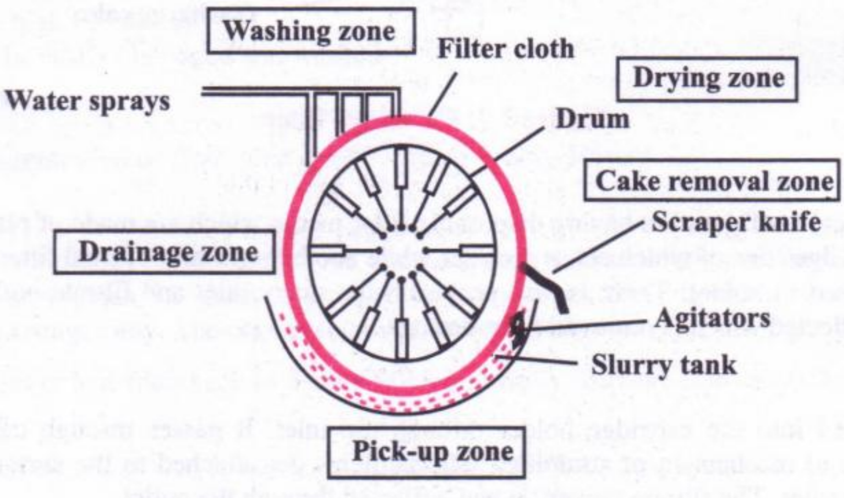


Figure 9.8: Rotary Drum filter

Working: The working of rotary drum filter is divided into various zones such as pick-up zone, drainage zone, washing zone, drying zone and cake removal zone. The drum is immersed to the required depth in the slurry, which is agitated with help of agitator to prevent settling of the solids. As drum rotates, vacuum is applied to those sectors of the drum which is submerged. A cake of the desired thickness is produced by adjusting the speed of rotation of the drum. The filtrate is passed out to the receiver. The drum leaves drainage zone and enter into water wash zone. The cake is then washed with sprays. The cake is partially dried by means of a current of air and cake enters into drying zone. Finally, pressure is applied under the cloth to aid the removal of the cake. The washed and partially dried cake is removed by means of a doctor knife. The cake is also discharged by string discharge and belt discharge filters. In string discharge filter, numbers of endless strings are placed over the width of the drum. String discharge filters are used when cake is sticky in nature. The wear of filter cloth is less in this case. In belt discharge filters short endless belts are used. Higher filtration rates may be achieved using belt discharge. All these steps completed in one cycle of drum. Then drum again receive fresh lot of slurry. When the solids of the slurry are too much that the filter cloth becomes blocked with the particles, a pre-coat filter may be used.

Advantages:

1. The rotary filter is continuous in operation
2. This filter is suitable for filter slurries containing a high proportion of solids.
3. Labour costs are very low due to automatic operation.
4. Rotary filter is suitable for filtration of highly concentrated solutions or thick slurries containing 15–30% of solids.
5. Variation of the speed of rotation enables the cake thickness to be controlled.
6. Very high capacity.

Disadvantages:

1. Complex design with many moving parts.
2. Very expensive because lot of accessories are connected such as vacuum pump, vacuum receivers , slurry pumps and agitators.
3. The cake tends to crack under vacuum, so washing and drying are not efficient.
4. As vacuum is applied, it is unsuitable for liquids near boiling point.
5. Gelatinous or slimy precipitates forming impenetrable cake will not separate cleanly from cloth

Uses:

1. Rotary filter is used for separation of the mycelium from the fermentation liquor in the manufacture of antibiotics.
2. It is suitable for slurry containing considerable amounts of solids in the range 15-30%.
3. These are used for collection of calcium carbonate, magnesium carbonate and starch.

9.15 MEMBRANE FILTERS

Membrane filters are microporous surfaces filters with pore size ranging from 0.005µm to 12 µm. They are made of cellulose acetate, cellulose nitrates, polytetrafluoroethylene (PTFE), polyvinylchloride, nylon etc. They must be handled very carefully. The membrane filters are available as discs or cartridges shapes. Filter having pore size 0.010 to 0.10 microns are used to remove virus particles from water or air. Filter having pore size 0.30 to 0.65 microns are used to remove bacteria. Large pore size filter are used in aerosols preparations. The most refined grade are used for laboratory purpose. Filter life is limited due to clogging. This problem is significant in case of thick solutions of large or fibrous particles like blood, gelatin, colloid, slimy plant extracts etc. Filter life can be increased by passing the slurry through a pre-filter. Finally it is passed through membrane filter. They are disposable, therefore chances of contamination is less.

Procedure: This technique involves filtering a known volume of water through a membrane filter. When the water sample is filtered, bacteria (larger than 0.45 µ) in the sample are trapped on the surface of the filter. The filter is then carefully removed, placed in a sterile Petri plate on a pad saturated with a liquid or agarbased medium, and incubated for 20 to 22 hours at 35°C. It is assumed that each bacterium trapped on the filter will then grow into a separate colony. By counting the colonies we can directly determine the number of bacteria in the water sample that was filtered.

The membrane filter is brittle on drying. As the membranes are brittle, the integrity tests are performed to predict the performance of a filter. Various integrity tests are:

(a) Bubble-point test

A minimum pressure is required to force the liquid out of the capillary is called the "bubble point pressure". The pressure is applied on the slurry side or the membrane, the first bubble will appear in the pore having the largest diameter. As the pressure increases, many bubbles appear on the filtrate side of the membrane. This pressure is taken as bubble point pressure.

(b) Bacterial challenge test

Suspension of specific bacterial culture is filtered through the membrane. The filtrate is incubated. After a specified time if bacterial growth take place in the medium then it is concluded that the bacteria had passed the membrane. It provide an idea about the nominal pore size of the membrane and about the integrity of the membrane. The various bacteria such as Pseudomonas diminuta, Pseudomonas aeruginosa, Serratia marcescens, Saccharomyces cerevisiae are used to test membrane filters of different sizes.

9.16 SEITZ FILTER

Seitz filter consist of perforated sheets and thick mats of asbestos disc. They are used to make liquid bacteria free. They are used to stop bacteria but not virus. Due to fibrous nature there are chances of shedding of fiber into the filtrate. Therefore some amount (in ml) of filtrate should always rejected.

Typical seitz filter having thickness of 2mm. For industrial purpose thicker pads are used. Fine shredded asbestos is commonly used because it provide highest adsorption of micro organism and other foreign particles. Seitz filters are supported on perforated metal, plastic or glass disc. The pads should not be reused to avoid contamination. Pads are cheap. The chances of clogging is also less because actual spacing between individual fibres are greater than retained particle size. For viscous solutions, seitz filter are preferred over other filters.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

1. **Define Bubble point pressure**

   Answer- It is the minimum pressure is required to force the liquid out of the capillary.

