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Shree H. N. Shukla Institute of Pharmaceutical Education and Research

B.Pharm

Sem 2

Subject Name: Pharmaceutical Engineering

Subject Code: BP203TP

UNIT-I. BP203TP (Pharmaceutical Engineering)

Syllabus:

1. Flow of fluids: Fluid statics, Types of Manometers, Reynolds number, Bernoulli's theorem, fluid heads, Energy Losses, Measurement of fluid flow meters – Orifice meter, Venturimeter, Pitot tube, Rotameter.
2. Size Reduction: Objectives, Mechanisms & Laws governing size reduction, factors affecting size reduction, principles, construction, working, uses, merits and demerits of Hammer mill, ball mill, fluid energy mill, Edge runner mill & end runner mill.
3. Size Separation: Objectives, applications & mechanism of size separation, official standards of powders, sieves, size separation Principles, construction, working, uses, merits and demerits of Sieve shaker, cyclone separator, Air separator, Bag filter & elutriation tank.

FLOW OF FLUID

Fluid includes both liquids and gases.

- Fluids may be defined as a substance that does not permanently resist distortion. an attempt to change the shape of a mass of fluid will result in layers of fluids sliding over one another until a new shape is attained.

During the change of shape *shear stresses* will exist, the magnitude of which depends upon the viscosity of the fluid and the rate of sliding. But when a final shape is reached, all shear stresses will disappear. A fluid at equilibrium is free from shear stresses.

- The density of a fluid changes with temperature and pressure. In case of a liquid the density is not appreciably affected by moderate change of pressure.

In case of gases, density is affected appreciably by both change of temperature and pressure.

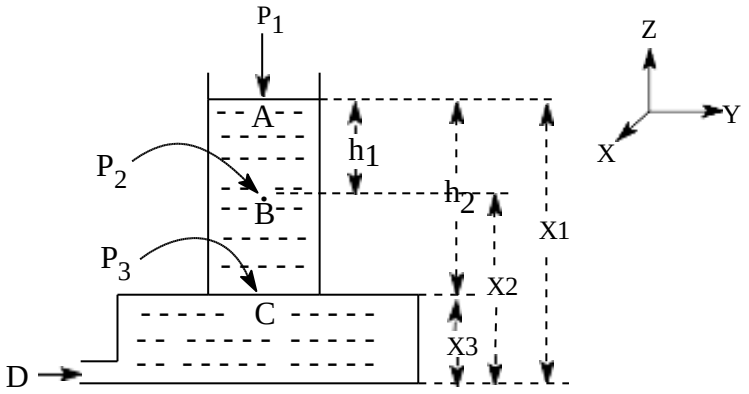
- The science of fluid mechanics includes two branches:

(i) fluid statics and (ii) fluid dynamics.

Fluid statics deals with fluids at rest in equilibrium.

Fluid dynamics deals with fluids under conditions where a portion is in motion relative to other portions.

FLUID STATICS



Hydrostatic pressure

In a stationary column of static fluid the pressure at any one point is the same in all directions. The pressure will also remain constant in any cross-section parallel to the earth's surface, but will vary from height to height.

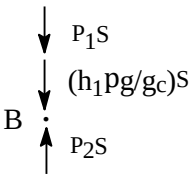
Let us consider, that the column of fluid in the figure is remaining at equilibrium. If the orifice D is open then the fluid will try to flow away. So either D is closed or a pressure is applied such that the liquid column stand at any desired height. The cross-section of the column is S (let). Now, say the pressure at the height $X_2 = P_2$ (in gravitational unit). At equilibrium all the forces acting on point B will be the same.

i.e. *Upward force* $=P_2S$

Downward forces:

Force given by atmosphere = P_1S

Force given by fluid column of height $h_1 = (h_1 p\, g/g_c)S$



Where, p is the density of the fluid.

At equilibrium upward and downward forces are equal at point B.

$$P_2S = P_1S + h_1\, p\, S\, g/g_c \qquad \text{eqn. (1)}$$

where, each term of force is expressed in gravitational units i.e. lb_f, gm-wt, kg-wt etc.

$g/g_c \approx 1.0$ so equation (1) can be written as

$$P_2S = P_1S + h_1\, p\, S$$

$$P_2 = P_1 + h_1\, p \qquad \text{eqn. (2)}$$

Similarly, $P_3 = P_2 + (h_2 - h_1)\, p$

$= P_1 + h_1\, p + h_2\, p - h_1\, p$

$= P_1 + h_2\, p$

$= P_1 + (X_1 - X_3)\, p$ [since $h_2 = X_1 - X_3$]

We can thus generalize for any point in the fluid, the pressure will be

$P_n = P_1 + p\, \Delta X$ where $\Delta X = X_1 - X_m$

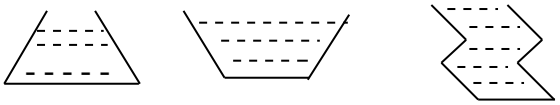
or, $P_n - P_1 = p\, \Delta X$

or, $\Delta P_n = p\, \Delta X \qquad \text{eqn. (3)}$

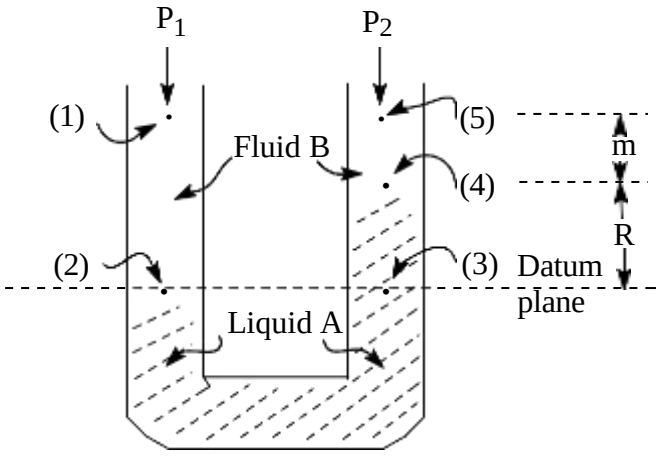
i.e. the pressure difference (ΔP_n) between any two points can be measured by the vertical distance between those two points, multiplied by the density of the fluid.

Since in equation (3) there is no term involving the cross-sectional area (S), it is not necessary that the vertical column be of uniform cross-section.

i.e. the shape may be any of the following types:



MANOMETERS



Simple Manometer

Manometers are used to measure the pressure of any fluid.

A U-tube is filled with a liquid A of density p_A. The arms of the U-tube above liquid A are filled with fluid B which is not miscible with liquid A and has a density of p_B. A pressure of P1 is exerted in one arm of the U-tube, and a pressure P2 on the other. As a result of the difference in pressure ($P_1 - P_2$) the meniscus in one branch of the U-tube will be higher than the other branch.

The vertical distance between these two surfaces is R. *It is the purpose of the manometer to measure the difference in pressure ($P_1 - P_2$) by means of the reading R.*

At equilibrium the forces at the two points (2 and 3) on the datum plane will be equal.

Let the cross sectional area of the U-tube be S.

** All the forces are expressed in gravitational unit.

Total downward force at point (2) = Forces at point (1)
+ force due to column of fluid B in between points (1) and (2).
= $P_1S + (m + R)\, p_B\, (g / g_c)\, S$

Total downward force at point (3) = Force at point (5)
+ Force due to column of fluid B in between points (5) and (4)
+ Force due to column of liquid A in between points (4) and (3)
= $P_2S + m\, p_B\, (g/g_c)\, S + R\, p_A\, (g/g_c)\, S$

At equilibrium:

Force at point (2) = Force at point (3)

or, $P_1S + (m + R)\, p_B\, (g / g_c)\, S = P_2S + m\, p_B\, (g/g_c)\, S + R\, p_A\, (g/g_c)\, S$

or, $P_1 - P_2 = R\, p_A\, (g/g_c) + m\, p_B\, (g/g_c) - m\, p_B\, (g/g_c) - R\, p_B\, (g/g_c)$

$= R\, (p_A - p_B)\, g/g_c.$

or, $\Delta P = P_1 - P_2 = R\, (p_A - p_B)\, g/g_c.$

It should be noted that this relationship is independent of the distance 'm' and cross sectional area 'S' of the U-tube, provided that P_1 and P_2 are measured from the same horizontal plane.

DIFFERENTIAL MANOMETER

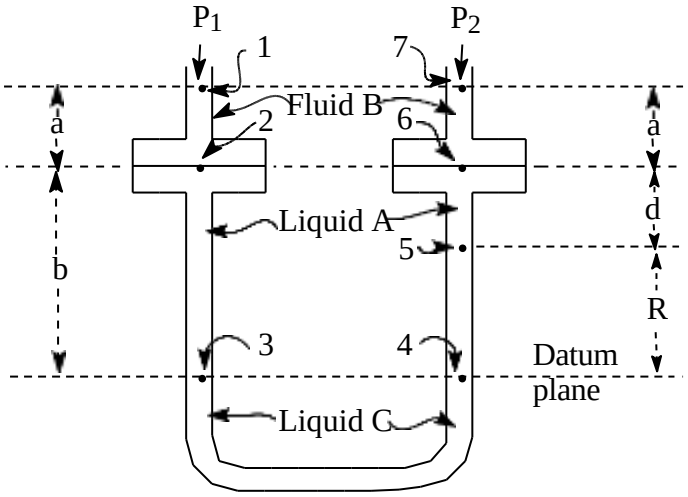


Fig. Differential manometer

For the measurement of smaller pressure differences, differential manometer is used.

The manometer contains two liquids A and C which must be immiscible.

Enlarged chambers are inserted in the manometer so that the position of the meniscus 2 and 6 do not change appreciably with the changes in reading.

So the distance between (1) and (2) = Distance between (6) and (7)

Total downward force on point (3)

$F_{left} = P_1S + a\, p_A\, g/g_c\, S + b\, p_A\, g/g_c\, S$

Total downward force on point (4)

$F_{right} = P_2S + a\, p_B\, g/g_c\, S + d\, p_A\, g/g_c\, S + Rp_C\, g/g_c\, S$

At equilibrium

$F_{left} = F_{right}$.

$P_1S + a\, p_A\, g/g_c\, S + b\, p_A\, g/g_c\, S = P_2S + a\, p_B\, g/g_c\, S + d\, p_A\, g/g_c\, S + Rp_C\, g/g_c\, S$

$P_1 - P_2 = (d - b)\, p_A\, g/g_c + Rp_C\, g/g_c$

$= - R\, p_A\, g/g_c + Rp_C\, g/g_c.$

$= R\,(p_C - p_A)\, g/g_c$

$$\Delta P = P_1 - P_2 = R\,(p_C - p_A)\, g/g_c$$

From this it follows that the smaller the differences $p_C - p_A$,the larger will be the reading R on the manometer for a given value of ΔP.

