CHAPTER SIX

MIXING

CONCEPT OF MIXING

- Mixing is a process in which at least two separate materials (which may be present in the same or different phases) are taken and forced them to be randomly distributed through one another by some mechanical means.
- It is a physical process of reducing non-uniformities in fluids by eliminating gradients of concentration, temperature and other properties.
- The term mixing implies taking atleast two separate phases and causing them to distribute randomly through one another.
- A substance which is uniform throughout in physical state and chemical composition is called a homogeneous substance or a phase. Phases may be liquid, solid or gaseous. Therefore, mixing may involve gases, liquids or solids in any possible combination of two or more components - two different liquids, a liquid and a gas, a liquid and a powdered solid or two different or same solids.

Homogeneous and Heterogeneous Mixtures

- A mixture in which its components/constituents are present in a single phase is called a homogeneous mixture. For example, a liquid mixture of methanol and water, a mixture containing CO_2, N_2 and O_2 gas.
- A mixture in which its components/constituents are present in distinct phases is called a heterogeneous mixture.

  For example, a liquid mixture of benzene and water forms a heterogeneous mixture made up of two immiscible liquid phases.

Importance of Mixing and Agitation

- In this chapter, we will deal with mixing of liquids with liquids, gases with liquids, liquids with solids and solids with solids.
- When the ratio of liquid to solid is large, mixing of solids with liquids can be performed in the same fashion as mixing of liquids with liquids. On the other hand, if the ratio of liquid to solid is small, solid-liquid mixing becomes similar to mixing of solids with solids (solid-solid mixing).
- It should be noted that agitation and mixing are not synonymous. Agitation refers to the induced motion of material in a circulatory pattern inside a tank or vessel, while mixing is the random distribution into and through one another, of two or more initially separate phases.

- The practical aims of mixing are :
  1. To promote a chemical reaction. It is the most important use of mixing in the chemical industry, since intimate contact between reacting phases/substances is necessary for a reaction to proceed properly.
  2. To produce simple physical mixtures - of two or more uniformly divided solids, two or more miscible liquids, etc.
  3. To carry out physical change - formation of crystals from a supersaturated solution.
  4. To accomplish dispersion in which a quasi-homogeneous material is produced from two or more immiscible fluids and from one or more fluids with finely divided solids.
- Based upon the objectives of the processing step, liquids are agitated for the following purposes :
  (i) Blending miscible liquids
  (ii) Dispersing a gas in the liquid
  (iii) Suspending or dispersing relatively lighter solid particles in the liquid to produce uniformity required for promoting mass transfer and assisting chemical reactions.
  (iv) Dispersing or contacting immiscible liquids
  (v) Promoting heat transfer between the liquid in the container and a coil or jacket surrounding the container.

Mixing liquids with liquids

- A propeller or a turbine in a tank is the most commonly used equipment for operations involving liquid-liquid and to some extent liquid-solid mixing.
- In liquid-liquid mixing, a system may contain liquids with or without solids that are not viscous (e.g., light oils) liquids with or without solids that are viscous but pourable (e.g. paints, heavy oils) and liquids with solids that form stiff pastes (oil-bound distempers).
- The usual form of equipment is a vertical vessel fitted with an agitator (i.e., an agitated vessel). The height of the vessel ranges from 1.5 to 2 times the diameter. The impeller diameter is usually one-third of the tank diameter.

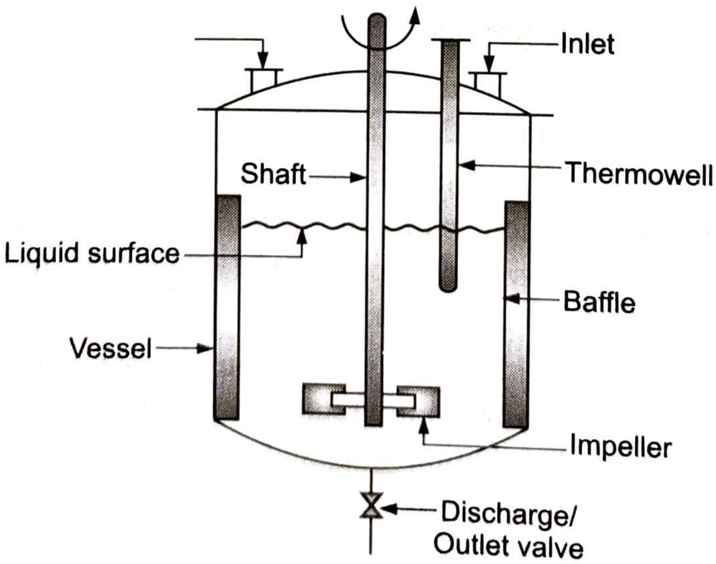


Fig. 6.1 : Typical Agitated Vessel

- An agitated vessel is a vertical, cylindrical vessel fitted with an agitator. The agitator is driven by an electrical motor directly or through a speed reducing gear box. It is provided with inlet and outlet connections, coil, jacket, etc.
- In the agitated vessel, the impeller creates a flow pattern, causing the liquid to circulate through the vessel and return ultimately to the impeller.
- An agitator is a combination of the impeller and shaft, i.e., impeller attached to the shaft. There are various types of impellers and so the agitator types. When we say turbine impeller, it is also termed as turbine agitator. The terms Impeller and Agitator are used interchangeably.

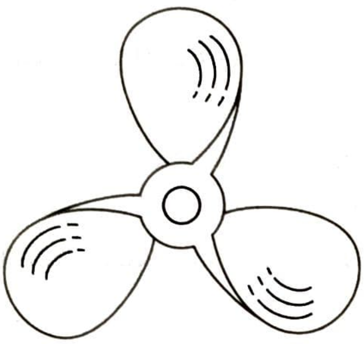
Construction and Flow Patterns of Impellers

- There are two types of impellers :
  1. Axial flow impellers and
  2. Radial flow impellers.
- Axial flow impellers make an angle of less than 90° with the shaft. They generate flow currents parallel to the axis of shaft.
- Radial flow impellers have blades parallel to the axis of the shaft. They generate flow currents in tangential (tangential to the circular path) or radial directions (perpendicular to the shaft).
- Impellers are further classified into three sub-types as :

  1. Propellers, 2. Paddles and 3. Turbines.
- Propellers and pitched blade turbines are axial flow impetters, whereas paddles, flat blade, curved blade, disc flat blade turbines are radial flow impellers.
- Axial impellers are used at high speeds to promote rapid dispersion and used at low speeds to keep solids in suspension. Radial flow impellers are used for large scale mixing of solid/liquid suspension.

Propellers

- A propeller is an axial-flow, high speed impeller commonly used for low viscosity liquids. It may be mounted centrally, off-centre or at an angle to the vessel. It is simple and portable. The diameter of propeller usually lies between 15 to 30% of the diameter of the vessel.
- A typical propeller is shown in Fig. 6.2. The most common propeller is a standard three bladed marine propeller. A propeller is shaped with a tapering blade to minimise the effect of centrifugal force and produce maximum axial flow.