2. **Define filtration**

   Answer- It is defined as a solid liquid separation process in which solids are separated from suspension by passing through a porous medium that accumulate the solids, but allows the passage of fluids.

3. **What are filter aids?**

   Answer- Filter aids are inert powders added to the liquid be filtered and increase the porosity and cake permeability.

4. **Define Permeability?**

   Answer- It is defined as flow rate of liquid having unit viscosity across unit area of cake and unit thickness under pressure difference of unity.

5. **Define Rate of filtration.**

   Answer- It is defined as volume of filtrate collected in unit time.

6. **Which material is preferred in case of cake filtration and why?**

   Answer- Cotton is preferred in case of cake filtration because it is light in weight , cheap and easily available.

SHORT ANSWER QUESTIONS

1. **Define Membrane filtration.**

   Answer- It is a separation process that uses a semipermeable membrane. ıt consist of two parts one is permeate containing the material that passes through the membranes, and other is retentate include species being left behind. Membrane filtration can also be classified in terms of the size range of the permeating species, the rejection mechanisms, the driving forces employed, the chemical structure and composition of the membranes, and the geometry of the construction. The most important types of membrane filtration are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and Reverse osmosis (RO).

2. **Describe qualities of good filter aid.**

   Answer- Good filter aids are light and chemically inert. They form high porosity filter cakes that allow high initial flow of liquid, provide pore spaces to trap and contain filterable solids and leave a high percentage of channels remaining open for flow. Example: Dicalite diatomite, perlite and cellulose.

3. **What are the objectives of filter aid? How they act?**

   Answer- The purpose of the filter aid is to prevent blockage of the medium and to form an open porous cake, thereby reducing the flow resistance of the filtrate. Filter aids are used in two ways:

   a. As a precoat layer to protect the filter medium and improves the clarity of the filtrate
   b. As body feed to enhance flow rates

4. **How pressure difference affects the rate of filtration?**

   Answer- Rate of filtration is proportional to the pressure difference across both the filter medium and filter cake. The pressure drop can be achieved by

   Maintaining a head of slurry above the filter medium. The pressure developed will depend on the density of the slurry.

   The pressure below the filter medium can be reduced below atmospheric pressure by connecting the filter receiver to a vacuum pump and developing a pressure difference across the filter.

   Pumping the slurry into the filter under pressure.

5. **Describe Darcy law**

Answer- When Fluid flow through a porous material, such as the filter cake is described by **Darcy's law**

$$V = \frac{KA\Delta P}{\eta L}$$

Where, K = permeability coefficient of cake, A = surface area of porous bed, ΔP = pressure difference across the filter, L = thickness of filter cake, η = viscosity of filtrate

6. **Describe Kozeny Carman Equation. Write its significance.**

Answer- The Kozney- Carman equation used for filtration is expressed as

$$V = \frac{A}{\eta S^2} \times \frac{\Delta P}{KL} \times \frac{\varepsilon^3}{(1-\varepsilon)^2}$$

Where, K = Kozeny constant, A = surface area of bed, ΔP = pressure difference across the filter, L = thickness of filter cake, η = viscosity of filtrate, ε = Porosity of cake or bed, S = specific surface area of particles consist of cake

For random packing of incompressible bed, Kozeny constant is generally considered as 5. A 10 % in porosity cause 3 fold changes in V (rate of flow). Kozney Carman equation is not applicable in actual condition where the depth of granular bed in less than actual length of path traversed by fluid, since actual flow path is sinuous instead of straight throughout the bed.

LONG ANSWER QUESTIONS

1. Write detailed note on
   a. Explain mechanism of filtration
      (Refer article 9.3)
   b. Application of filtration
      (Refer article 9.2)
2. Explain various theories of filtration
   (Refer article 9.5)
3. Explain the factors influencing rate of filtration.
   (Refer article 9.6)
4. Write detailed note on
   a. Filter aids
      (Refer article 9.7)
   b. Filter medium
      (Refer article 9.8)
5. Describe Principle, Construction, Working, Uses, Merits and demerits of plate & frame filter press
   (Refer article 9.10)
6. Describe Principle, Construction, Working, Uses, Merits and demerits of meta filter
   (Refer article 9.11)
7. Describe Principle, Construction, Working, Uses, Merits and demerits of Cartridge filter
   (Refer article 9.13)
8. Describe Principle, Construction, Working, Uses, Merits and demerits of Rotary Drum Filter
   (Refer article 9.14)
9. Write detailed note on
   a. Membrane filter
      (Refer article 9.15)
   b. Seitz filter
      (Refer article 9.16)

MULTIPLE CHOICE QUESTIONS

1. **The process of separation of insoluble particles from suspension or slurry is called**
   a. Filtration b. Sieving
   c. Distillation d. Drying
2. **The separation process in which the amount of solid in liquid is not more than 1 % w/v is called**
   a. Clarification b. Filtration
   c. Centrifugation d. Evaporation
3. **Which of the following theory not describe rate of filtration?**
   a. Darcy law b. Poiseuille's equation
   c. Kozeny Carman Equation d. Noyes Whitney equation
4. **The rate of flow of the filtrate through the filter cake is ___________to the thickness of the cake**
   a. inversely proportional b. directly proportional
   c. remain constant d. none of the above
5. **Which of the following is not a filter aid?**
   a. Diatomaceous earth b. Perlite
   c. Cellulose d. Cotton
6. **Which of the following filtration equipment operate in operation**
   a. Rotary drum filter b. Membrane filter
   c. Meta filter d. Seitz filter
7. **Which of the following factor influence rate of filtration?**
   a. Area of filter surface b. Pressure drop
   c. Viscosity of Filtrate d. All of the above
8. **Filter aids are added to the liquid**
   a. To increase the porosity b. To increase cake permeability
   c. Both a and b d. None of the above
9. **Which of the following is/are classification of filtration equipment**
   a. Plate and frame filter press b. Meta filter
   c. Both a and b d. Filter leaf
10. **Filter having pore size _______________microns are used to remove virus particles from water or air**
    a. 0.010 to 0.10 b. 0.30 to 0.65
    c. 0.65 to 0.95 d. 1.0 to 1.5
11. **Sweetland filter is variant of _______**
    a. Filter leaf b. Meta filter
    c. Cartridge filter d. Seitz filter

ANSWERS

1.a 2.a 3.d 4.a 5.d 6.a 7.d 8.c 9.c 10.a 11.a

10 CHAPTER — CENTRIFUGATION

Selected Definitions

Centrifugation: It is the process in which centrifugal force is used as driving force for phase separation.