INCLINED MANOMETER

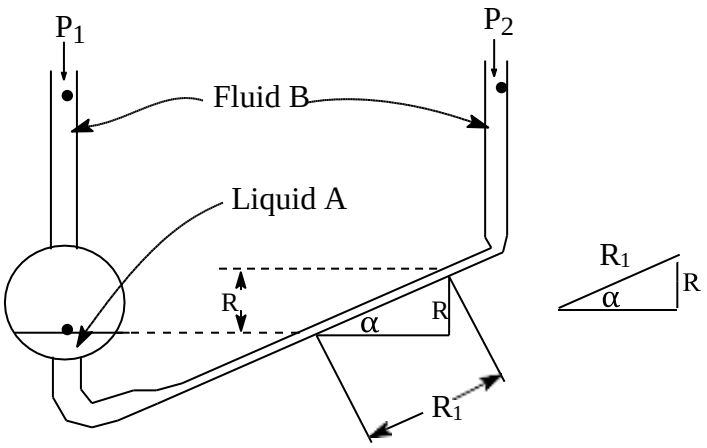


Fig. Inclined manometer

For measuring small difference in pressure this type of manometer is used.
In this type of manometer the leg containing one meniscus must move a considerable distance along the tube. Here the actual reading R is magnified many folds by R_1, where

$$R = R_1 \sin \alpha$$

where α is the angle of inclination of the inclined leg with the horizontal plane.

In this case $\Delta P = P1 - P2$

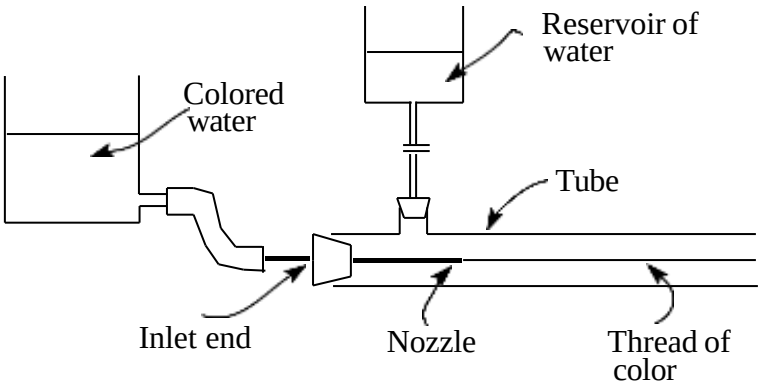
$= R (p_A - p_B) g/g_c$.

In this type of gauge it is necessary to provide an enlargement in the vertical leg so that the movement of the meniscus in this enlargement is negligible within the range of the gauge.

By making α small the value of R is multiplied into a much larger distance R_1.

FLUID DYNAMICS

Reynolds' Experiment



This experiment was performed by Osborne Reynolds in 1883. I Reynolds experiment a glass tube was connected to a reservoir of water in such a way that the velocity of water flowing through the tube could be varied.

At the inlet end of the tube a nozzle was fitted through which a fine stream of coloured water can be introduced.

After experimentation Reynolds found that when the velocity of the water was low the thread of color maintained itself through the tube. By putting one of these jets at different points in cross section, it can be shown that in no part of the tube there was mixing, and the fluid flowed in parallel straight lines.

As the velocity was increased, it was found that at a definite velocity the thread disappeared and the entire mass of liquid was uniformly colored. In other words the individual particles of liquid, instead of flowing in an orderly manner parallel to the long axes of the tube, were now flowing in an erratic manner so that there was complete mixing.

When the fluid flowed in parallel straight lines the fluid motion is known as **Streamline flow** or **Viscous flow**.

When the fluid motion is erratic it is called turbulent flow. The velocity at which the flow changes from streamline or viscous flow to turbulent flow it is known as the critical velocity.

THE REYNOLDS NUMBER

From Reynolds' experiment it was found that critical velocity depends on

1. The internal diameter of the tube (D)
2. The average velocity of the fluid (u)
3. The density of the fluid (p) and
4. The viscosity of the fluid (μ)

Further, Reynolds showed that these four factors must be combined in one and only one way namely (Dup / μ) . This function (Dup / μ) is known as the Reynolds number. It is a dimensionless group.

it has been shown that for straight circular pipe, when the value of the Reynolds number is less than 2000 the flow will always be viscous.

i.e. NRe < 2000 ⇒ viscous flow or streamline flow

NRe > 4000 ⇒ turbulent flow

Dimensional analysis of Reynolds number

[D] = L (ft)

[u] = L/θ (ft / sec)

[p] = M / L^3 (lb/ft^3)

[μ] = M / (Lθ) {lb/(ft sec)}

$$\left[\frac{Dup}{\mu}\right] = \frac{(L)\,(L/\theta)\,(M/L^3)}{\frac{M}{L\theta}} = \frac{L\,L\,M\,L\,\theta}{M\,\theta\,L^3}$$

= 1 ⇒ dimensionless group

BERNOULLI'S THEOREM

When the principle of conservation of energy is applied to the flow of fluids, the resulting equation is called *Bernoullis theorem.*

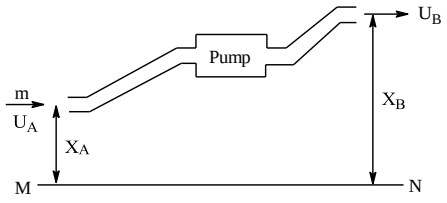


Fig. Bernoullis theorem

Let us consider the system represented in the figure, and **assume** that the temperature is uniform through out the system. This figure represents a channel conveying a liquid from point A to point B The pump supplies the necessary energy to cause the flow. Let us consider a liquid mass **m** (lb) is entering at point A.

Let the pressure at A and b are P_A and P_B ($lb\text{-force}/ft^2$) respectively.

The average velocity of the liquid at A and B are u_A and u_B (ft/sec).
The specific volume of the liquid at A and B are V_A and V_B (ft^3/lb).
The height of point A and B from an arbitrary datum plane (MN) are X_A and X_B (ft) respectively.
Potential energy at point A, (W1)= mgX_A ft-poundal [absolute unit]
= $m (g/g_C)X_A$ ft-lb force = mX_A ft-lb force [gravitational unit]
Since the liquid is in motion
m Kinetic energy at point A, (W2) = $^1/_2 . m u_A^2$ ft-poundal
= $(^1/_2 . m u_A^2)/ g_C$ pound-force

As the liquid **m** enters the pipe it enters against pressure of P_A lb-force/ft^2 and therefore.
Work against the pressure at point A, (W3) = mP_AV_A $ft\text{-}lb_f$.
N.B. Force at point A = P_A S [S = Cross-section area]
Work done against force P_A S = P_A (S h) = P_A V
m Total energy of liquid **m** entering the section at point a will be (E1) = W1 + W2 + W3

$$E1 = [\ mX_A + (^1/_2 . m u_A^2)/ g_C + mP_AV_A\ ]\ ft\text{-}lb_f.$$

After the system has reached the steady state when ever **m** (lb) of liquid enters at A another **m** (lb) pound of liquid is displaced at B according to the principle of the conservation of mass. This **m** (lb) leaving at B will have energy content of

$$E2 = [\ mX_B + (^1/_2 . m u_B^2)/ g_C + mP_BV_B\ ]\ ft\text{-}lb_f.$$

Energy is added by the pump. Let the pump is giving **w** $ft\text{-}lb_f$ / lb energy to the liquid

$$E3 = m w \quad ft\text{-}lb_f.$$

Some energy will be converted into heat by friction. It has been assumed that the system is at a constant temperature; hence, it must be assumed that the heat is lost by radiation or by other means. Let this loss due to friction be F $ft\text{-}lb_f$ / lb of liquid.

$$E4 = -mF \quad ft\text{-}lb_f \quad \text{[negative sign for loss]}$$

m The complete equation representing energy balance across the system between points A and will therefore be

$$E1 + E3 + E4 = E2$$

or, $mX_A + (^1/_2 . m u_A^2)/ g_C + mP_AV_A + m w - mF = mX_B + (^1/_2 . m u_B^2)/ g_C + mP_BV_B$

Now, the unit of energy term is $ft\text{-}lb_f$ / lb

m The BERNOULLI'S THEOREM.

$$X_A + \frac{U_A^2}{2g_C} + P_AV_A + w - F = X_B + \frac{U_B^2}{2g_C} + P_BV_B$$

The density of the liquid p be expressed lb_m / ft^3, then
$V_A = 1 / p_A$ and $V_B = 1 / p_B$ then Bernoulli's equation can be written in the form also

$$X_A + \frac{U_A^2}{2g_C} + \frac{P_A}{p_A} + w - F = X_B + \frac{U_B^2}{2g_C} + \frac{P_B}{p_B}$$

FLUID HEADS

All the terms in Bernoulli's theorem have unit of **ft-lb$_f$ / lb$_m$** which is numerically equal to '**ft**' only. That is each and every time terms can be expressed by height.

Dimensional Analysis

[ft] = L

[lb$_f$] = $(ML\theta^{-2}) / (L\theta^{-2}) = M$

[lb$_m$] = M

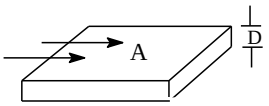
[ft-lb$_f$ / lb$_m$] = L~~M~~ / ~~M~~ = L

That is every term has a dimension of length (or height) if the terms are expressed in gravitational unit. This height are termed as **heads** in the discussions of hydraulics. Each term has different names:

Potential heads	X_A , X_B.
Velocity heads	$U_A^2 / (2 g_C)$, $U_B^2 / (2 g_C)$
Pressure heads	$P_A V_A$, $P_A p_A$, $P_B V_B$, $P_B p_B$.
Friction head	F
Head added by the pump	w

FRICTION LOSSES

In Bernoulli's equation a term was included to represent the loss of energy due to friction in the system. The frictional loss of a fluid flowing through a pipe is a special case of general law of the resistance between a solid and fluid in relative motion.



Let us consider a solid body of any designed shape, immersed in a stream of fluid.