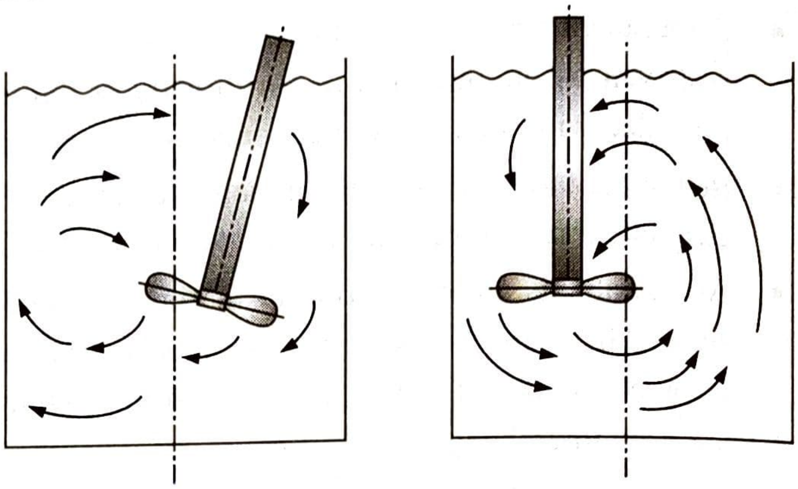


Fig. 6.2 : Standard three blade propeller Fig. 6.3 : Propeller, off centre and angular (unbaffled)

- Small propellers rotate at full motor speeds, whereas large ones rotate at a speed of 400 to 800 r.p.m.
- Propellers may also be mounted near the bottom of the cylindrical wall of a vessel as shown in Fig. 6.4 for blending low viscosity fluids or suspending slow settling sediments in very large tanks.

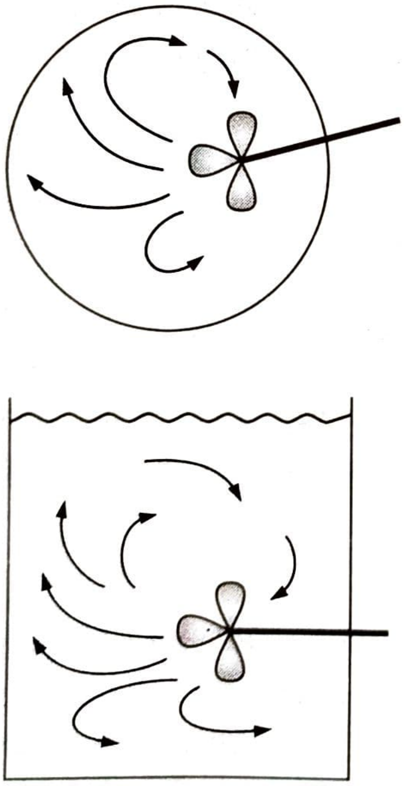


Fig. 6.4 : Side entering propeller

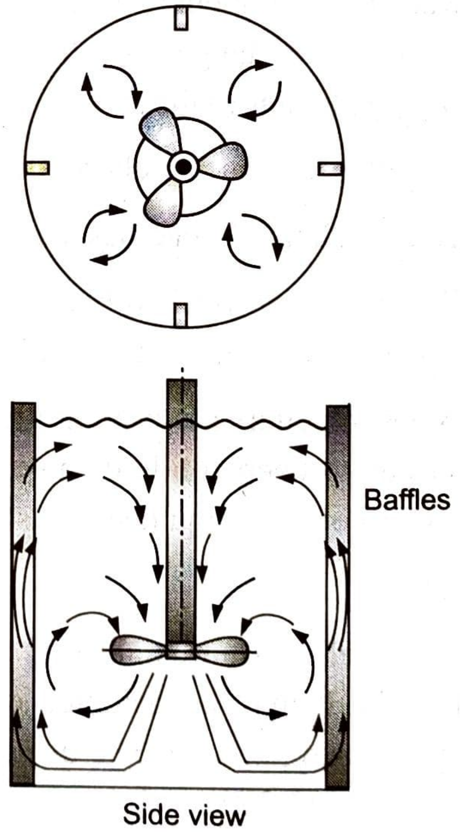
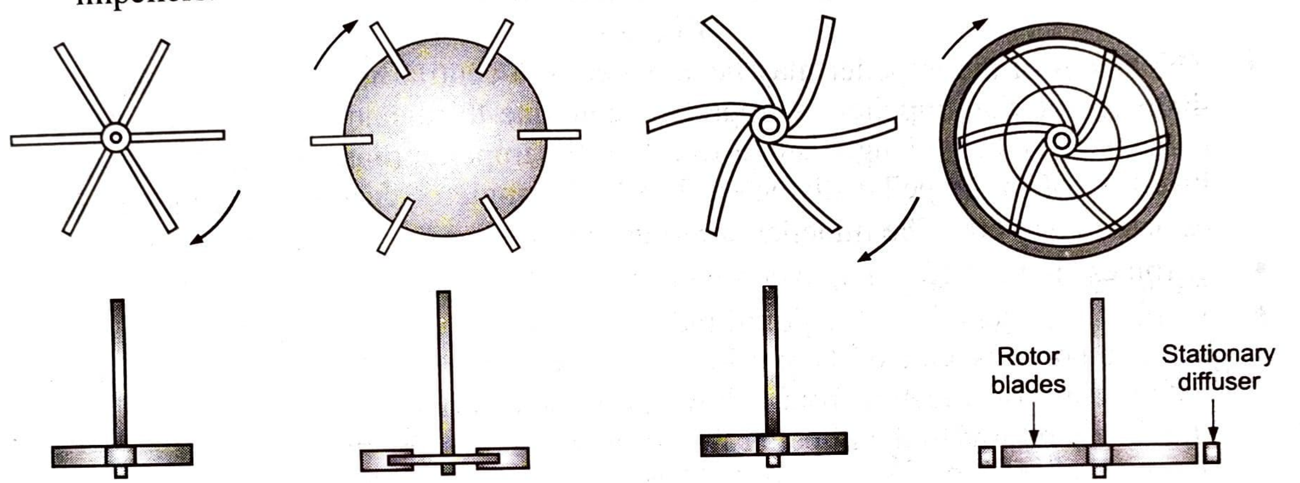


Fig. 6.5 : Flow pattern in a baffled vessel with centrally, mounted propeller or axial flow turbine

- Propeller drives the liquid straight down to the bottom of the vessel, at the bottom the stream spreads radially in all directions towards the wall, then the liquid flows upward along the wall, and finally returns to the suction of impeller from the shaft. Such a flow pattern is shown in Fig. 6.4. These agitators are used in situations where strong vertical currents are desired, e.g., for suspending heavy particles.