Centrifuge: The equipment used for separation is known as centrifuge.

Centrifugal effect (C) or Relative Centrifugal Force: It is the ratio of the centrifugal force (F) and gravitational forces (G).

10.1 INTRODUCTION

Centrifugation is the process in which centrifugal force is used as driving force for phase separation. The separation between the liquid and solid phases are on the basis of the particle size and density difference. The equipment used for separation is known as centrifuge. Centrifuges are also used for separation of macromolecules, separation of two immiscible liquids, to concentrate small molecular species, and to concentrate gases having different molecular weight. Centrifugation is widely employed when filtration process is not applicable.

10.2 APPLICATIONS

1. Centrifugation is widely used in bulk drug industry to separate crystalline material from suspension.
2. Centrifugation is used for isolation of bacterial cells, actinomycetes mycelium and spores from liquid growth.
3. Centrifugation is used for separation of blood cells from blood
4. Ultracentrifuge is used for separation of virus particle which are utilize in industrial applications
5. Centrifugation is used for separating drug present in blood, urine and tissue fluid. This is essential for evaluation of pharmacokinetic parameters and bioequivalence studies.
6. Centrifugation is used to obtain pure form of insulin by selective precipitating other fraction of protein and separating them by ultracentrifugation.
7. Ultracentrifugation is used to determine molecular weight of polymers, serum albumin, insulin and methyl cellulose.

10.3 PRINCIPLE OF CENTRIFUGATION

The centrifuge involves the principle of sedimentation, where the acceleration at centripetal force causes denser substances to separate along the radial direction at the bottom of the tube and the lighter objects will tend move up the tube. The particle having size more than 5 μm are separated by simple filtration process while the particle having size 5 μm or less do not sediment under gravity. The centrifugal force is used to separate them.

Let us consider a body of mass (*m*) rotating in a circular path with radius (*r*) at a velocity of (*v*). The force (F) acting on the body in a radial direction is given by

$$F = \frac{mv^2}{r} \tag{10.1}$$

The gravitational force acting upon the same body is given as

$$G = mg \tag{10.2}$$

Where, G = gravitational force
g = acceleration due to gravity

The centrifugal effect (C) or Relative Centrifugal Force is the ratio of the centrifugal force (F) and gravitational forces (G). It is expressed as

$$C = \frac{F}{G} \tag{10.3}$$

Or

$$C = \frac{mv^2}{mgr} = \frac{v^2}{gr} \tag{10.4}$$

By substituting the value of $v = 2\pi rn$ in above equation

$$C = \frac{(2\pi rn)^2}{gr} = \frac{4\pi^2 r^2 n^2}{gr} = \frac{4\pi^2 rn^2}{gr} \tag{10.5}$$

Where n = speed of rotation (revolutions per second of centrifuge)
As 2r = d (diameter of the rotation). By putting this value in above equation it yields,

$$C = \frac{2\pi^2 dn^2}{g} \tag{10.6}$$

The value of gravitational constant is 9.807 m/s^2, so

$$\text{Centrifugal effect} = 2.013\ n^2 d \tag{10.7}$$

From this equation, it is concluded that centrifugal effect is directly proportional to d (diameter) and n^2 (speed of rotation)

10.4 APPLICATIONS OF THIS PRINCIPLE

1. If the particles of suspensions are very small then high centrifugal effect will be necessary to separate the particles. To separate such suspensions the size of the centrifuge is kept smaller but it is rotated at very high speed (rpm).
2. If a large amount of material is to be separated and a low centrifugal effect is required to separate the suspension then the diameter (D) of the centrifuge is increased and speed (n) is kept low.

10.5 CLASSIFICATION OF CENTRIFUGES

Centrifuges may be classified as:

Classification of centrifuges

- **Perforated basket centrifuge**
- **Non-perforated basket centrifuge**
- **Semi continuous centrifuge**
- **Super centrifuge**

10.6 PERFORATED BASKET CENTRIFUGE

Principle: In perforated basket centrifuge, separation occurs through perforated wall depends on the difference in the densities of solid and liquid phases.

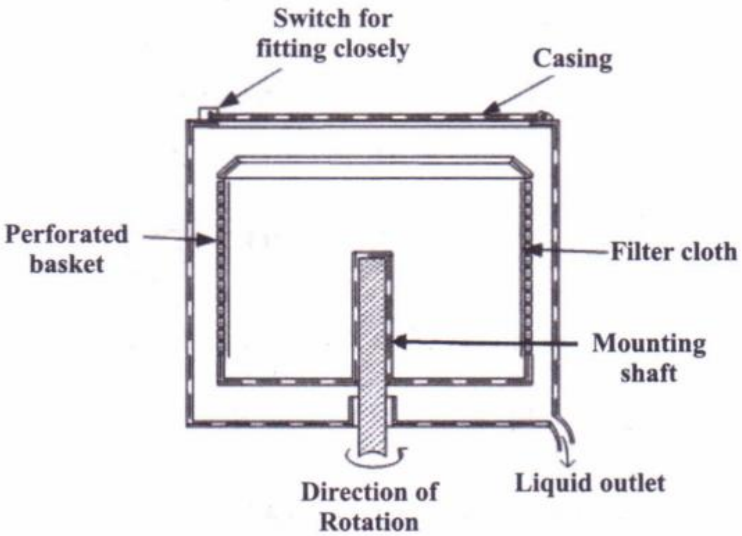


Figure 10.1: Construction of perforated basket centrifuge

Construction

It consist of stainless steel perforated basket lined with filter cloth. The basket should be made of corrosion resistant material. The basket is covered with vulcanite or copper or lead or monel. The basket is mounted on shaft. If basket is mounted above the driving shaft then this arrangement is known as under-driven. If basket is suspended from a shaft then it is known as over-driven. The shaft is driven by motor. The basket is surrounded by casing which collect the filtrate and discharge through outlet. The diameter of basket is 0.90 meter. The basket require 5 kilowatt power for starting and after attaining desired speed the power is reduced to 2 kilowatt. The diameter of perforation depends on crystal size. The basket operated at speed of 1000 rpm.