Let, the area of contact between the solid and f fluid = A

If the velocity of the fluid passing the body is small in comparison to the velocity of sound, it has been found experimentally that the resisting force depends only on the roughness, size and shape of the solid and on the velocity, density and viscosity of the fluid. Through a consideration of the dimensions of these quantities it can be shown that,

$$\frac{F}{A} = \frac{pu^2}{g_c} \phi\left[\frac{Dup}{\mu}\right]$$

where, F = total resisting force

A = area of solid surface in contact with fluid

u = velocity of the fluid passing the body

p = density of fluid

μ = viscosity of fluid

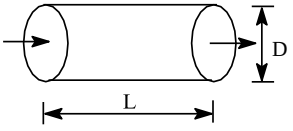
$g_c = 32.2$ (lb$_m$ ft)/ (lb$_f$ s^2)

ϕ = some friction whose precise form must be determined for each specific case.

The form of function ϕ depends upon the geometric shape of the solid and its roughness.

FRICTION IN PIPES

In a particular case of a fluid flowing through a circular pipe of length L, the total force resisting the flow must equal the product of the area of contact between the fluid and the pipe wall and F/A of the friction loss equation.



The pressure drop will be:

$$\Delta P_f = \frac{\text{Total force}}{\text{Cross sectional area}}$$

$$= \frac{(F / A)(L\pi D)}{\pi D^2/4}$$

$$= \frac{F}{A}\,\frac{L\pi D}{\pi D^2/4}$$

Since $\frac{F}{A} = \frac{pu^2}{g_c}\,\phi\left[\frac{Dup}{\mu}\right]$ Therefore $\Delta P_f = \frac{pu^2}{g_c}\,\phi\left[\frac{Dup}{\mu}\right]\left[\frac{4L\pi D}{\pi D^2}\right]$

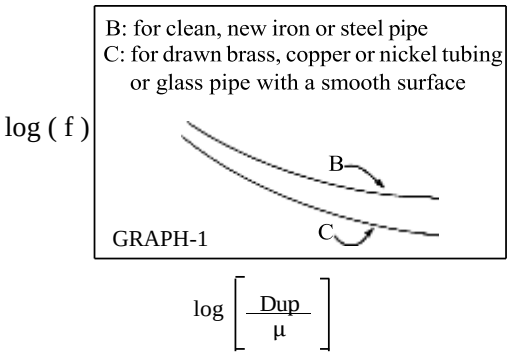
$$= \frac{4\,u^2\,L\,p}{g_c D}\,\phi\left[\frac{Dup}{\mu}\right] \text{ --------- eqn (1)}$$

where ΔP_f = pressure drop due to friction (lb/ft^2)
F / A = resisting force ($ft\text{-}lb_f$ per ft^2 of contact area)
L = length of pipe (ft)
D = inside diameter of the pipe (ft)
p = density of fluid (lb_m / ft^3)
u = average velocity of fluid (ft / s)
μ = viscosity of fluid (lb_m / ft / s)
g_c = 32.2 (lb_m ft / lb_f s^2)

For many decades Fanning's equation was used:

$$\Delta P_f = \frac{2\,f\,u^2\,L\,p}{g_c D} \text{ ——— eqn (2)}$$

In Fanning's equation the value of '**f** ' was taken from tables. This equation however has been widely used for so many years that most engineers still use the Fanning's equation, except that instead of taking values of 'f' from arbitrary tables a plot of the equation f = (Dup / μ) is used.
The graph (Graph-1) is not that much accurate : Error: [?]5 to 10 % may be expected for laminar flow .



By combining Hagen Poiseulles equation a new simple form of equation can be obtained.

$$f = \frac{16}{\frac{Dup}{\mu}} = \frac{16}{\text{Reynolds No}}$$

MEASUREMENT OF FLUID FLOW

Methods of measuring fluids may be classified as follows:-

1) *Hydrodynamic methods*
   (a) Orifice meter
   (b) Venturimeter
   (c) Pitot tube
   (d) Rotameter
   (e) Weirs

2) *Direct displacement*
   (a) Disc meters
   (b) Current meters

3) *Dilution method and*

4) *Direct weighing or measuring*

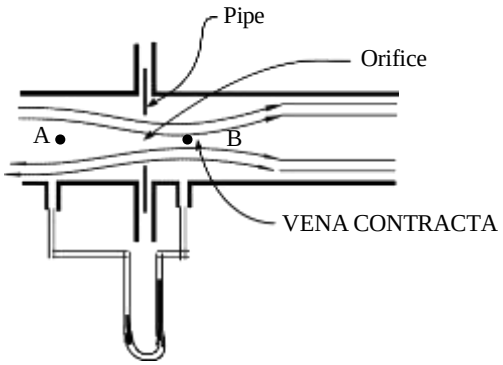
ORIFICE METER

Objective:

To measure the flow of fluids.

i) Velocity of fluid through a pipe (ft/sec)

ii) Volume of liquid passing per unit time (ft^3/sec, ft^3/min, ft^3/hr).



Description

An orifice meter is considered to be a thin plate containing an aperture through which a fluid issues. The plate may be placed at the side or bottom of a container or may be inserted into a pipe line.

A manometer is fitted outside the pipe. One end at point A and the other end at point B (see fig.). The pressure difference between A and B (i.e. before and after the orifice) is read, and the reading is then converted to fluid flow-rate.

Derivation

Bernoulli's equation is written between these two points, the following relationship holds

$$X_A + \frac{U_A^2}{2g_c} + \frac{P_A}{p_A} - F + w = X_B + \frac{U_B^2}{2g_c} + \frac{P_B}{p_B} \quad \text{.....(1)}$$

Conditions	Equation (1) changes to:
i) The pipe is horizontal m $X_A = X_B$.	$\frac{U_A^2}{2g_c} + \frac{P_A}{p_A} - F + w = \frac{U_B^2}{2g_c} + \frac{P_B}{p_B}$
ii) If frictional losses are assumed to be inappreciable then F = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{p_A} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{p_B}$
iii) If the fluid is a liquid then pA = pB = p (let)	$\frac{U_A^2}{2g_c} + \frac{P_A}{p} + w = \frac{U_B^2}{2g_c} + \frac{P_B}{p}$
iv) Since no work is done on the liquid, or by the liquid between A and B. m w = 0	$\frac{U_A^2}{2g_c} + \frac{P_A}{p_A} = \frac{U_B^2}{2g_c} + \frac{P_B}{p_B}$ ..... (2)

Equation (2) may be written as:

$$U_B^2 - U_A^2 = \frac{2g_C}{p}(P_A - P_B) \quad \text{..... (3)}$$

Since, $P_A - P_B = \Delta P$, and since $\frac{\Delta P}{p} = \Delta H$

m equation (3) can be written as

$$\sqrt{U_B^2 - U_A^2} = \sqrt{2g_C\ \Delta H} \quad \text{.....(4)}$$

N.B. $P_A = H_A\ p\ g / g_c$

$P_B = H_B\ p\ g / g_c$

$P_A - P_B = (H_A - H_B)p\ g / g_c$

or, $\Delta P = \Delta H\ p\ g / g_c$.

Since, $g / g_c \approx 1.0$ hence, $\Delta H = \Delta P / p$

If the pipe to the right of the orifice plate were removed so that the liquid issued as a jet from the orifice, the minimum diameter of the stream would be less than the diameter of the orifice. This point of minimum cross-section is known a vena-contracta.

Point B was chosen at the vena-contracta. In practice the diameter of the stream at the vena-contracta is not known, but the orifice diameter is known. Hence equation (4) may be written in terms of the velocity through the orifice, as a result a constant (Co) has to be inserted in the equation (4) to correct the difference between this velocity and the velocity at the vena-contracta. There may be some loss by friction and this also may be included in the constant. Equation (4) then becomes:

$$\sqrt{U_0^2 - U_A^2} = C_0\sqrt{2g_C\ \Delta H} \quad \text{..... (5)}$$

where U_0 = velocity through the orifice.

The pressure difference ΔP between A and B is read directly from the manometer.

In equation (5)

ΔH is measured from manometer (ΔP/p)

g_c is constant

C_0 is constant and known for a particular orifice meter.

U_0 and U_A is unknown

So to solve both U_0 and U_A another equation is required. We can assume that the volume flow-rate at A and orifice are equal, we can thus deduce the following equation.

$$U_A \frac{\pi d_P^2}{4} = U_O \frac{\pi d_O^2}{4} \quad \text{or,} \quad \frac{U_A}{U_O} = \left(\frac{d_O}{d_P}\right)^2 \quad \text{..... (6)}$$

where, d_P = diameter of pipe

d_O = diameter of orifice

d_P and d_O are already known

Now we can solve equation (5) and (6) to get the value of both U_A and U_O.

U_A = velocity of fluid in the pipe

$U_A \times \frac{\pi d_P^2}{4}$ = volume flow rate of fluid in the pipe.

The constant Co depends on the

- ratio of the orifice diameter to the pipe diameter

- position of the orifice taps
- value of Reynolds number for the fluid flowing in the pipe.

For values of Reynolds number (based on orifice diameter i.e. $Re = \frac{d_O u_O p}{\mu}$ of 30,000 or above, the value of Co may be taken as 0.61.

Advantage

It is very simple device and can be easily installed i.e. cost of installation is less.

Fluids of various viscosity can be measured just by changing the orifice diameter.

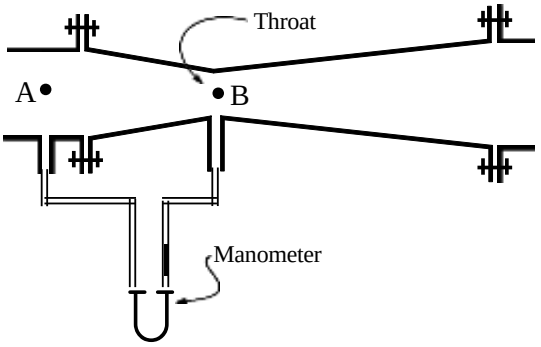
Disadvantage

The orifice always results in a permanent loss of pressure (head), which decreases as the ratio of orifice diameter to pipe, diameter increases i.e. cost of operation, particularly for long term, is considerable.

VENTURIMETER

Description

The venturimeter, as shown in the figure consists of two tapered sections inserted in the pipeline, with the tapers smooth and gradual enough so that there are no serious loss of energy. At point B the section of venturimeter has minimum diameter. This point is called the 'throat' of the venturimeter.



The venturimeter is fitted within a pipe. The pressure difference at A and B is measured by a manometer.