Turbines

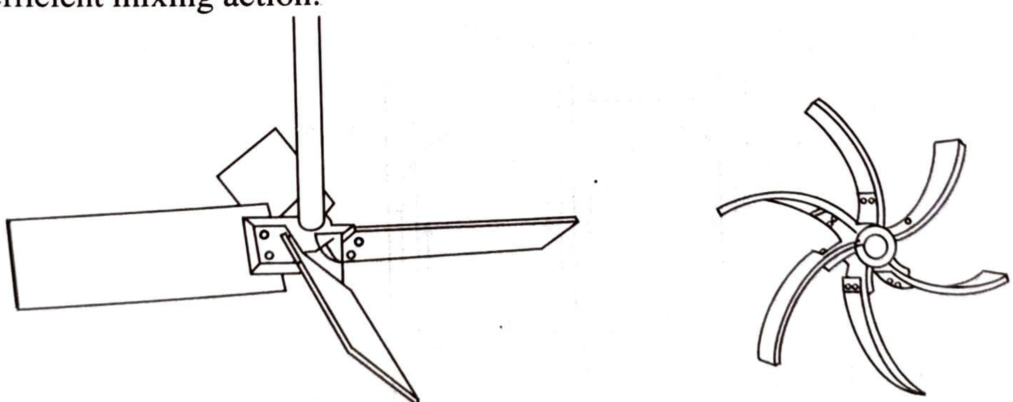
- Various types of turbine impellers are shown in Fig. 6.6. Pitched blade turbine is an axial flow impeller while curved blade and flat blade turbines are radial flow impellers.



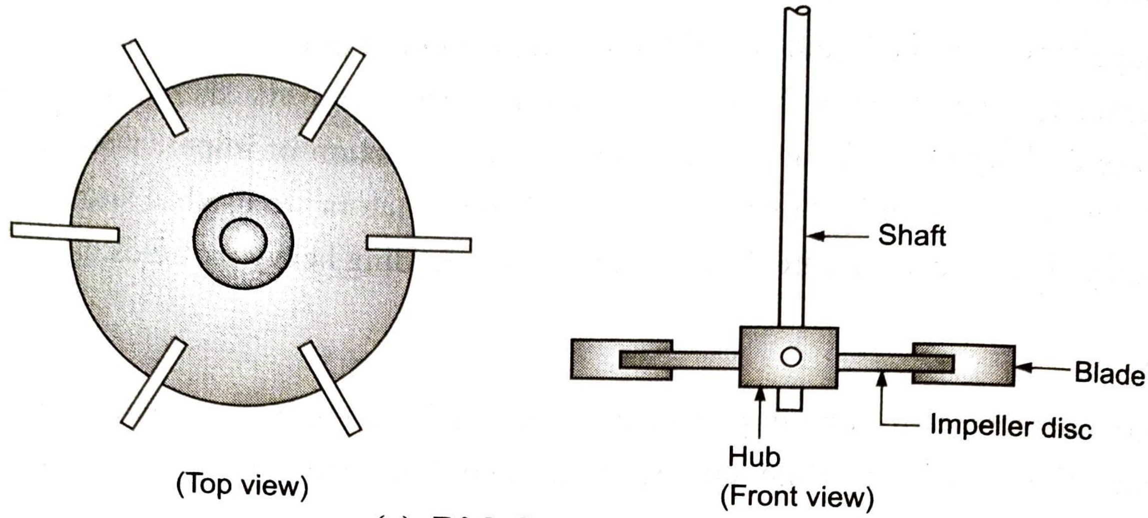
(a) Open straight blade **(b) Bladed disk/ Flat disk blade** **(c) Vertical curved blade** **(d) Shrouded curved blade with diffuser ring**

Fig. 6.6 : Turbine impellers

- They are capable of creating a vigorous mixing action due to centrifugal and rotational motions generated by them. A stator ring surrounding this impeller gives an efficient mixing action.



(a) Pitched blade turbine **(b) Curved blade turbine**



(c) Disk flat blade turbine

Fig. 6.7

- The blades of the impeller may be attached to a central hub or to a central disc. The diameter of the impeller is kept between one-third and one-sixth of the vessel diameter. The blade length is one-fourth of the impeller diameter. With a central disc, it is 1/8th of the impeller diameter. The blade angle of curved blade turbine may be between 30 to 60°. The impeller speed usually ranges from 50 to 250 r.p.m.
- Turbines are very effective over a wide range of viscosities (upto 10^4 cP).
- Turbine impellers drive the liquid radially against the wall, where the stream divides into two portions. One of the portions flows downward to the bottom and then returns to the centre of impeller from below, while other flows upward towards the surface and finally returns to the impeller from the above (See Fig. 6.8).

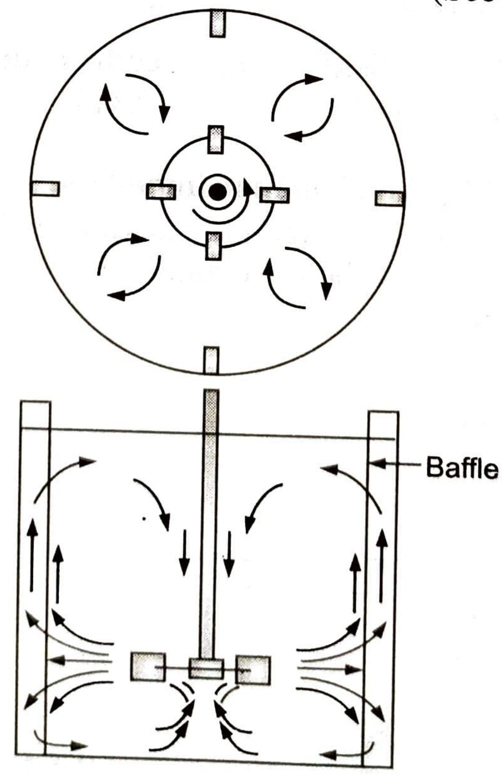
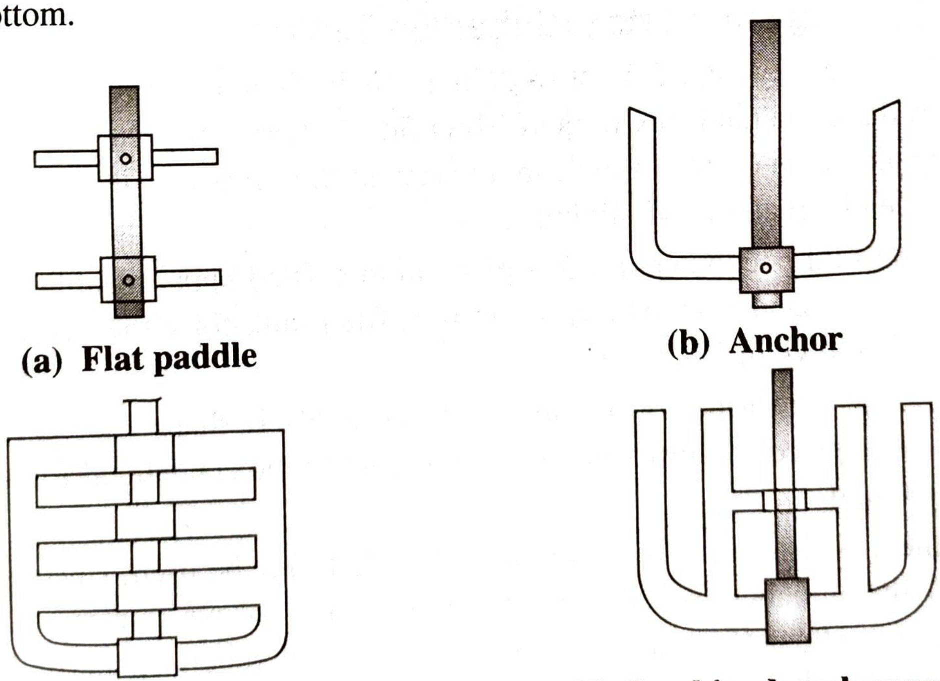