Working

The material is loaded into the basket. The amount of loaded material should be optimum. The loading of material should provide even distribution. The power is supplied to rotate the basket. But when fully loaded basket is rotated at high speed then there are chances of great strain and vibration due to centrifugal force. The basket contains perforated wall. During centrifugation liquid phase leaves through perforated wall and collected at outlet while solid phase retains in the basket. Then turned off the power. Centrifuge is stopped by applying brake. The basket keep to rest and then solid is removed. The solid cake is cut by blade and unloaded.

Uses

Perforated basket centrifuge is used to separate crystalline drug such as aspirin and sulfamethoxazole from mother liquor, to separate sugar crystals and to separate precipitated protein from insulin.

Advantages

1. This centrifuge are employed when solid concentration in slurry is high.
2. It occupy very little space
3. Rapid process
4. The resulting product contain very low moisture content

Disadvantages

1. On prolonged operation the centrifugal force put greater strain on basket which cause wear and tear of equipment.
2. On prolonged operation, solid get converted into hard cake which is difficult to remove.
3. It is a batch operation.

10.7 NON-PERFORATED BASKET CENTRIFUGE

Principle

In this centrifuge the basket contains non perforated side wall. The separation of solid and liquid phase depends on difference in densities of both phases without porous barrier. During centrifugation solid deposited at side of basket while liquid remained at top which is removed by skimming tube.

Construction

It consist of non perforated basket made of steel. The material is loaded into basket through feed tube. The basket is mounted on vertical shaft which is rotated by motor. The liquid is removed with the help of skimming tube.

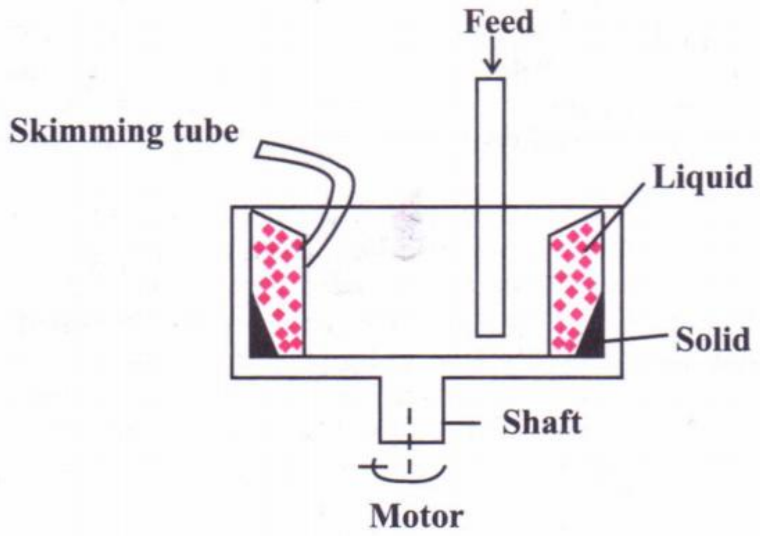


Figure 10.2: Construction of non perforated basket centrifuge

Working

The suspension is fed into the basket continuously through feed tube. During centrifugation solid deposited at side of basket while liquid remained at top which is removed by skimming tube. When sufficient amount of solid get deposited at the side of basket then it is removed intermittently by hand and continuously by scraper blade.

Uses

Non perforated basket centrifuge is employed when deposited solids provide high resistance to the flow of liquid.

10.8 SEMI CONTINUOUS CENTRIFUGE

Principle

In Semi Continuous centrifuge, separation occurs through perforated wall depends on the difference in the densities of solid and liquid phases.

Construction

It consist of perforated basket mounted on horizontal shaft and run continuously by motor. The side of the basket is perforated. Feed or suspension is introduced through feed pipe. There is also provision of wash pipe which is used to wash the crystals. The thickness of feed depends on the feeler which rides over the feed. The layer of cake is removed by a chute fitted with a knife. The knife cuts down the cake within the basket. The knife-chute assembly is raised with the help of a hydraulic apparatus.

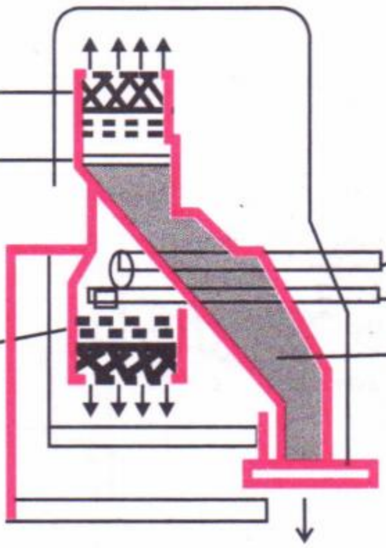


Figure 10.3: Construction of semi-continuous centrifuge

Working

The basket is rotated horizontally with a motor. The suspension is introduced through the pipe. The slurry passes through the perforated side. The crystals remain inside the basket. The filtrate is eliminated from the outlet. When the height of the cake is approximately 2-3 inches, the suspension inlet is stopped by a "feeler diaphragm valve assembly". The basket rotates a predetermined time and then the cake is washed with water. The basket is rotated for another predetermined time. After that, the hydraulic apparatus raises the knife-chute assembly to cut the cake. The cake is collected through the chute.

Advantages

1. This centrifuge is used to separate crystals from mother-liquor.
2. This is used to clarify Liquids by removing unwanted solids dirt from oils.

Disadvantage

1. Complicated process
2. Sometime chances of breakage of crystal during discharge.
3. High power consumption

10.9 SUPER CENTRIFUGE

Principle

It is a continuous centrifuge used to separate two immiscible liquid phases. It is a sedimentation type centrifuge. During centrifugation, the heavier liquid is thrown against the container wall while the lighter liquid remains as an inner layer. The two layers are simultaneously separated.

Construction

It consists of a long, hollow, cylindrical bowl of small diameter which is suspended from a flexible spindle at the top and the bottom is fitted loosely in a bush. It is rotated on its vertical axis. Feed is introduced through the bottom through a nozzle with pressure. Two liquid outlets are provided at different heights. Inside the bowl, baffles are present to catch the liquid and force it to travel at the same speed of rotation as the bowl wall.