Derivation

If the Bernoulli's equation is written between these two points the following relationship holds.

$$X_A + \frac{U_A^2}{2g_c} + \frac{P_A}{p_A} - F + w = X_B + \frac{U_B^2}{2g_c} + \frac{P_B}{p_B} \quad \text{..... (1)}$$

Conditions	Equation (1) changes to:
i) The pipe is horizontal m $X_A = X_B$	$\frac{U^2_A}{2g_c} + \frac{P_A}{p_A} - F + w = \frac{U^2_B}{2g_c} + \frac{P_B}{p_B}$
ii) If frictional losses are assumed to be inappreciable then F = 0	$\frac{U^2_A}{2g_c} + \frac{P_A}{p_A} + w = \frac{U^2_B}{2g_c} + \frac{P_B}{p_B}$
iii) If the fluid is a liquid then pA ?pB = p (let)	$\frac{U^2_A}{2g_c} + \frac{P_A}{p} + w = \frac{U^2_B}{2g_c} + \frac{P_B}{p}$
iv) Since no work is done on the liquid, or by the liquid between A and B. i.e. w = 0	$\frac{U^2_A}{2g_c} + \frac{P_A}{p_A} = \frac{U^2_B}{2g_c} + \frac{P_B}{p_B}$ ..... (2)

Equation (2) may be written as:

$$U^2_B - U^2_A = \frac{2g_C}{p}(P_A - P_B) \quad \text{..... (3)}$$

Since, $P_A - P_B = \Delta P$, and since $\frac{\Delta P}{p} = \Delta H$

m equation (3) can be written as

$$\sqrt{U_B^2 - U_A^2} = \sqrt{2g_C \Delta H} \quad \text{.....(4)}$$

N.B. $P_A = H_A p g / g_c$
$P_B = H_B p g / g_c$
$P_A - P_B = (H_A - H_B) p g / g_c$
or, $\Delta P = \Delta H p g / g_c$.
Since, $g / g_c \approx 1.0$ hence, $\Delta H = \Delta P / p$
If the pipe to the right of the orifice plate were removed so that the liquid issued as a jet from the orifice, the minimum diameter of the stream would be less than the diameter of the orifice. This point of minimum cross-section is known a vena-contracta.

Since there are practically no losses dude to eddies and since the cross-section of the high velocity part of the system is accurately defined hence equation (4) may be written as

$$\sqrt{U_B^2 - U_A^2} = C_V \sqrt{2g_C \Delta H} \text{ .....(5)}$$

where U_B = velocity at the throat of the venturimeter

In case of venturimeter the value of coefficient $C_V = 0.98$.

Comparison between orificemeter and venturimeter:

Orifice meter	Venturimeter
1. Installation is cheap and easy. 2. The power loss is considerable in long run. 3. They are best used for testing purposes or other cases where the power loss is not a factor, as in steam lines. 4. Installing a new orifice plate with a different opening is a simple matter.	1. Installation is costly. It is less easier than orifice meter. (*Disadvantage*) 2. Power loss is less in long run even negligible (*Advantage*) 3. Venturimeters are used for permanent installation. 4. Installation of a different opening require replacement of the whole venturimeter. (*Disadvantage*)

PITOT TUBE

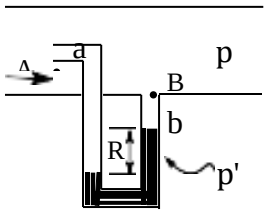


Fig 1

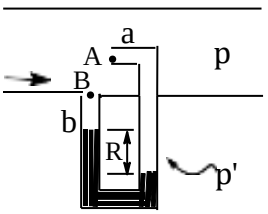


Fig 2

The pitot tube is a device to measure the local velocity along a streamline. The configurations of the device are shown in the figure. The manometer has two arms. One arm 'a' is placed at the center of the pipe and opposite to the direction of flow of fluid. The second arm 'b' is connected with the wall of the pipe. The difference of liquid in two arms of the manometer is the reading.

The tube in the 'a' hand measures the pressure head (X_A) and the velocity head ($\frac{U_A^2}{2g_C}$). The 'b' hand measures only pressure head (X_B).

$$X_A + \frac{U_A^2}{2g_C} = X_B \qquad \text{or, } X_A - X_B = \frac{U_A^2}{2g_C} \qquad \text{or, } \Delta X = \frac{U_A^2}{2g_C} \quad \text{.....(i)}$$

Here ΔX_B is the pressure head of the fluid whose flow is to be measured that corresponds to R.

Since the manometer measures the pressure according to the following equation.

$$\Delta X = (p' - p)\, R\, g/g_C$$

or, $= (p' - p)\, R$ [Since $g/g_C \approx 1$]

where, p' = density of the liquid in the manometer

p = density of the fluid in the pipe.

Replacing ΔX in the equation (i) gives,

$$(p' - p)\, R = \frac{U_A^2}{2g_C} \qquad [U = U_A \text{ (let)}]$$

$$U = \sqrt{\frac{2\,(p' - p)\, g_C\, R}{p}} \quad \text{.....(ii)}$$

The velocity measured is the maximum velocity inside the pipe.

$$U_{max} = \sqrt{\frac{2\, g_C\, (p' - p)\, R}{p}}$$

By orifice meter or venturimeter average velocity of fluid is measured. With pitot tube velocity of only one point (i.e. at the center of the pipe) is measured. To convert U_{max} to average velocity ($\bar{U}$) the following relationship is taken into concern.

where, D = diameter of the pipe

U_{max} = maximum velocity of fluid

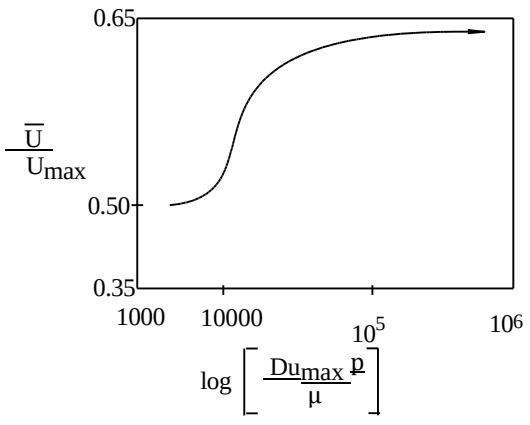
p = density of the fluid flowing

μ = viscosity of the fluid flowing

$\bar{U}$ = average velocity in the pipe

Disadvantage of pitot tube

1. It does not give the average velocity directly.
2. When velocity of gases are measured the reading are extremely small. In these cases some form of multiplying gauge like differential manometer and inclined manometers are used.



where D= diameter of the pipe

U_{max} = maximum velocity of fluid

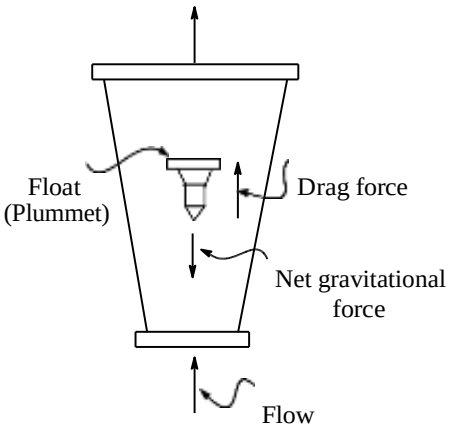
p = density of the fluid flowing

μ = viscosity of the fluid flowing

U = average velocity in the pipe

ROTAMETER

Construction of rotameter:



It consists essentially of a gradually tapered glass tube mounted vertically in a frame with the large end up. The fluids flow upward through the tapered tube.

Inside the tapered tube a solid plummet or float having diameter smaller than that of the glass tube is placed. The plummet rises or falls depending on the velocity of the fluid.

Principles of rotameter:

For a given flow rate, the equilibrium portion of the float in the rotameter is established by a balance of three forces.

1. The weight of the float (w)
2. The buoyant force of the liquid on the float (B)
3. The drag force on the float (D)

'w' acts downward and B and D acts upward.

At equilibrium:

$$W = B + D$$

or, $$D = W - B$$

or, $$F_D g_C = V_f p_f g - V_f p g .$$

where, F_D = drag force

V_f = volume of float

p_f = density of float

p = density of fluid

The quantity of V_f can be replaced by $\frac{m_f}{p_f}$, where m_f is the mass of the float, and equation (i) becomes:

$$F_D g_C = V_f (p_f - p) g = \frac{m_f}{p_f} (p_f - p) g = m_f \left(1 - \frac{p}{p_f}\right) g$$

For a given meter operating on a certain fluid, the right-hand side of equation- (ii) is constant and independent of the flow rate. Therefore F_D is also constant, when the *flow increases the position of the float must change to keep the drag force constant*.

$$F_D = K_1 \frac{U_{max}^2}{2g_c} \qquad \text{where, } K_1 = \text{constant}$$

If the tube is tapered, and difference between the diameters of float and tube are small then it can be shown that the height at which the plummet is floating is proportional to the rate of flow.

Advantages:

1. The flow rates can be measured directly.
2. Measured in linear scale and
3. Constant and small head loss.

SIZE REDUCTION

Definition

Size reduction (or Comminution):
Size reduction or *comminution* is the process of reducing substances to smaller particles.

Size separation (or Classification):
Size separation (or classification) is a process in which particles of desired size are separated from other fractions.

Objectives

Objectives of size reduction

1. Size reduction leads to increase of surface area.
   Example-I: The rate of dissolution of solid drug particles increases many folds after size reduction. Griseofulvin, an antifungal drug, when administered in its micronized form shows around five times better absorption.
   Example-II: The absorptive power of charcoal and kaolin increases after size reduction due to increase in surface area.
2. Size reduction produces particles in narrow size range. Mixing of powders with narrow size range is easier.
3. Pharmaceutical suspensions require finer particle size. It reduces rate of sedimentation.
4. Pharmaceutical capsules, insufflations (i.e. powders inhaled directly into the lungs), suppositories and ointments require particles size to be below 60μm size.

Objectives of size separation

1. Any solid materials, after size reduction, never gives particles of the same size but contains particles of varying sizes. The size-reduced particles are then passed through sieves to get fractions of narrow size range.
2. During tablet granulation the granules should be within narrow size range, otherwise, weight variation will take place during tablet punching.

Factors affecting size-reduction

The pharmaceutical industry uses a great variety of materials, including chemical substances, animal tissues and vegetable drugs.

A. Factors related to the nature of raw materials
Hard materials: Hard materials like pumice and iodine are most difficult to comminute. During size reduction these types of materials will produce abrasive wear of milling surfaces, which will then contaminate the material.
Fibrous materials: Crude drugs obtained from plants like glycyrrhiza, rauwolfia, ginger etc. are fibrous in nature and cannot be crushed by pressure. So they may be size-reduced by cutter mill.
Friable materials: Sucrose and dried filter cakes are friable (i.e. brittle) hence they are easy to comminute by hammer mill or fluid energy mill.