Fig. 6.8 : Flow pattern with turbine impeller in a baffled vessel

- Turbines are especially effective in developing radial currents, but with a baffled vessel they also induce vertical flow currents. To avoid vortexing and swirling with turbines, baffles or a diffuser ring can be used
- It is a common practice to locate the agitator at a height not less than one agitator / impeller diameter length from the bottom of a vessel and it should be submerged in the liquid at a depth equal to twice the diameter of agitator / impeller at low speeds and four times at high speeds. When the depth of the liquid is more than twice the agitator diameter, it may be advisable to use two impellers on the same shaft.

Paddles

- Paddle agitators with two or four flat blades are very common. The blades of these agitators are usually vertical and extend close to the vessel wall. They are simply pushers and cause the mass to rotate in laminar swirling motion with practically no radial flow along the paddle blades or any axial flow (vertical motion). The circulation is poor and the mixing action is insufficient. These rotate with a speed ranging from 20 to 150 r.p.m. The total length of this impeller lies between 50 to 80% of the inside diameter of the vessel (commonly 80% of the diameter). The width of the blade is 1/4 to 1/10th of the paddle diameter.
- In some designs, the shape of blades is similar to the shape of the bottom of a vessel so that they scrap the surface or pass over it with a close clearance. Such a type of paddle is known as an anchor agitator. Anchors are very useful for preventing deposits on a heat transfer surface as in reaction vessels and are commonly employed for obtaining improved heat transfer in high viscosity fluids but are poor mixers.
- Gate and anchor are used to sweep the entire peripheral area of the vessel, both walls and bottom.



(a) Flat paddle

(b) Anchor

(c) Gate

(d) Combined anchor and gate

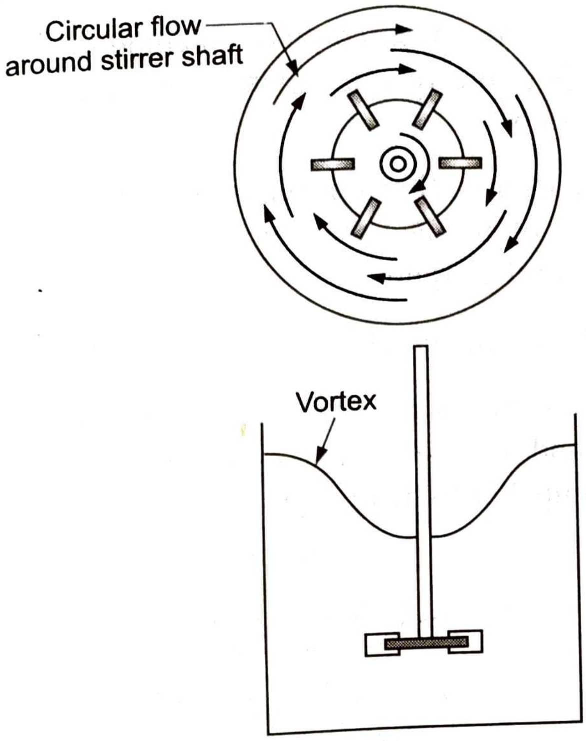
Fig. 6.9 : Paddle agitators

Flow Patterns in Agitated Vessels

- The factors on which the type of flow pattern in an agitated vessel depends are :
  (i) Type of impeller
  (ii) Characteristics of the fluid and
  (iii) Size and proportions of the vessel, baffles and agitator.
- The velocity of the fluid at any point in the agitated vessel has three components, namely radial, longitudinal and tangential. The overall flow pattern depends on the variations in these velocity components from point to point. The radial velocity component acts in a direction perpendicular to the shaft of the impeller. The longitudinal velocity component acts in a direction parallel to the shaft. The tangential or rotational component acts in a direction tangent to the circular path around the shaft. With a vertical shaft in the vessel, the radial and tangential components are in a horizontal plane and the longitudinal component is vertical. Both the radial and longitudinal components are useful and produce the flow necessary for the mixing action.
- If the shaft is vertical and located at the centre in the vessel, the tangential component is generally undesirable since it follows a circular path around the shaft and creates a vortex at the surface of the liquid and tends to continue.
- In circulatory flow, the liquid flows in the direction of motion of the impeller blades. In case of unbaffled vessels, circulatory flow is generated by all types of impellers. When the swirling is strong, the flow pattern in the vessel is virtually the same irrespective of the design of the impeller. At high speeds, the vortex is deep and may reach the impeller. Because of this gas/air from the top of the liquid surface is drawn down into the content of the vessel, which is not desirable.

Concept of Swirling and Vortex (Unbaffled Tanks)

- If a low viscosity liquid is stirred in an unbaffled tank by a centrally mounted agitator, there is a tendency for a swirling flow pattern to develop, for the lighter fluid (usually air) to be drawn in to form a vortex at the surface of the liquid. This reduces the degree of agitation and mixing.
- The above said phenomenon takes place in unbaffled tanks regardless of the type of impeller. A typical flow pattern in an unbaffled tank for either axial or radial flow impeller is shown in Fig. 6.10.
- In vortexing, the surface of the liquid takes roughly U-shape and efficient mixing no longer takes place. A vortex is produced owing to the centrifugal force acting on the rotating liquid.
- Thus, there is a limit to the rotational speed that may be used, since once the vortex reaches the impeller, severe air entrainment may occur (air may be sucked in). In addition to this effect, the swirling mass of liquid generates an oscillating surge in the vessel which when coupled with the deep vortex may create a large fluctuating force acting on the agitator shaft.