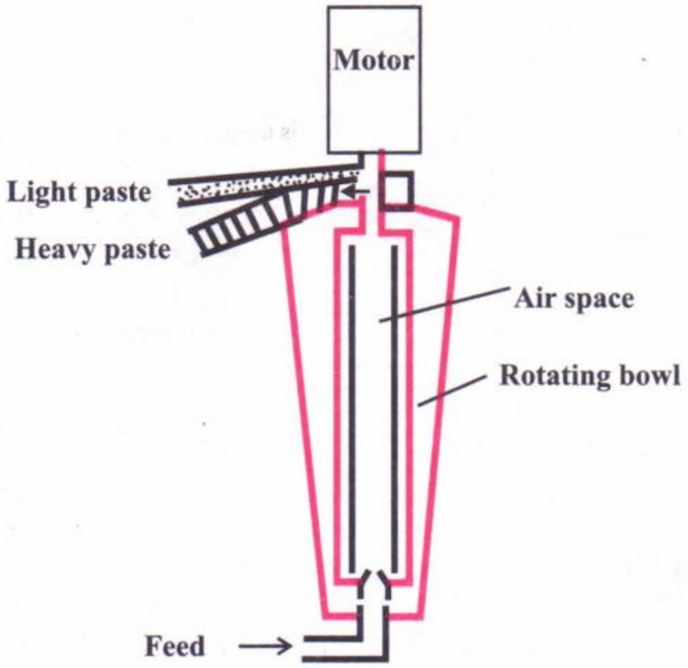


Figure 10.4: Construction of supercentrifuge

Working:

The centrifuge rotate on its vertical axis at approximately 2000 rpm. The feed is introduced in the lower part through a nozzle with pressure. During centrifugation, two liquid phases were separated according to their densities. The heavier liquid moves towards the periphery and the lighter liquid forms an inner layer. Both liquids ascend to the upper part of the vertical bowl. These two layers are simultaneously removed separately from different heights through modified outlets.

Use

Supercentrifuge is widely used for separating liquid phases of emulsions in food, biochemical and pharmaceuticals industries.

Advantage

This type of centrifuge is employed in case where amount of solid in liquid is small and it is necessary to remove it only at long intervals.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

1. Define **Centrifugation**

   Answer- It is the process in which centrifugal force is used as driving force for phase separation.

2. **Define Centrifugal effect (C) or Relative Centrifugal Force.**

   Answer- It is the ratio of the centrifugal force (F) and gravitational forces (G).

3. **Write two applications of centrifugation.**

   Answer-

   1. Centrifugation is widely used in bulk drug industry to separate crystalline material from suspension.
   2. Centrifugation is used for isolation of bacterial cells, actinomycetes mycelium and spores from liquid growth.

4. **What are the use of Supercentrifuge?**

   Answer- Supercentrifuge is widely used for separating liquid phases of emulsions in food, biochemical and pharmaceuticals industries.

SHORT ANSWER QUESTIONS

1. **Write Principle of Non-perforated basket centrifuge**

   Answer- In this centrifuge the basket contains non perforated side wall. The separation of solid and liquid phase depends on difference in densities of both phases without porous barrier. During centrifugation solid deposited at side of basket while liquid remained at top which is removed by skimming tube.

2. **Write principle of Super Centrifuge**

   Answer- It is a continuous centrifuge used to separate two immiscible liquid phases. It is a sedimentation type centrifuge. During centrifugation, the heavier liquid is thrown against the container wall while the lighter liquid remains as an inner layer. The two layers are simultaneously separated.

3. **Describe under-driven and over driven arrangement in Perforated basket centrifuge.**

   Answer- In Perforated basket centrifuge, stainless steel perforated basket is mounted on shaft. If basket is mounted above the driving shaft then this arrangement is known as under-driven. If basket is suspended from a shaft then it is known as over-driven.

LONG ANSWER QUESTIONS

1. Write detailed note on
   a. Principle behind centrifugation
   (Refer article 10.3)
   b. Applications of Centrifugation
   (Refer article 10.2)
2. Describe construction, working, uses, merits and demerits of Perforated basket centrifuge.
   (Refer article 10.6)
3. Describe construction, working, uses, merits and demerits of Non-perforated basket centrifuge
   (Refer article 10.7)

4. Describe construction, working, uses, merits and demerits of semi continuous centrifuge.
   (Refer article 10.8)
5. Describe construction, working, uses, merits and demerits of super centrifuge.
   (Refer article 10.9)

MULTIPLE CHOICE QUESTIONS

1. **The centrifugal effect is**
   a. ratio of the centrifugal force and gravitational forces
   b. sum of the centrifugal force and gravitational forces
   c. product of the centrifugal force and gravitational forces
   d. None of the above
2. **Which centrifuge is used to separate crystalline drug such as aspirin and sulfamethoxazole from mother liquor?**
   a. Perforated basket centrifuge
   b. Non Perforated basket centrifuge
   c. Super centrifuge
   d. semi continuous centrifuge
3. **Which centrifuge is used when deposited solids provide high resistance to the flow of liquid?**
   a. Perforated basket centrifuge
   b. Non Perforated basket centrifuge
   c. Super centrifuge
   d. semi continuous centrifuge
4. **The process in which centrifugal force is used as driving force for phase separation is called**
   a. Centrifugation
   b. Filtration
   c. Evaporation
   d. Distillation

ANSWERS

1.a 2.a 3.b 4.a

11 CHAPTER MATERIALS OF PHARMACEUTICAL PLANT CONSTRUCTION

Selected Definitions

Thermoplastic: They get softened with application of pressure and heat but regain their original shape on cooling.

Thermosetting: They are permanently shaped to rigid structure when pressure and heat is applied.

Blooming or weathering: When glass wares are stored over a month in damp atmosphere having variations in temperature. Due to this, salts leach out of glass and appear as fine crystals.

11.1 INTRODUCTION

For manufacturing of pharmaceuticals, bulk drugs etc, number of equipments are used. The equipments are generally used for processing and packing of products. A wide variety of materials are used for manufacturing of theses equipments. Some products are highly acidic while some are highly alkaline. Some products such as storage of biological products need to be handled carefully. Therefore design of equipment, material selection and fabrication technique need to be considered carefully. These factors affects the success or failure of new chemical plant. If container will not compatible with material then there are chances of contamination. The proper choice of material is very important. The choice based on expert advice, previous experience and laboratory tests.

The material used for construction of plant is classified as metals (ferrous and non ferrous) and non metals (organic and inorganic).