Plastic materials: Synthetic gums, waxes and resins become soft and plastic during milling. These low melting substances should be chilled (made cold) before milling. These types of materials are milled by using hammer mill and fluid energy mill.
Hygroscopic materials: Hygroscopic materials absorbs moisture rapidly hence they must be comminuted inside a closed equipment like ball-mill.
Thermolabile materials: Thermolabile materials like vitamins and antibiotics are milled inside chilled equipment.
Inflammable materials: Fine dust, such as dextrin, starch and sulphur, is a potential explosive mixture under certain conditions. All electrical switches should be explosive proof and the mill should be earthed properly.
Particle size of the feed: For a mill to operate satisfactorily, the feed should be of proper size.
Moisture content: Presence of more than 5% moisture hinders the milling process and produces a sticky mass.

B. Factors related to the nature of the finished product
Particle size: Moderately coarse powders may be obtained from various impact mill. If very fine particles like micronized particles of griseofulvin may be obtained from fluid energy mill.
Ease of sterilization: When preparations are intended for parenteral (injection) purpose and ophthalmic uses, size reduction must be conducted in a sterile environment. Mills should be sterilized by steam before use.
Contamination of milled materials: In case of potent drugs and low dose products, contamination of the products should be avoided. Equipment free from wearing (e.g. fluid energy mill) may be used in this case.

Laws governing energy and power requirements of mills
During size reduction energy is supplied to the equipment (mill). Very small amount of energy (less than 2%) actually produce size reduction. Rest of the energy is dissipated (wasted) in:

(i) Elastic deformation of particles
(ii) Transport of material within the milling chamber
(iii) Friction between the particles
(iv) Friction between the particles and mill
(v) Generation of heat
(vi) Vibration and noise.
(vii) Inefficiency of transmission and motor.

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

Rittinger's theory
Rittinger's theory suggests that energy required in a size reduction process is proportional to the new surface area produced.

$$E = K_R (S_n - S_i)$$

where, E = energy required for size reduction
K_R = Rittinger's constant

S_i = initial specific surface area
S_n = final specific surface area

Application: It is most applicable in size reducing brittle materials undergoing fine milling.

Bond's theory

Bond's theory states that the energy used in crack propagation is proportional to the new crack length produced

$$E = 2K_B \left(\frac{1}{\sqrt{d_n}} - \frac{1}{\sqrt{d_i}} \right)$$

where, E = energy required for size reduction
K_B = Bond's work index
d_i = initial diameter of particles
d_n = final diameter of particles

Application: This law is useful in rough mill sizing. The work index is useful in comparing the efficiency of milling operations.

Kick's theory

Kick's theory states that the energy used in deforming (or fracturing) a set of particles of equivalent shape is proportional to the ratio of change of size, or:

$$E = K_K \log \frac{d_i}{d_n}$$

where, E = energy required for size reduction
K_K = Kick's constant
d_i = initial diameter of particles
d_n = final diameter of particles

Application: For crushing of large particles Kick's theory most useful.

Walker's theory

Walker proposed a generalized differential form of the energy-size relationship:

$$dE = -K \frac{dD}{D^n}$$

where E = amount of energy (work done) required to produce a change
D = size of unit mass
K = Constant
n = constant

For n =1.0 Walker equation becomes Kick's theory used for coarse particles > 1 μm.
For n =1.5 Walker equation becomes Bond's theory. This theory is used when neither Kick's nor Rittinger's law is applicable.
For n =2.0 Walker equation becomes Rittinger's theory used for fine particles < 1 μm size.

Methods of size reduction

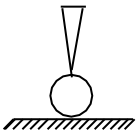
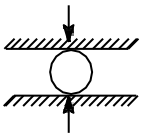
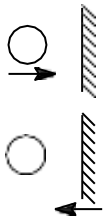
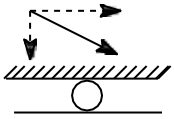
	Method	Diagram	Common Examples
Approximate increase in fineness of product ↓	Cutting		Scissors Cutter mill
	Compression		Roller mill Crusher mill
	Impact		Hammer mill
	Attirtion (Pressure and friction)		File Fluid energy mill

Table: Uses of size reduction methods

Degree of size reduction	***Typical methods***	***Examples***
Large pieces	Cutter or compression mills	Rhubarb
Coarse powders	Impact mills	Liquorice, cascara
Fine powders	Combined impact and attrition mills	Rhubarb , belladonna
Very fine powders	Fluid energy mills	Vitamins and antibiotics

HAMMER MILL

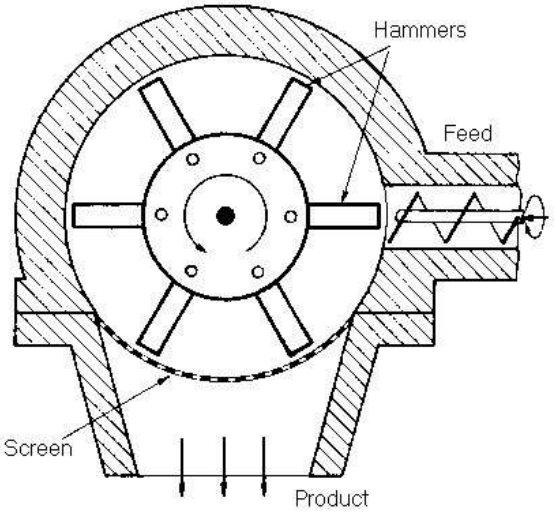


Fig. Hammer Mill

Method of size reduction: Impact

Construction and working principle:
Hammer mill consists of a stout metal casing, enclosing a central shaft to which four or more *hammers* are attached. These are mounted with *swivel* joints, so that the hammers swing out to a radial position when the shaft is rotated. The lower part of the casing consists of screen through which materials can escape, when sufficiently size reduced. The material is collected in a container placed below the screen.

- The screen can be changed according to the particle size required.
- According to the purpose of operation the hammers may be square-faced, tapered to a cutting form or have a stepped-form.
- The interior of the casing may be undulating in shape, instead of smooth circular form for better impact.
- The rotor operates at a speed of 80cycles per second.

Advantages:
(a) It is rapid in action, and is capable of grinding many different types of materials.
(b) The product can be controlled by variation of rotor speed, hammer type and size and shape of mesh.
(c) Operation is continuous.
(d) No surface moves against each other so very little problem of contamination of mill materials.

Disadvantages:
(a) High speed of operation generates heat that may affect thermolabile materials or drugs containing gum, fat or resin.
(b) The rate of feed should be controlled otherwise the mill may be choked.
(c) Because of high speed of operation, the hammer mill may be damaged if some foreign materials like stone, metal pieces etc. are present in the feed.

Applications: Powdering of crystals and filter cakes.

BALL MILL

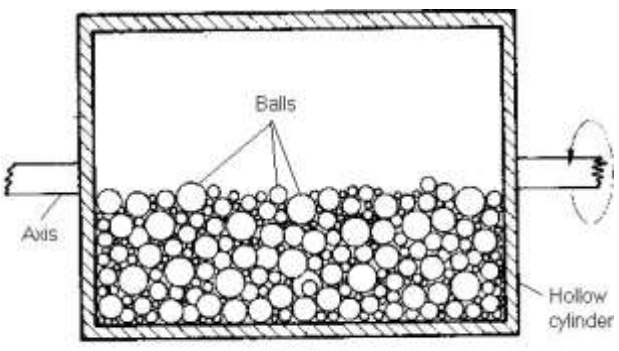


Fig. Ball mill

Construction
The ball mill consists of a hollow cylinder rotated on its horizontal axis. Inside the cylinder balls or pebbles are placed.
Cylinder:

- Cylinder may be made up of metal, porcelain or rubber.
- Rubber reduces the abrasion. Diameter of the cylinder ranges from 1 to 3m in pharmaceutical practice.

Balls:

- Balls occupy about 30 to 50% of the volume of the cylinder.
- Diameter of the balls depends on the feed size and diameter of the cylinder. The diameter of balls ranges from 2cm to 15cm.
- Balls may be of metal, porcelain or pebbles.

Working Principle:

Larger particles are fed through an opening of the cylinder. The opening is closed. The cylinder is rotated at the critical speed of ball mill. The optimum size reduction in a ball mill depends o the following factors:

Feed quantity:

Too much feed will produce cushioning effect and too little feed will produce loss of efficiency of the mill.

Speed of rotation of the cylinder:

- At low speed the mass of balls will slide or roll over each other and only a negligible amount of size reduction will take place.
- At high speeds, balls will be thrown out to the wall of the cylinder due to centrifugal force and no grinding will occur.
- At $2/3^{rd}$ 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. By this means the maximum size reduction is obtained by impact of the particles between the balls and by attrition between the balls. Generally it is 0.5 cycles per seconds (cps).

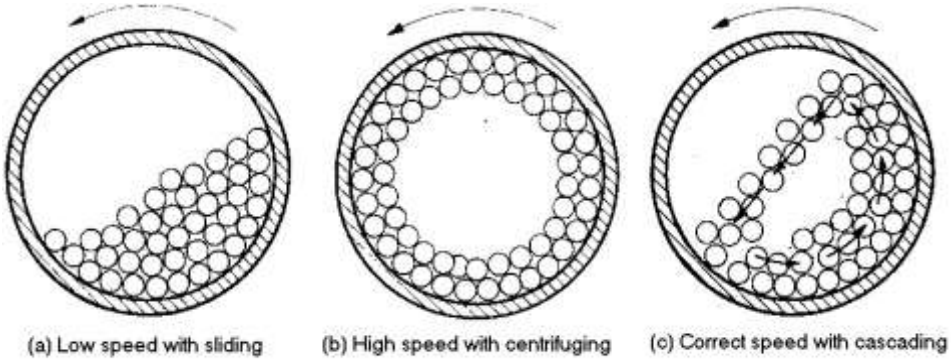


Fig. Ball mill operation

Advantages

1. It is capable of grinding a wide variety of materials of differing hardness.
2. It can be used in completely enclosed form, which makes it suitable for use with toxic materials.
3. It can produce very fine powders.
4. It is suitable both for dry and wet milling. Wet milling is required for preparation of pharmaceutical suspensions.

Disadvantages

1. Wear occurs from the balls and the inside surface of the cylinder hence there is possibility of contamination of product with mill material. Abrasive materials increase wear.
2. Soft or sticky materials may cause problems by caking on the sides of the mill or by holding the balls in aggregates.
3. The ball mill is a very noisy machine, particularly if the cylinder is made of metal.