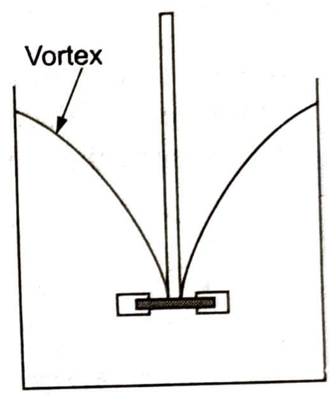


Fig. 6.10 : Vortex formation and circulation pattern in an unbaffled agitated vessel

Fig. 6.11 : Vortex at very high impeller speed

Prevention of Swirling and Vortex Formation

- There are three methods for the prevention of swirling and vortex formation :
  (i) Off-centre mounting of the impeller.
  (ii) Use of baffles.
  (iii) Use of diffuser ring with turbines.
- In small vessels, the impeller can be mounted off-centre as shown in Fig. 6.12. In larger vessels, the agitator may be mounted in the side of the tank with a shaft in horizontal plane but at an angle with radius, as shown in Fig. 6.13.

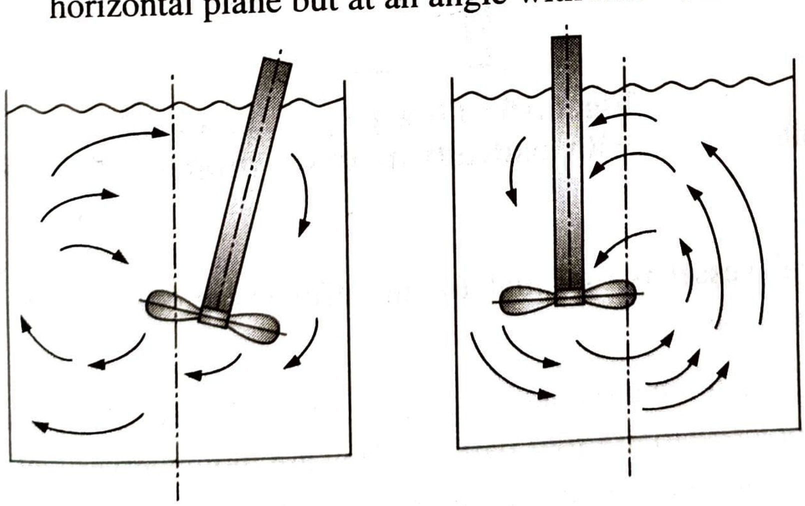


Fig. 6.12 : Propeller, off-centre and angular (unbaffled)

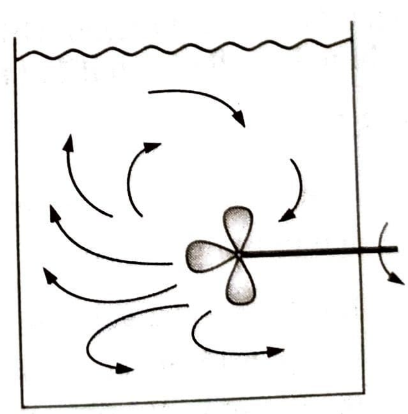


Fig. 6.13 : Side entering propeller

- In large vessels with vertical agitators, the most common method of reducing swirling is to install baffles along the side of the vessel, which hinder rotational flow without disturbing radial or longitudinal flow.
- In an unbaffled vessel, there are strong tangential flow currents and vortex formations at moderate speeds but in the presence of baffles, the vertical flow currents are increased and there is more rapid mixing of the liquid.
- With side entering, inclined and off-centre propellers, baffles are not needed.
- In case of turbines, the principal currents are radial and tangential. The tangential components induce (lead to) swirling and vortexing that must be stopped by the baffles or by the use of diffuser ring for impeller to be most effective.

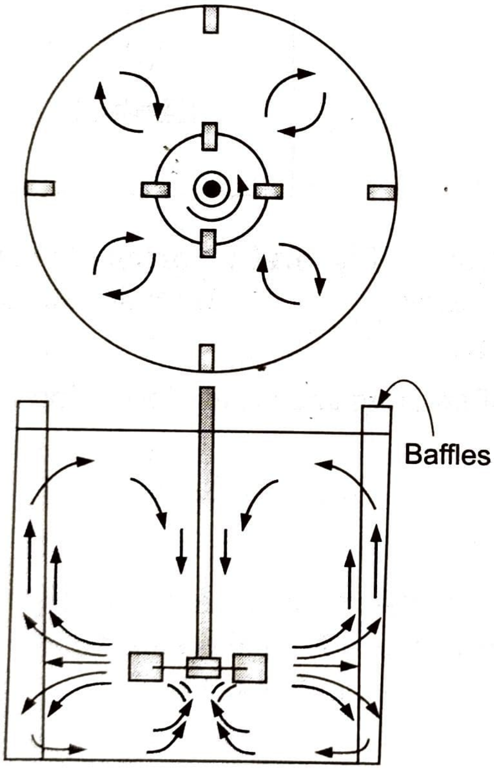


Fig. 6.14 : Flow pattern with turbine impeller in baffled tank

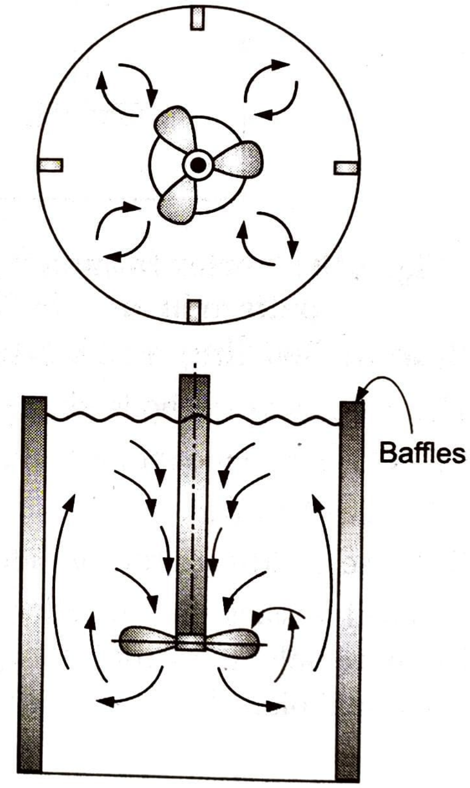


Fig. 6.15 : Flow pattern in a baffled tank with centrally mounted propeller agitator

BAFFLING

- Use of baffles in a vertical vessel is essential for the efficient mixing action and minimisation of vortex formation.
- Baffles are flat vertical strips that are mounted against the wall of the vessel as shown in Fig. 6.15. It is common practice to use four baffles. They are mounted vertically on the vessel wall, projecting radially from the wall and located 90° apart. The width of the baffle should be one-tenth to one-twelfth of the tank/vessel diameter.

- The baffle height should be at least twice the diameter of the impeller and approximately centred on the impeller.
- If the solids are to be kept in suspension, baffles should be set out from the wall with a gap of about 1/5th of the baffle width between baffle and vessel to minimise the accumulation of solids on or behind them.
- The flow patterns in Fig. 6.10 and Fig. 6.15 are quite different, but in both the cases of baffles there is a large top to bottom circulation without vortexing. Baffles convert swirling motion into a preferred flow pattern to accomplish process objectives.
- The addition of baffles in a vessel considerably increases the power requirement for mixing.