11.2 FACTORS AFFECTING DURING MATERIALS SELECTED FOR PHARMACEUTICAL PLANT CONSTRUCTION

The selection of a material for the construction of the equipment depends on the following properties

1. **Chemical factors**
   a. Contamination of the product
   b. Corrosion of material of construction
2. **Physical factors**
   a. Strength
   b. Mass
   c. Wear properties
   d. Thermal conductivity
   e. Thermal expansion
   f. Ease of fabrication

g. Cleaning

h. Sterilization

i. Transparency

3. **Economic factors**

11.2.1 Chemical Factor

Each time a chemical is placed in a container or equipment, the chemical is exposed to the construction material of the container or equipment. Therefore, the construction material can contaminate the product or the product can destroy the construction.

a. **Product contamination:**

Iron contamination can change the color of products (such as gelatin capsules), catalyze some reactions that can increase the decomposition rate of the product. The leaching of glass can make the aqueous product alkaline. This alkaline medium can catalyze the decomposition of the product. Heavy metals, such as lead, inactivate penicillin.

b. **Corrosion of construction material:**

The products can be corrosive in nature. They can react with the material and can destroy it. This cause decrease the life of the equipment. Extreme pH, strong acids, strong alkalis, powerful oxidizing agents, tannins, etc., they reacts with the materials, therefore, some alloys that have a special chemical resistance are used.

11.2.2 Physical factors

a. **Strength:** The material must have sufficient physical strength to withstand the pressure and stress required. Iron and steel can satisfy these properties. The tablet punching machine, the die and the upper and lower punches are made of stainless steel to withstand very high pressure. The glass, although it has strength but is fragile. The aerosol container must withstand very high pressure, so tin containers covered with some polymers are used. The plastic materials are weak, so they are used in some packaging materials, such as **blister packs.**

b. **Mass:** For transportation, lightweight packaging materials are used. Plastic, aluminum and paper packaging materials are used to package pharmaceutical products.

c. **Wear properties:** When there is a possibility of friction between two surfaces, the softer surface disappears and these materials contaminate the products. For example, during milling and grinding, grinding surfaces can wear out and contaminate the powder. When pharmaceutical products of very high purity are required, grinding surfaces of ceramic and iron are not used.

d. ***Thermal conductivity*:** In evaporators, dryers, stills and heat exchangers, the materials used should have very good thermal conductivity. In this case, iron, copper or graphite tubes are used for effective heat transfer.

e. **Thermal expansion:** If the material has a very high coefficient of thermal expansion then as the temperature increases, the shape of the equipment changes. This produces unequal stresses and can cause fractures. Therefore, materials that are capable of maintaining the shape and dimension of the equipments at the working temperature should be used.

f. **Ease of fabrication:** During the manufacturing of equipment, the materials undergo various processes, such as casting, welding and forging. For example, glass and plastic can be easily molded into containers of different shapes and sizes. The glass can be used as a coating material for reaction vessels.

g. **Cleaning:** Smooth and polished surfaces facilitate ease in cleaning. After completing the operation, the equipment is thoroughly cleaned so that the previous product can not contaminate the next product. The surfaces of glass and stainless steel can be smooth and polished.

h. **Sterilization:** In the production of parenterals, ophthalmic and bulk drugs, all equipment must be sterilized. This is usually done by introducing high pressure steam. The materials must withstand at high temperature (121° C) and pressure (15 pounds per square inch). If there are rubber materials, it must be vulcanized to withstand the high temperature.

i. **Transparency:** In the reactors and fermentors a visual port is provided to observe the progress of the process that takes place inside the chamber. In this case, borosilicate glass is often used. In parenteral and ophthalmic containers, the particles, if any, are observed with polarized light. The walls of the containers must be transparent to see through it. The glass is used as perfect material.

11.2.3 Economic factors

The initial cost of the equipment depends on the material used. Several materials may be suitable for construction from the physical and chemical point of view, but of all the materials only the cheapest material for the construction of the equipment is chosen. Materials that require a lower maintenance cost are used because in the long term it is economical.

11.3 CLASSIFICATION OF MATERIAL FOR PLANT CONSTRUCTION

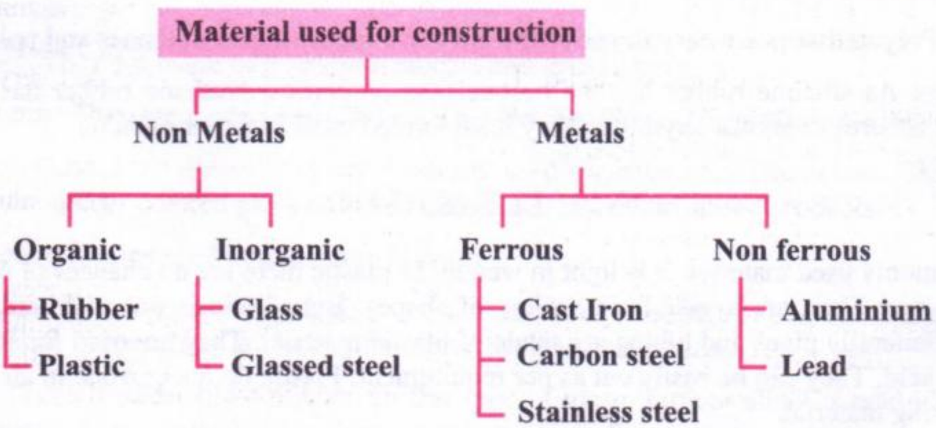


Figure 11.1: classification of material used for construction

NON METALS-ORGANIC

11.4 RUBBER

It is used as lining material

1. **Latex :**

Advantages: The latex is ready to use directly outside the container. Latex is economical, exhibits good abrasion resistance and is an elastic moldable rubber. Latex molds are also good for casting wax and gypsum.

Disadvantages: Low-cost latex products generally shrink. Making molds with latex rubber is slow and time consuming. Latex molds are generally not suitable for melting resins.

2. Polysulfide rubber :

Advantages: The polysulfide molds are very soft, "elastic" and long lasting, some have a useful life of 40 years.

Disadvantages: It has an offensive smell. The polysulfides must be accurately mixed by weight otherwise they will not work. Polysulfide rubber costs more than latex.

3. Silicone rubbers:

Advantages: Silicone rubber has the best release properties of all mold rubbers. The combination of good release properties, chemical resistance and heat resistance makes silicone the best choice for the production of resin castings.

Disadvantages: The silicones generally have a high cost.

4. Polyurethane rubbers:

Advantages: Polyurethanes are easy to use. They are less expensive than silicones and polysulphides.

Disadvantages: As silicone rubber has the best release properties, urethane rubber has the worst release properties and adheres to almost anything. They have limited shelf life after opening.

11.5 PLASTIC

Plastic is commonly used material. It is light in weight. In plastic there are no chances of contamination as in metallic container. They are available in variety of shapes. But plastic is not preferred in case of higher temperature. Generally pipes and tubing are made of plastic material. They are used for storage of inorganic salt and weak acid. They can be easily cut as per requirement. Plastic do not corrode in air or water. It is also used as insulating material.