Applications:
Large ball mills are used to grinding ores prior to manufacture of pharmaceutical chemicals.
Smaller ball mills are used for grinding of drugs or excipients or for grinding suspensions.

Various types of ball mills:
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 within the cylinder and the smaller balls are collected in the conical portion. As a result, coarser grinding takes place in the cylinder portion and finer grinding takes place in the apex of the conical portion. The product is more finer and uniform than general cylindrical ball mill.

Tube mill: They consist of long cylinder and can grind to a finer product than the conventional ball mill.

Rod mill: Instead of balls they contain rods, which extend the length of the mill. These rods are useful with sticky materials since rods do not form aggregates like balls.

Vibration mill: In this type of mills vibratory movements are given instead of rotation. The cylinder is mounted on springs which set up vibration. 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.

FLUID ENERGY MILL
Construction:
It consists of a loop of pipe, which has a diameter of 2 to 20cm. The height of the loop may be up to 2m. Several nozzles are fitted at the bottom of the pipe. A classifier is fitted at the product collection point.

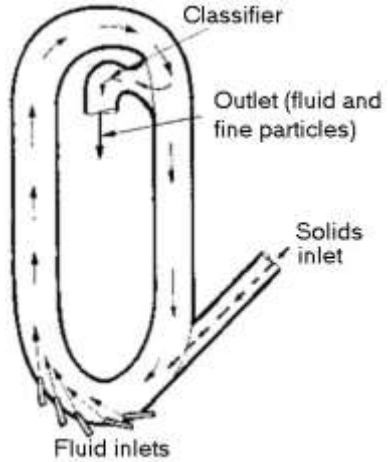


Fig. Fluid energy mill

Working principle
A fluid usually air, is injected at very high pressure through nozzles at the bottom of the loop. This gives rise to a high velocity of circulation that produce turbulence. Solids are introduced into the stream through the feed inlet. As a result of high degree of turbulence, impacts and attrition occur between the particles. A *classifier* is fitted in the system so that only finer size particles are collected as products and the larger size particles are again sent to the stream of air for further size reduction.
The feed to the mill is previously size reduced and passed through a 100mesh screen.
The size of the product may be 5µm or below.

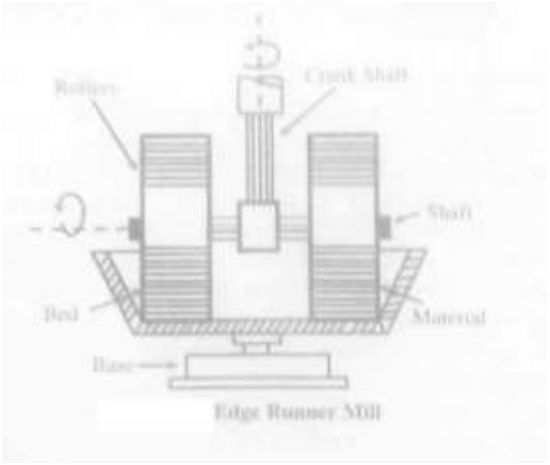
Advantages:
1. The particle size of the product is smaller than that produced by any other method of size reduction.
2. Expansion of gases at the nozzles lead to cooling, counteracting the usual frictional heat that can affect heat-sensitive (thermolabile) materials.
3. Since the size reduction is by inter-particulate attrition there is little or no abrasion of the mill and no contamination of the product.

4. For oxygen or moisture sensitive materials inert gases like nitrogen can be used instead of normal air.
5. This method is used where fine powders are required like micronization of griseofulvin (an antifungal drug), antibiotics etc.

EDGE RUNNER MILL

Edge runner mill or roller stone mill has two large grinding wheel or stones, which rotate slowly in a large bowl containing the materials and crushes them into fine powders.

Principle: Edge runner mill works on the principles of shearing forces developed by the rotating stones. The stones are heavy weighted and easily crush the materials thus reducing their size.



Construction: Edge runner mill weighs several tones due to the presence of two heavy rollers, made up o stone or metal, which moves on another bed of stones or granite. The rollers have a central shaft and revolve around their individual axis. Farther they are mounted on a horizontal shaft and move around the bed.

Working: It works on a batch type process. The material to be crushed is kept on the shallow stone bed. A scrapper keeps it on the way of the stone wheel, which revolve around its axis and also around the stone bed. The outer part of the wheel travels a greater distance than the inner part to achieve size reduction by shearing and crushing. After crushing the material for a specific time, the resulting materials are collected and the desired size can be obtained by passing it through sieve.

Uses: 1) It is used for crushing hard materials into fine powders. 2) It is used for plant based product.

Merits: 1) It can produce very fine particles of drugs. 2) It does not required much more attention while operating. 3) Simple and easy to install.

Demerits: 1) It cannot be used for sticky materials. 2) The milling process is time taking. 3) Produce noise.

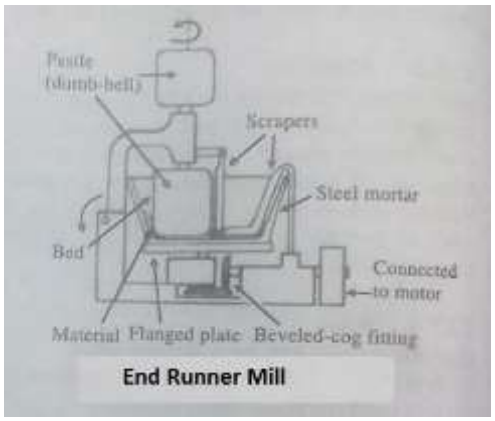
END RUNNER MILL

End runner mill is a type of mortar and pestle, having shallow mortar and a flat bottomed pestle. It operates like a wet grinding used in the houses.

Construction: The end-runner mill consists of a weighted pestle mounted eccentrically in a ceramic, granite or metal mortar, which is rotated by a motor. The pestle rotates by friction and is free to rise and fall in the mortar so that its grinding action involves both impact and shear, the material being crushed and rubbed between it and the rotating mortar.

Spring-loaded scrapers ensure that material is constantly returned to the grinding area and at the end of the operation the pestle can be swung clear of the mortar to facilitate emptying and cleaning.

Uses: End runner mill provides moderately fine powder and operates successfully with fibrous materials, bark, woods fruits, leaves, etc.



End Runner Mill

Advantages: 1) It produces fine particles. 2) Requires less attention during the milling operation.

Disadvantages: 1) It is not suitable for milling sticky materials. 2) Machine noise leading to noise pollution

SIZE SEPARATION

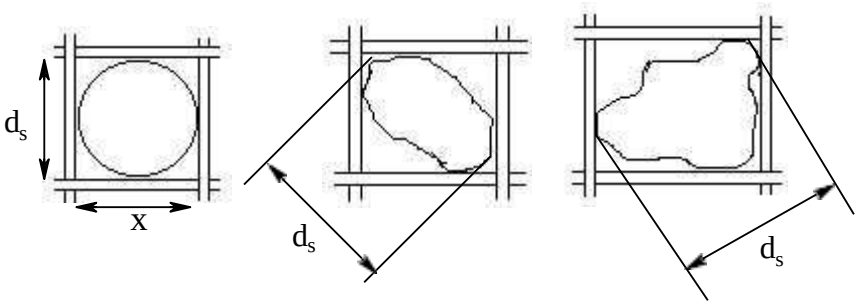
Definition: Size separation is a unit operation that involves the separation of a mixture of various size particles into two or more portions by means of screening surfaces. Size separation is also known as sieving, sifting, screening. This technique is based on physical differences b/w the particles such as size, shape and density.

Application/uses of size separation:
Application/uses of size separation Determination of particle size & size distribution used for production of tablet and capsule. It is a quality control tool for analysis of raw material. To optimize the process condition such as method of agitation, time of screening, feed rate etc. To measure the efficiency of size reduction equipments .

SIEVES
Sieves Sieves for pharmacopeial testing are constructed from wire cloth with sqare meshes, woven from wires of brass, bronze, stainless steel etc., Number of sieve: No of meshes in a length of 2.54 cm in each transfer direction parallel to the wires. Nominal size of aperture: Distance between the wires. Length of the side of the square aperture. (in mm or µm). Nominal diameter of the wire: Made of suitable diameter in order to give a suitable aperture and sufficient length. Approximate % sieving area: The area of the meshes as a percentage of the total area of the sieve. Generally the sieving area is kept within the range of 35-40% in order to give suitable strength to the sieve. Tolerance average aperture size: Fine sieves cannot be woven with same accuracy.

Sieve Analysis

Equivalent diameter
Sieve diameter, d_s , is the particle dimension that passes through a square aperture (length = x).



Sieve diameter, d_s for various particle shapes

Range of analysis
The International Standards Organization (ISO) sets lowest sieve diameter of 45µm. Powders are usually defined as particles having a maximum diameter of 1000µm, so this is the upper limit. In practice sieve analysis can be done over a range of 5 to 125000µm.

ISO Range : 45 to 1000 µm
Range available in practice: 5 to 125000 µm

Sample preparation
- Powders in dry state is usually used.
- Powders in liquid suspension can also be analyzed by sieve.

Principle of measurement with sieve
Sieve analysis utilizes a set of sieves. Each sieve is a woven, punched or electroformed mesh, often in brass or stainless steel, with known aperture diameter which form a physical barrier

to particles. In sieve analysis a set of sieves (known as 'stack' or 'nest' of sieves) are arranged in such a way that the smallest aperture will be at the bottom and the largest aperture will be at the top.

1. A sieve-nest usually comprises 6 to 8 sieves with an aperture progression based on √2 or 2√2 change in diameter between adjacent sieves.
2. Initial weight (W_0) of powder sample was taken on the first sieve (i.e. topmost sieve). The sieve-set was closed and shaking was started. After shaking for a stipulated time, the sieve-set was taken out. All the sieves were disassembled.
3. The powder retained on each sieve was collected on a paper (bearing the mesh number) and weighed.