Power Consumption of Impellers

- Usually, electrical power is used to drive impellers in agitated vessels.
- An empirical correlation of the power (or power number) with other variables of a system allows us to do fairly accurate prediction of the power requirement of a given impeller to rotate at a given speed. Such correlations can be obtained by using a method of dimensional analysis. The power requirement of the impeller is a function of geometrical details of the impeller and vessel, the viscosity and the density of liquid, and the rotation speed of impeller.
- An empirical correlation that can be obtained for a given system from the dimensional analysis is of the following form :

$$\frac{P}{N^3 D_a^5 \rho} = F\left(\frac{N D_a^2 \rho}{\mu} \frac{N^2.D_a}{\rho}\right) \qquad \ldots (6.1)$$

where $\frac{P}{N^3 D_a^5 \rho}$ is the power number (N_P)

$\frac{N D_a^2 \rho}{\mu}$ is the Impeller Reynolds number (N_{Re})

$\frac{N^2.D_a}{\rho}$ is the Froude number (N_{Fr})

N = rotation speed in revolution per sec.

D_a = diameter of impeller

ρ = density of fluid

and μ = viscosity of fluid

- When $N_{Re} > 10,000$, the flow in the vessel is turbulent and when $N_{Re} < 10$, the flow is laminar. For N_{Re} between 10 and 10,000 the flow is in a transition region in which the flow is turbulent at the impeller and laminar in the remote parts of the vessel.

  Equation (6.1) can also be written as :

$$N_P = f(N_{Re}, N_{Fr}) \quad \text{... (6.2)}$$

- The Froude number, N_{Fr}, represents the influence of gravitation and affects the power consumption only when vortex is present. If the speed of impeller is increased, in unbaffled vessels, the centrifugal force acting in the liquid causes the free surface of the liquid to assume a paraboloid form by raising the liquid level at the wall and lowering the level at the shaft. This is called vortex. The vortex is avoided by use of baffles. For Reynolds number < 300, vortex may not be observed even for the unbaffled vessel. The Reynolds number accounts for the viscous forces and it usually true that in agitated vessels, the viscous forces are significant. Thus, Equation (6.2) reduces to

$$N_P = f(N_{Re}) \quad \text{... (6.3)}$$

- The power consumption is related to the density and the viscosity of the liquid, the rotational speed, and the impeller diameter by plotting power as a function of Reynolds number as shown in Fig. 6.9.

At lower Reynolds number (laminar flow), the relationship between N_P and N_{Re} may be given as

$$N_P = C_o/N_{Re}, \quad \text{... (6.4)}$$

where C_o is a constant for a given impeller and given geometrical details.

Rearranging Equation (6.4), we get

$$N_P.N_{Re} = C_o \quad \text{... (6.5)}$$

Substituting the values of N_P and N_{Re} in Equation (6.5), we get

$$P = C_o \mu D_a^3 N^2 \quad \text{... (6.6)}$$

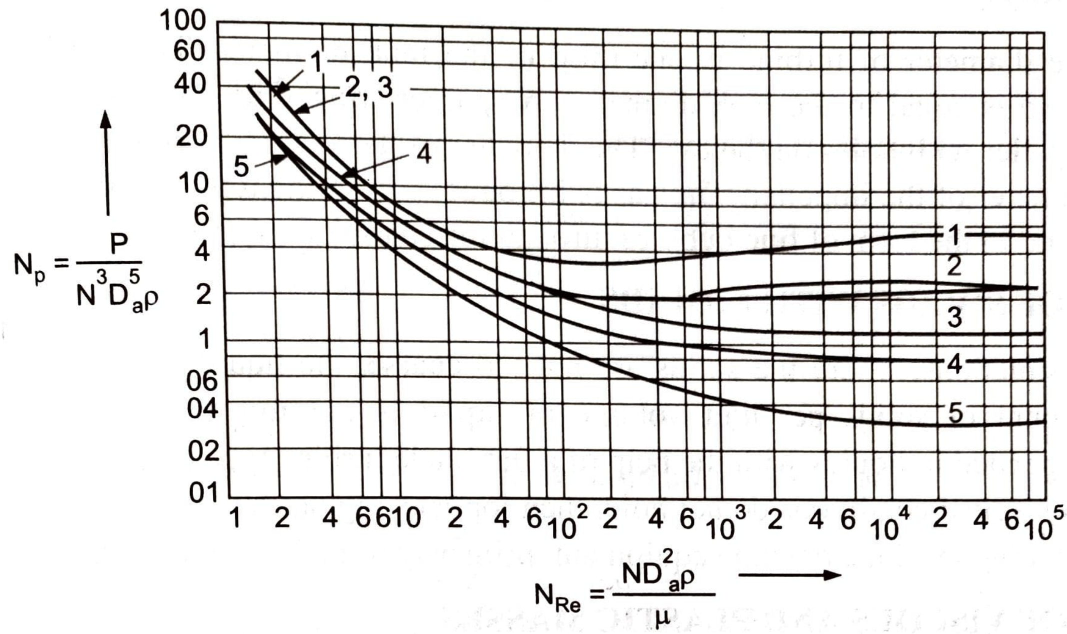
Equation (6.6) indicates that if the speed is doubled, power consumption will increase by a factor of four.

For higher values of N_{Re}, the Froude number plays important part. In this case, power number is constant i.e.

$$N_P = \text{constant} = C' \quad \text{... (6.7)}$$

$$P = C' \rho D_a^5 N^3 \quad \text{... (6.8)}$$

Equation (6.8) indicates that if the speed is doubled, the power consumption increases by factor of eight in the turbulent flow region.



Curve 1 : Curve blade turbine, 4 baffles each width of baffle D_T / 12, D_T - tank diameter.

Curve 2 : Open straight blade (six blade) turbine, 4 baffles each $D_T/12$.

Curve 3 : Pitched blade turbine, 4 baffles each $D_T/12$.

Curve 4 : Propeller, 4 baffles each 0.1 D_T . Pitch = 2 D_a.

Curve 5 : Propeller, 4 baffles each 0.1 D_T, Pitch = D_a.

Fig. 6.16 : Power Consumption

MIXING OF GASES WITH LIQUIDS

- This is usually accomplished by spraying (sparging) a gas under a turbine (flat blade) near the bottom of a cylindrical vessel. Injecting the gas under a propeller is useless because the flow from the propeller is axial and downward. The equipment which can be used for the said purpose consists of a baffled vertical vessel incorporating a flat blade turbine agitator.