11.5.1 Types:

1. **Thermoplastic:** They get softened with application of pressure and heat but regain their original shape on cooling.

Table11.1: Different type of thermoplastic and their uses

Thermoplastics	Uses
Polyethylene	Cables, buckets, pipes
Polypropylene	Milk cartons, ropes
Teflon (fluorocarbons)	Gaskets, coating
Polyvinylchloride (PVC)	Manufacture of Gloves

2. **Thermosetting:** They are permanently shaped to rigid structure when pressure and heat is applied. Example Phenol-formaldehyde. They cannot withstand on severe abrasion.

NON METALS-INORGANIC

11.6 GLASS

Glass container is widely used in daily life. It is composed of sand (pure silica), soda ash (sodium carbonate), limestone (calcium carbonate) and cullet (broken glass). Cullet act as fusion agent for whole mixture. Glass in its solid state is considered as supercooled liquid.

11.6.1 Types

There are different varieties of glasses are used such as

1. **Soft glass:** They are made of sodium silicate and calcium silicate. It is used for making glass bulbs and window glasses.
2. **Hard Glass:** They are made of potassium silicate and calcium silicate. They are used for making glass apparatus
3. **Flint Glass:** They are made of potassium silicate and lead silicate.
4. **Quartz glass:** They are made of pure silica. They are used for making silica crucible.
5. **Pyrex Glass and Jena glass:** They are generally used for laboratory glasswares. The iron oxide is added to give amber colored glass but iron oxide could leach into stored products.

There are 4 type of glasses used in pharma industry IP

1. **Type I (Borosilicate glass):** It is highly resistant to alkali leaching. In this alkali and earth cations are replaced by boron. They are less brittle. Easy to clean and sterilize.
2. **Type II (Treated Soda Lime glass):** In this type of glass, surface alkali is neutralized by sulfur dioxide vapors. They are used for making containers for buffered aqueous solution having pH below 7.
3. **Type III (soda lime glass):** It release 10 times more alkali than type I and type II glass. It offers moderate hydrolytic resistance. It is used for dry powder and oleaginous solutions.
4. **Type IV (General purpose soda lime glass):** It is not used for parenterals. It is used as container for tablets, oral solutions, suspensions, ointment and liquid for external use.

When glasswares are stored over a month in damp atmosphere having variations in temperature. This cause **Blooming or weathering**. As a result salts leach out of glass and appear as fine crystals. In this case salt is washed off with water and acid. Pharmaceutical glass containers should comply with official test for hydrolytic resistance.

11.6.2 Advantages of glass:

1. Attractive in appearance
2. Available in variety of size, shapes and colors.
3. Inert
4. Cheap
5. Does not deteriorate with age.
6. Amber colored glass protect against light.

11.6.3 Disadvantage:

1. Fragile in nature and damaged by thermal shock

11.7 GLASSED STEEL

It is inorganic product of fusion. It is cooled to rigid condition without crystallizing. They are used in heavy vessels. It has excellent resistant to all acids. This is suitable in case of transparent pipes.

Ferrous metals

They are widely used as construction material because it is mechanically strong, easy available and economical.

11.8 CAST IRON

It is the combination of iron with carbon content greater than 2%. It is cheap and available easily so greater in demand. It is resistant to concentrated sulfuric acid, nitric acid and dilute alkalies. It has low thermal conductivity. The main disadvantage of cast iron is hard and brittle. Gray cast iron contain Carbon, silicone, Manganese and Selenium. It is easy to mold into any shape. Gray cast iron prevent material from corrosion but it is not preventive against dilute acids. Malleable iron (white cast iron with carbon content 2.5%) is also available and it is also corrosion resistant. Nickel resistant cast iron have also superior toughness, easy to weld, corrosion and as well as heat resistant. A number of cast iron alloys like Duriron and Durichlor are available in market.

Uses:

a. It is used to jacketed steam pans
b. It is used as lining material with plastic

11.9 CARBON STEEL

It is an iron alloy having low percentage of carbon content. It is cheapest and easy to fabricate. It is most versatile metal used in industry. It is easily weldable and excellent ductility. But carbon steel has limited resistant to corrosion and it also react with caustic soda. Low alloy steel has high mechanical strength. It contain 0.4% Carbon, 0.7% Manganese, 1.85% Nickel, 0.8% Chromium and 0.25% Molybdenum.

The properties of carbon steel can be altered by alloying with Nickel, chromium and silicone. Carbon steel-Nickel alloy is tough and corrosion resistant. Carbon steel-chromium alloy increase hardness and more resistant to corrosion. At elevated temperature strength of carbon steel can be enhanced by preparing carbon steel-Molybdenum alloy.

Uses:

a. It is used for construction of pipes and plates.
b. It is used as supporting structure for plant vessels
c. It is used as fabricating material for large storage tanks for water, sulfuric acid and organic solvents.

11.10 STAINLESS STEEL

It is an alloy of iron. It contain 12 to 30% Chromium, 0 to 2% Nickel, low percentage of Carbon, Columbium, Copper, Molybdenum, Selenium, tantalum and titanium. It is widely used in industries because it is heat resistant, corrosion resistant, easily fabricated, and have high tensile strength.

There are different type of stainless steel are available

a. **Martensitic (type 410):** It contain 12 to 20% chromium, 0.2 to 0.4% Carbon and 2% nickel. It is mild resistant to corrosion and organic exposure. It is less ductile. It is used to prepare sinks, bench tops, storage tanks and mixing elements.
b. **α-Ferritic (type 430):** It contain 15 to 30% chromium and 0.1% carbon. It is better resistant to corrosion. It is also resistant to oxidation and temperature. It is easy to machine. It is not good against reducing agents and hydrochloric acids. It is used in tower lining, baffles, heat exchangers, tubing, condensers, pump shafts and furnace parts.
c. **□-Austenitic:** It contain 13 to 20% chromium, 0.1% <0.25% carbon and -22% nickel. It is highly corrosion resistant, easy to weld, easily clean and sterilized. It can be easily weld. It is used in fermentors, evaporators, storage vessels, extraction vessels.
d. **Others:** Type 316, 316L and 317 with 2.5 to 3.5% Molybdenum are most corrosion resistant.

NON-FERROUS METALS

11.11 ALUMINIUM

It is available in large number of alloys. Aluminum is cheap and light in weight. It has adequate mechanical strength. Their maintenance and cleaning is easy. Thermal conductivity of aluminium is 60% of pure copper. Its tensile strength is 10,000 lb/sq. in. It is resistant to corrosion. It can also used for concentrated nitric acid and acetic acid. It is used in wide variety of chemical equipments. But mechanical strength of aluminium decreases greatly above 150^0C. For food and pharmaceutical uses super grade of Aluminium is used. It is used as container for storage of meat. It is used in heat transfer applications.