TABLE - 1

Sieve number (Passed/ Retained)	Size of opening (Passed / Retained)	Arithmetic mean Size of openings d (μm)	Weight Retained on smaller sieve (gm)	% Retained on smaller sieve	Cumulative % oversize
M1/M2	d1/d2	½(d1 + d2)	W1	p1=100w1/ W	p1
M2/M3	d2/d3	½(d2 + d3)	W2	p2=100w2/ W	p1+p2
M3/M4	d3/d4	½(d3 + d4)	W3	p3=100w3/ W	p1+p2+p3
--	--	--	--	--	--
--	--	--	--	--	--
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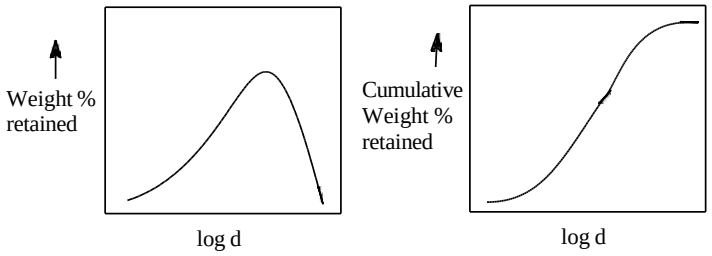
			Total = W	Total = 100	

TABLE – 2: Plot

log d	Weight % retained	Cumulative % oversize

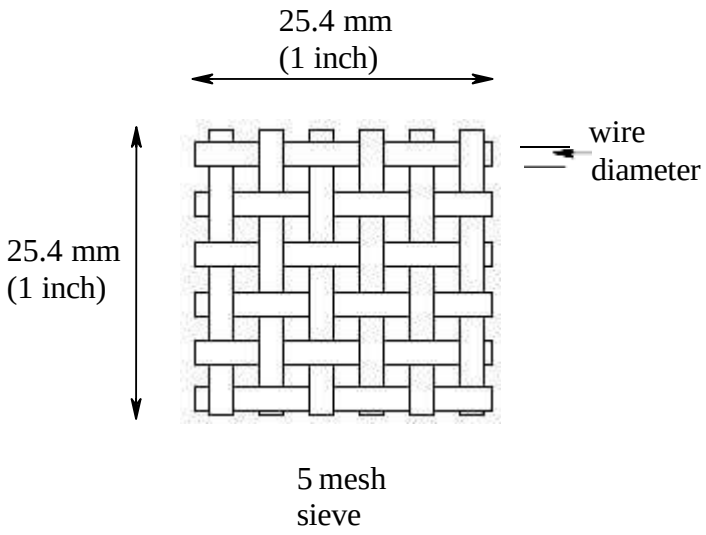


STANDARDS OF SIEVES

It is required that wire-mesh sieves will be made from wire of uniform, circular cross-section and for each sieve the following particulars are stated:

Number of sieve

This is the number of meshes in a length of 25.4mm (i.e. 1 inch), in each direction.



5 mesh sieve

Nominal size aperture

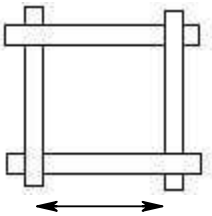
This is the distance between the wires, so that it represents the length of the side of the square aperture.

N.B. While it is the diameter of the largest sphere that would pass the mesh, it is not necessarily the maximum dimension of the particle, plate like particles will pass through diagonally and long fibrous particles require only suitable orientation.

Nominal diameter of the wire

The wire diameter is selected to give a suitable aperture size. It is also required to give the necessary strength to avoid distortion.

The diameter of the wire is represented by Standard Wire Gauge.



Approximate screen area

This standard expresses the area of the meshes as a percentage of the total area of the sieve.

It is governed by the diameter of the wire. It is generally kept within 35 to 45% of the total area of the sieve.

This represents the useful area of a sieve. Greater screen area is preferred.

$$\text{Approximate Screen Area} = \frac{\text{Total sieve area - Area occupied by the wire}}{\text{Total area of the screen}} \text{x } 100\%$$

Aperture tolerance average

Some variation in the aperture size is unavoidable and this variation is expressed as a percentage, known as aperture tolerance average. It is the maximum limit within which the dimension of meshes can be allowed to vary and still be acceptable for sieving.

Finer wires are likely to be subject to a greater proportional variation in diameter than coarse mesh. Hence, the aperture tolerance average is smaller for sieves of 5 to 10 mesh than in case of 300mesh.

Tyler Standard Screen Scale

Mesh	Clear Opening, mm	Wire Diameter, mm
3	6.680	1.778
4	4.699	1.651
6	3.327	0.914
8	2.362	0.813

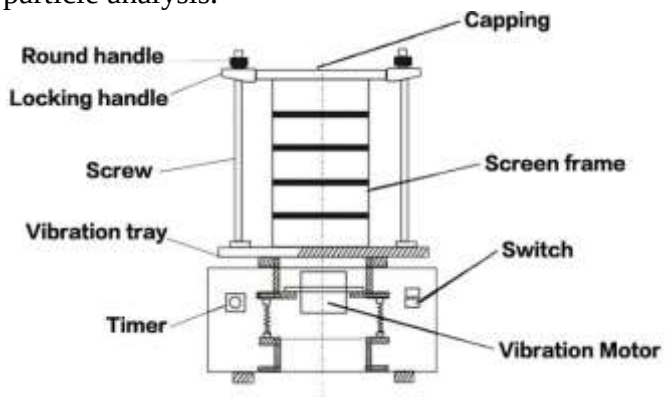
10	1.651	0.889
14	1.168	0.635
20	0.833	0.437
28	0.589	0.318
35	0.417	0.310
48	0.295	0.234
65	0.208	0.183
100	0.147	0.107
150	0.104	0.066
200	0.074	0.053

SIZE SEPARATION EQUIPMENTS

SIEVE SHAKER

Sieve shaker is an instrument that used in particle analysis. It is used to shake a stack of test sieves which are placed in order (largest aperture on the top and smallest on the bottom), so that materials get sifted through according to particle sizes.

Sieve shakers can replace manual hand sieving to conduct sample size reduction, material separation and assist particle analysis.



Operation: Select the sieves with mesh sizes that are to be used and stack them together beginning with a pan at the bottom. Then the finest sieve followed by increasing coarser sieves with the coarsest on top. Place stack of sieves in the shaker with the bottom pan resting on the cradle platform. Cover the top sieve so that the stack can be easily secured in the shaker. Secure the stack with the sieve hold-down bar on the top of the stack and screw the nuts on the vertical support rods firmly against the holder. Adjust and tighten the nuts at the top of the vertical support rods according to the weight of the material in the sieves. The greater the weight of the load, the tighter the nuts should be. Start the motor and observe the initial sieving action to see if the sieves are fastened securely, readjust and tighten the nuts if necessary. Set the built-in timer for the desired shake time and turn the machine on. The machine will stop when the timer has expired. Weigh the materials and record the weight and percentage of the original dry weight that is retained in each individual sieve and in the bottom pan.

Advantages

- Test sieve shakers are capable of conducting sample size reduction utilising maximum number of 10 test sieves in one experiment. Where as, the number of test sieves used in manual hand sieving will be a lot more restricted because of the weight of both samples and test sieve itself

- Sieving analysis with a shaker has the advantage of accuracy. The vibratory frequency and amplitude of sieving is consistent, which ensures the accuracy of the test results when repeatable tests are required
- Using a sieve shaker is a more efficient method compared with manual hand sieving. Once the timer is set up the experiment will run automatically without needing users to be present. More important, sieving time is significantly reduced considering a lot more test sieves are shaking simultaneously.
- Shakers provide more flexibility than manual hand sieving, especially when the sieving analysis requires assistance with liquid or glass beads. With some models of shaker, the user can adjust sieving power and speed according to the size, weight and density of the samples.

SHAKING SCREEN

Principle:

Particles of different sizes are separated by passing them through a sieve, which oscillates to-and-fro continuously.

Construction:

Shaking screen consists of metal frame to which a screen is fixed at the bottom. The screen cloth may be riveted directly or fitted by using a removable bolted frame. The metal frame is suspended by hanger rods, so that it can move freely. The metal frame may be suspended either horizontally or in inclined position. One side of the frame is attached with an ordinary eccentric on a rotating shaft. The entire frame experiences a reciprocating (to-and-fro) motion.

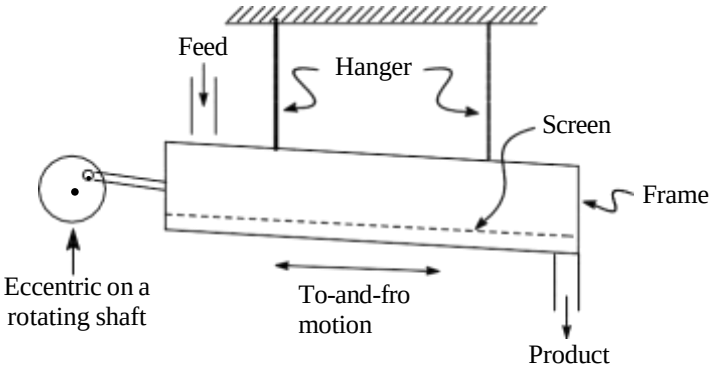


Fig. Shaking screen

Working:

The screen is allowed to shake in a reciprocating motion. The feed (material to be screened) is introduced on to the screen from a side. . Fine particles are screened off initially. The remaining materials moves forward and the over-sized particles are collected at the other end.

Advantages:

It requires low-head room and low power requirement.

Disadvantages:

High cost of maintenance of screens and supporting structures.

Its capacity is low.

SHAKING AND VIBRATING SCREENS (ROTEX SCREEN)

Principle: Rotex screen works on oscillating agitation (to-and-fro motion) by means of an eccentric mechanism. Further vibrations are caused by rubber balls.

Construction:

This equipment consists of a set of

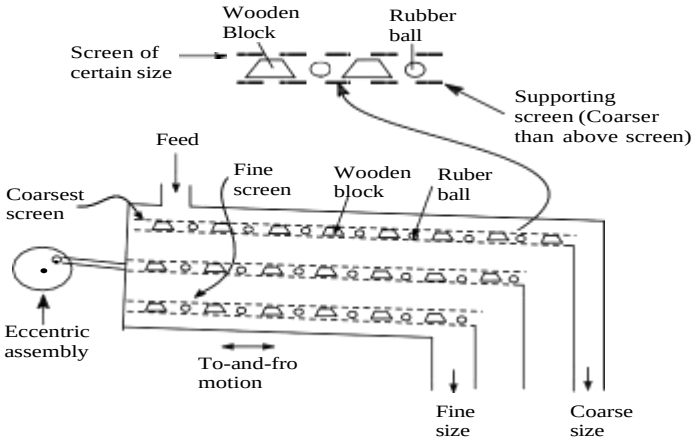


Fig. Rotex Screen

screens, which are slightly inclined at 5 degrees with horizontal axis. Each screen set is double layered. The upper screen is of a fixed size and the lower one is coarser screen, which is a supporting sieve. Between these two screens, wooden blocks are placed at different intervals. Between the wooden blocks rubber balls are placed. This two-sieve system represents one unit. Several such units are arranged in the descending order, i.e. sieve or larger size opening remains at the top and finer size opening remains at the bottom. The overall assembly of screens is supported on sliding contacts at the lower end. The upper end of the screen system is connected to an eccentric pin on a flywheel.