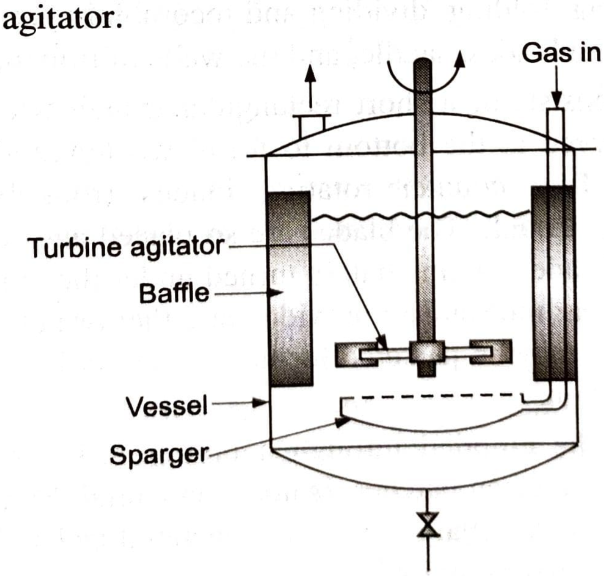


Fig. 6.17 : Mechanically agitated vessel for gas-liquid system

- The diameter of turbine is one-third of the tank diameter. The depth of a pool of liquid is equal to the tank diameter. A sparger (ring shaped) is mounted below the impeller with holes on the top. The diameter of the sparger is equal to or less than the diameter of the impeller. The gas is introduced from the top and injected in a pool of liquid in the form of fine bubbles through the sparger as shown in Fig. 6.17.

MIXING OF SOLIDS WITH LIQUIDS

- In situations, where the solids are not too coarse, the liquid is not viscous, and the amount of solids per unit volume of liquid is not too great, the solids can be suspended in liquids with the help of a flat blade turbine type of agitator. If any of the above cited conditions do not hold, then for carrying out mixing, one has to look for a kneading machine or some equipment primarily used for mixing solids with solids.

MIXING OF VISCOUS AND PLASTIC MASSES

- In machines used for viscous and plastic masses, either the material must be brought to the agitator or the agitator must visit all parts of mix. The mixing action in these machines is described as a combination of low-speed shear, smearing, wiping, folding, stretching, and compressing. These machines must be ruggedly built because the forces generated in these mixers are large. The power consumption with these mixers is high. Mixers described in this part are double arm kneaders, banbury mixers and mullers.

TYPES OF MIXERS

Sigma Mixer/Kneading Machine (Double-Arm Kneader)

- In kneading machines, the mixing action is a combination of bulk movement, smearing, stretching, folding, dividing and recombining as the material is pulled and squeezed against the blades, saddle, and the walls of trough.
- A sigma mixer consists of a short rectangular trough with a saddle shaped bottom [i.e., trough is curved at the bottom to form two longitudinal half cylinders and a saddle section]. Two counter rotating blades (roughly z-shaped outline) are incorporated in the trough. The blades are so placed and so shaped that the material turned up by one blade is immediately turned under the adjacent one. The blades are driven through a gear mechanism provided at either or both ends. The trough may be open or closed and may be jacketed for heating or cooling. The machine is operated in a batchwise fashion.
- The machine can be emptied through a bottom valve where 100% discharge or thorough cleaning, between batches, is not as essential. More commonly, double-arm kneaders are tilted for discharge by power operated jacks. Fig. 6.18 shows a double-arm kneader/sigma mixer employing sigma blades.
- The material to be kneaded is dropped into the trough and mixed for a period of about 5 to 20 minutes or longer. The trough is then unloaded by tilting it.

- It is used for mixing very stiff masses.

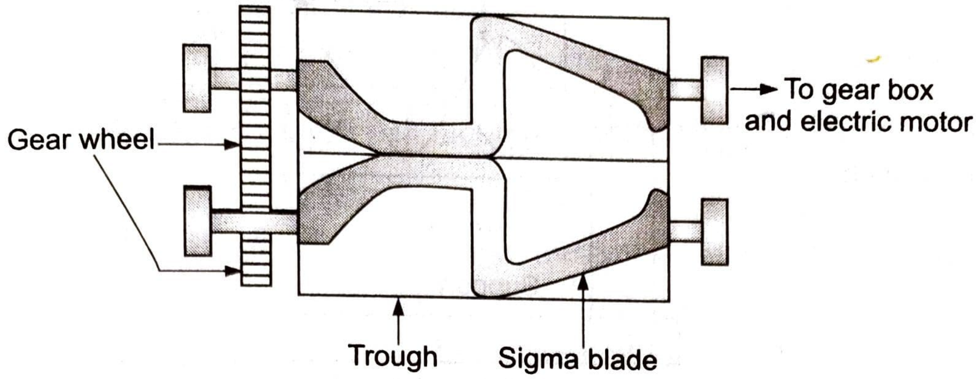


Fig. 6.18 : Kneading Machine/Double arm kneader (sigma mixer) – top view

- Various designs of mixing blades are shown in Fig. 6.19. The sigma blade [Fig. 6.19 (a)] is most widely used. The mixer employing sigma blades is capable of starting and operating with either liquids or solids or a combination of both. The sigma blade has good mixing action and is relatively easy to clean when sticky materials are being handled.
- The dispersion blade (Fig. 6.19) builds up high shear forces required to disperse powder or liquids into plastic or to rubbery masses. The double-naben blade [Fig. 6.19 (c)] is useful for heavy plastic materials.