Aluminium alloy with improved mechanical properties and qualities are available which is also corrosion resistant. Aluminium-clad alloy is used for greater mechanical strength. Hot dipped aluminized steel is preferred when Sulfur is present. Aluminium is used in biosynthetic processes because it is non toxic to microorganism.

Uses: It is used for manufacturing of container (tanks), rail tankers and barrels.

11.12 LEAD

In pharmaceutical industry, lead is used in less percentage because in large amount it produce toxicity. It is cheap. It is generally used for non food products. The addition of Silver (Ag) and Copper (Cu) make lead corrosion resistant and fatigue resistant. Lead has poor structural quality due to low melting point. Therefore antimony is added to hardens the lead. Lead pipes are used for solutions containing sulfuric acid. The main disadvantage of lead is high coefficient of expansion which may cause permanent deformation.

11.13 OTHERS

a. Copper and its alloy are also used in chemical processing because it has low temperature properties.

b. Nickel and its alloy are also used for handling alkalies and storing and shipping of high purity caustic soda and potash. It is also used to store chlorinated solvents and phenol.

c. Titanium is also used as construction material due to strong, corrosion resistant, resistant to hot chloride solutions and nitric acid. But it is costly.

REVIEW QUESTIONS

VERY SHORT ANSWER QUESTIONS

Q1. Define Thermosetting plastic

Answer- They are permanently shaped to rigid structure when pressure and heat is applied

Q2. What are Type I glass?

Answer- they are Borosilicate glass. It is highly resistant to alkali leaching. In this alkali and earth cations are replaced by boron. They are less brittle. Easy to clean and sterlize.

Q3. What are Hard Glass?

Answer- They are made of Potassium silicate and calcium silicate. They are used for making glass apparatus.

Q4. Write composition of Martensitic (type 410).

Answer- It contain 12 to 20% chromium, 0.2 to 0.4% Carbon and 2% nickle.

Q5. Define Blooming or weathering.

Answer- When glasswares are stored over a month in damp atmosphere having variations in temperature. As a result salts leach out of glass and appear as fine crystals.

SHORT ANSWER QUESTIONS

Q1. Why Stainless Steel is used as construction material in industries?

Answer- It is an alloy of iron. It contain 12 to 30% Chromium, 0 to 2% Nickel, low percentage of Carbon, Columbium, Copper, Molybdenum, Selenium, tantalum and titanium. It is widely used in industries because it is heat resistant, corrosion resistant, easily fabricated, and have high tensile strength.

Q2. Write importance of glassed steel in pharma industry.

Answer- It is inorganic product of fusion. It is cooled to rigid condition without crystallising. They are used in heavy vessels. It has excellent resistant to all acids. Suitable in case of transparent pipes.

Q3. Explain different types of glasses used in pharma industry.

Answer- There are 4 type of glasses used in pharma industry IP

1. **Type I (Borosilicate glass):** It is highly resistant to alkali leaching. In this alkali and earth cations are replaced by boron. They are less brittle. Easy to clean and sterilize.
2. **Type II (Treated Soda Lime glass):** In this type of glasses, surface alkali is neutralized by sulfur dioxide vapors. These are used for making containers for buffered aqueous solution having pH below 7.
3. **Type III (soda lime glass):** It release 10 times more alkali than type I and type II glass. It offer moderate hydrolytic resistance. It is used for dry powder and oleaginous solutions.
4. **Type IV (General purpose soda lime glass):** It is not used for parenterals. It is used as container for tablets, oral solutions, suspensions, ointment and liquid for external use.

Q4. Describe usefullness of Nickle and its alloy.

Answer- They are used for handling alkalies and storing and shipping of high purity caustic soda and potash. It is also used to store chlorinated solvents and phenol.

Q5. Write advantages and disadvantages of Silicone rubbers.

Answer- Advantages: silicone rubber has the best release properties of all mold rubbers. The combination of good release properties, chemical resistance and heat resistance makes silicone the best choice for the production of resin castings.

Disadvantages: silicones generally have a high cost.

LONG ANSWER QUESTIONS

Q1. Explain the factors which should be considered during selection of material for pharmaceutical plant construction.

(Refer article 11.2)

Q2. Write detailed note on rubber as material for plant construction

(Refer article 11.4)

Q3. Write detailed note on

a. Plastic
b. Glass

(Refer article 11.5, 11.6)

Q4. Define stainless steel. Explain the properties of different types of stainless steel used?

(Refer article 11.10)

Q5. Discuss the application, advantages and disadvantages of Aluminium

(Refer article 11.11)

Q6. Write note on

a. Advantages of glass **(Refer article 11.6.2)**
b. Lead as construction material **(Refer article 11.12)**
c. Types of plastic **(Refer article 11.5.1)**

MULTIPLE CHOICE QUESTIONS

1. **Which of the following is not a physical factors affecting during selection of materials for Pharmaceutical plant construction?**
   a. Mass b. Wear properties
   c. Thermal conductivity d. Corrosion of material of construction
2. **Which of the following metal is used as construction material**
   a. Cast iron b. Glass
   c. Rubber d. Plastic
3. **Addition of _______ produce amber colored glass**
   a. iron oxide b. Zinc oxide
   c. Magnesium oxide d. Aluminum oxide
4. **Which of the following glass are made of potassium silicate and lead silicate?**
   a. Soft glass b. Flint glass
   c. Hard glass d. Quartz glass
5. **Soft glass** are made of
   a. sodium silicate and calcium silicate.
   b. Potassium silicate and calcium silicate
   c. Potassium silicate and magnesium silicate
   d. Pure silica
6. **Borosilicate glass is also known as**
   a. Type I b. Type II
   c. Type III d. Type IV
7. **Which of the following is/ are of cast iron alloys available in market**
   a. Duriron b. Durichlor
   c. Both a and b d. Duraderm
8. **Which of the following is/are of the type of stainless steel**
   a. Martensitic b. Ferritic
   c. Austenitic d. All of the above
9. **The tensile strength of Aluminum is**
   a. 10,000 lb/sq.in. b. 200 lb/sq.in.
   c. 200000 lb/sq.in d. 50 lb/sq.in

ANSWERS

1. d 2. a 3. a 4. b 5. a 6. a 7. c 8. d 9. a