Working:

The screen system is allowed to agitate with the help of eccentric. The shaking motion of the screen causes the balls to fly between the screens. As they strikes the inclined surface of the wooden blocks, the balls deflect upward and strike the screen cloth and thus prevents blocking of the mesh. The feed is introduced at the higher end of the screen. The material passes through the upper screen and reaches the next screen. This process continues until all the materials are separated into fractions. The fractions are collected separately at the outlet point.

Uses: Rotec screen is used for handling a variety of dry powders, granules and dry foods.

CYCLONE SEPARATOR

Principle

In cyclone separator centrifugal force is used to separate solid from fluids. The separation process depends on particle size and particle density. It is also possible to allow fine particles to be carried with the fluid.

Construction

It consists of a short vertical, cylindrical vessel with a conical base. The upper part of the vessel is fitted with a tangential inlet. The solid outlet is at the base. Fluid outlet is provided at the center of the top portion, which extends inwardly into the separator. Such an arrangement prevents the air short-circuiting directly from the inlet to the outlet of the fluid.

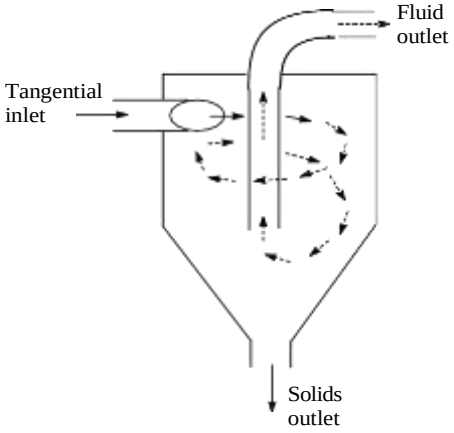


Fig. Cyclone separator

Working

The solids to be separated are suspended in a stream of fluid (usually air or water). Such feed is introduced tangentially at a very high velocity, so that rotary movement takes place within the vessel. The centrifugal force throws the particles to the wall of the vessel. As the speed of the fluid (air) diminishes, the particles fall to the base and collected at the solid outlet. The fluid (air) can escape from the central outlet at the top.

Uses

1. Cyclone separators are used to separate solid particles from gases.
2. It is also used for size separation of solids in liquids.
3. It is used to separate the heavy and coarse fraction from fine dust.

AIR SEPARATOR

Principle

The cyclone separator alone cannot carry out size separation on fine materials. For such separations a current of air

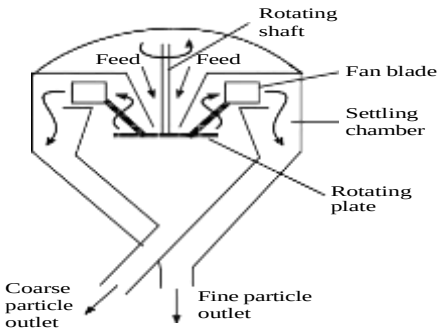


Fig. Air separator

combined with centrifugal force is used. The finer particles are carried away by air and the coarser particles are thrown by centrifugal force, which fall at the bottom.

Construction

It consists of a cylindrical vessel with a conical base. A rotating plate is fitted on a shaft placed at the center of the vessel. A set of fan blades are also fitted with the same shaft. At the base of the vessel two outlets are provided: one for the finer particles and the other for coarse particles.

Working

The disc and the fan are rotated by means of a motor. The feed (powder) enters at the center of the vessel and falls of the rotating plate. The rotating fan blades produce a draft (flow) of air in the direction as shown in the diagram. The fine particles are picked up by the draft of air and carried into space of settling chamber, where the air velocity is sufficiently reduced so that the fine particles are dropped and removed through the fine particle outlet.

Particles too heavy to be picked up by the air stream are removed at the coarse particle outlet.

Uses

Air separators are often attached to the ball mill or hammer mill to separate and return over sized particles for further size reduction.

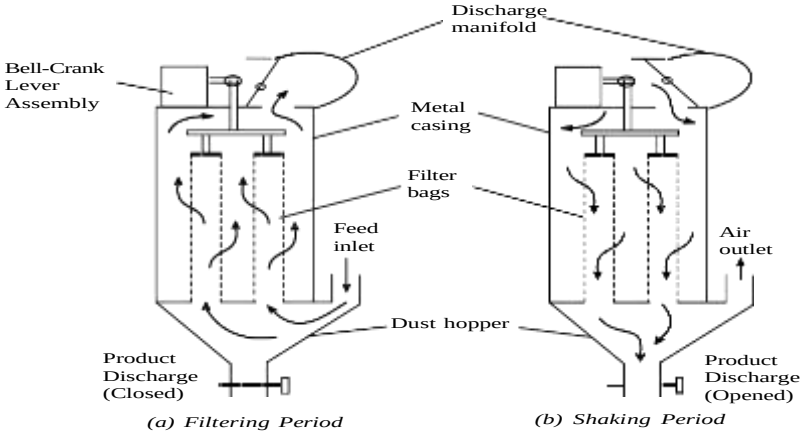


Fig. Bag filter

BAG FILTER

Principle

In a bag filter, size separation of fines (or dust) from the milled powder is achieved in two steps. In the first step, the milled powder is passed through a bag (made from cloth) by applying suction on the opposite side of the feed entry. This facilitates the separation. In the next step, pressure is applied in order to shake the bags so that powder adhering to the bag falls off, which is collected from the conical base.

Construction

It consists of a number of bags made of cotton or wool fabric. These are suspended in a metal container. A hopper is arranged at the bottom of the filter to receive the feed. At the top of the metal container, a provision is made for vacuum fan and exhaust through discharge manifold. At the top of the vessel a bell-crank lever arrangement is made to change the action from filtering to shaking.

Working

(a) *Filtering period*: During this period the vacuum fan produce a pressure lower than the atmospheric pressure within the vessel. Gas to be filtered enters the hopper, passes through the bags, and out of the top of the apparatus. The particles are retained within the bags.

(b) *Shaking period*: During this period the bell-crank lever first close the discharge manifold and air enters through the top so the vacuum is broken. At the same time it gives a violent jerking action to the bags so that they are freed from the dust. The fine particles are collected at the conical base.

Uses

1. Bag filters are used along with other size separation equipment, e.g. a cyclone separator.
2. They are use on the top of fluidized bed dryer for drying to separate the dusts.

3. They are used to clean the air of a room.
4. Household vacuum cleaner is a simple version of bag filter.

COTTRELL PRECIPITATOR

Principle

If a gas is subjected to a strong unidirectional electrostatic field, the gas become ionized and drifts toward one electrode. If a finely divided solid particle (or liquid droplet) is suspended in the gas, the particle (or droplet) will become charged and will drift toward the same electrode as the ionized gas.

Construction

There will be two electrodes: (i) Discharge electrode and (ii) Collecting electrode.

- The discharge electrode is usually a wire, chain, wire screen or other arrangement with a large surface.
- The collecting (or smooth) electrode may be parallel plate or pipe.
- In case of parallel plate design the gas flows parallel to plates.
  Plate dimensions: Length = 10 to 18 ft Width = 3 to 6 ft.
- In case of pipe design the pipes are placed vertically and a wire (discharge electrode) is fitted at the center of the pipe. Gas flows from the bottom to the top of the pipe. At the bottom of the pipe a hopper is given to collect the particles. *Pipe dimensions*: Height 6 to 15 ft.

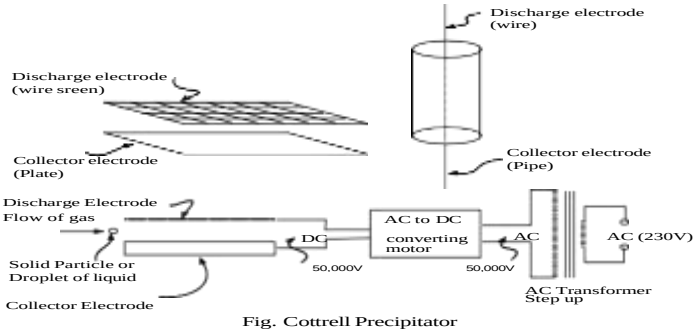


Fig. Cottrell Precipitator

Working

AC current is first stepped up with a step up transformer to raise the potential difference to 50,000 to 60,000 volts. Then the voltage is made unidirectional by a motor-disc assembly where the motor is rotating at a speed similar to the frequency (i.e. cycles per second or Hz) of the AC current. This results in a pulsating but unidirectional electrostatic field.

The particles will be charged and precipitated on the smooth plate or pipe, which is then collected through the hopper.

Use

The Cottrell process is successfully used for the removal of fine dusts from all kind of waste gases.

SIZE SEPARATORS BASING ON SEDIMENTATION THEORY (ELUTRIATION TANK)

Principle:

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.

Stoke's law

When a solid particle is suspended in a liquid the particle settles downward at a velocity, V. This velocity is called sedimentation rate. It is found that this 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. All this parameters can be combined in the form of Stoke's equation:

$$V = \frac{d^2(p_1 - p_2)g}{18\eta}$$

Where d = diameter of the particle
p_1 = density of the particle
p_2 = density of the liquid
g = acceleration due to gravity
η = viscosity of the liquid.

CONTINUOUS SEDIMENTATION TANK

A shallow tank is arranged with inlet and outlet pipes as shown in the figure. Particles entering the tank will be acted upon 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 so that the velocity of sedimentation is proportional to the square of the diameter of the particles.

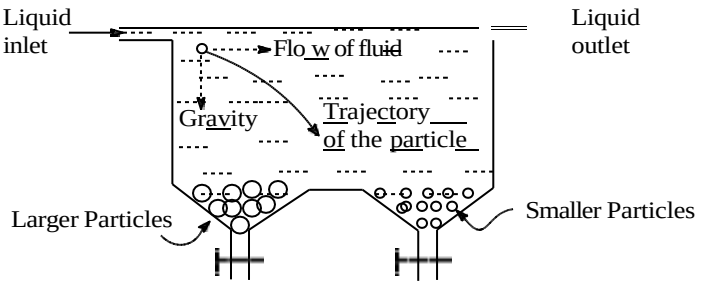


Fig. Sedimentation Tank

Thus the particles will settle at the bottom of the tank in such a way that the coarsest (largest) particles will settle near to the inlet of liquid and the finest particles near to the outlet of the liquid. Partitions are arranged at the floor of the tank to enable collection of different size fraction particles.

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