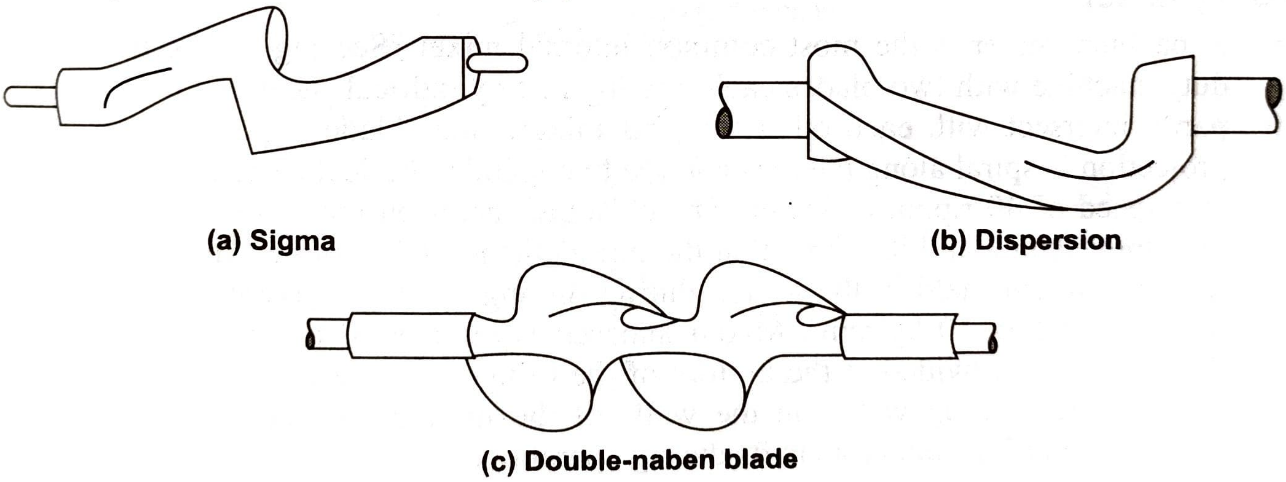


Fig. 6.19 : Blades for double arm kneaders

Ribbon Blenders

- Ribbon blenders mix solids by mechanical shuffling and are used to handle dry powders.
- A ribbon blender consists of a horizontal semicylindrical trough incorporating a central shaft and a helical ribbon agitator. A typical ribbon blender is shown in Fig. 6.20. In this mixer, two counteracting ribbons are mounted on the same shaft. One of the ribbons moves the solids slowly in one direction, while the other one moves the solids quickly in the other direction. The ribbons may be continuous or discontinuous. Mixing takes place due to the turbulence generated by counteracting ribbons and not only by motion of the solids through the trough.

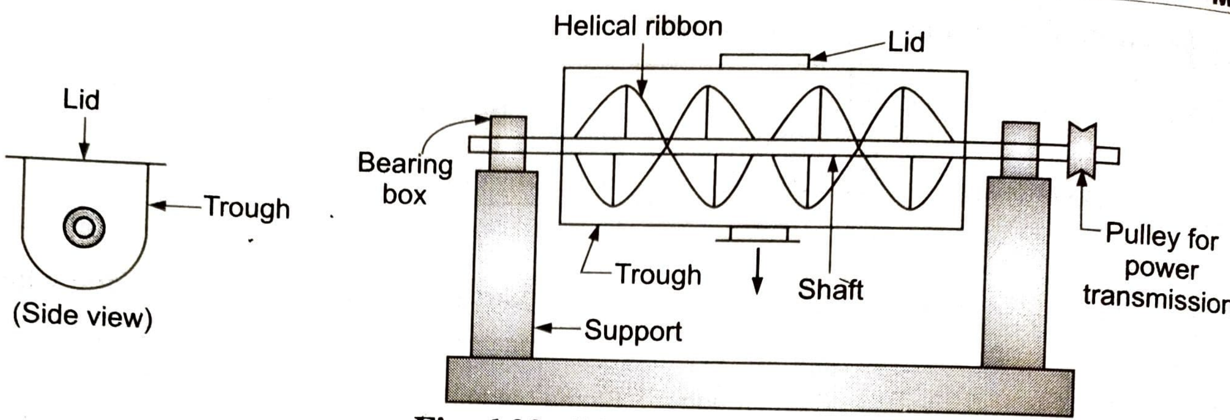


Fig. 6.20 : Ribbon blender

- Ribbon blenders are used for batch or continuous mixing. In batch operated ribbon blenders, the solids are charged and mix until satisfactory and discharged from the bottom.

  In continuously operated units, the solids are fed from one end of the trough and discharged from the other end. In the path from the feed to discharge end, solids are mixed.
- For light duty, the trough may be open or lightly covered, while for operation under pressure or vacuum, the trough is closed and heavy-walled. Ribbon blenders are very effective for handling thin pastes and dry powders that do not flow easily.

Banbury Mixer

- A banbury mixer is the most common internal mixer (See Fig. 6.21). It is a heavy duty machine with two blades each rotating in a cylindrical sheet, but these cylinders partly intersect with each other. In this mixer, the blade is pear shaped, but the projection is spiral along the axis and the two spirals interlock. The machine operates at a speed of 40 r.p.m. or lower. The clearance between the blades and the walls is extremely small, and it is here that the mixing action takes place. The material is fed from above and held in the trough during mixing by an air-operated piston under a pressure of 1 to 10 kgf/cm^2. Mixed material is discharged through a heavy sliding door which is provided at the bottom of the trough. The heat generated is taken out by spraying cooling water on the walls of the mixing chamber and circulating it through the hollow agitator shafts during operation.
- The banbury mixer is used mainly in plastic and rubber industries.

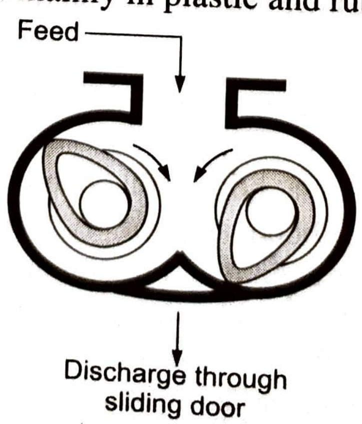


Fig. 6.21 : Banbury internal mixer

Muller Mixers

- Mulling is a smearing or rubbing similar to that in a mortar and pestle.
- A muller mixture consists of a pan incorporating muller wheels.
- In one of the designs of muller mixer, the pan is stationary and wheels rotate (See Fig. 6.22); while in the other design, the pan is rotated and the axis of the wheels is held stationary. In the stationary pan muller mixer, the central vertical shaft is driven, causing the muller wheels to roll in a circular path over a layer of solids on the pan floor. Plows direct the solids under the muller wheels during mixing or to an opening in the pan floor for the discharge of the mixer at the end of the cycle. The muller wheels crush the material, breaking down lumps and agglomerates.
- Capacity of the muller mixer ranges from a fraction of cubic meter to more than 1.6 m^3 and the corresponding power requirement ranges from 1/3 to 75 hp.
- Mullers are used for handling batches of heavy solids and pastes. These are also effective in uniformly coating the particles of granular solids with a small amount of liquid.

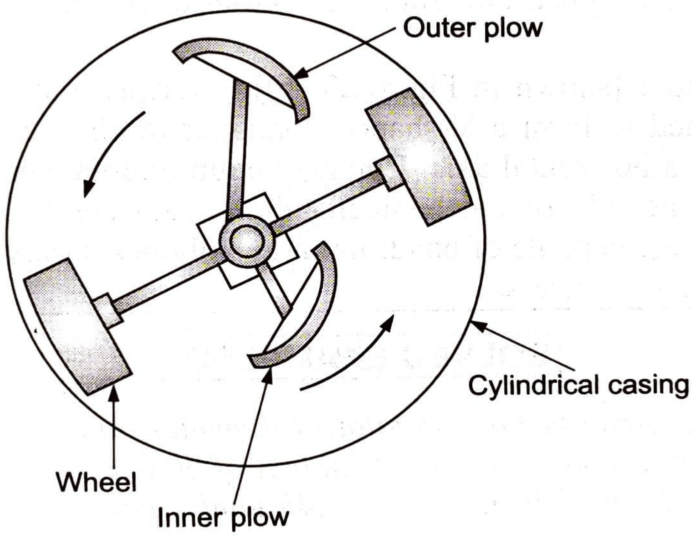
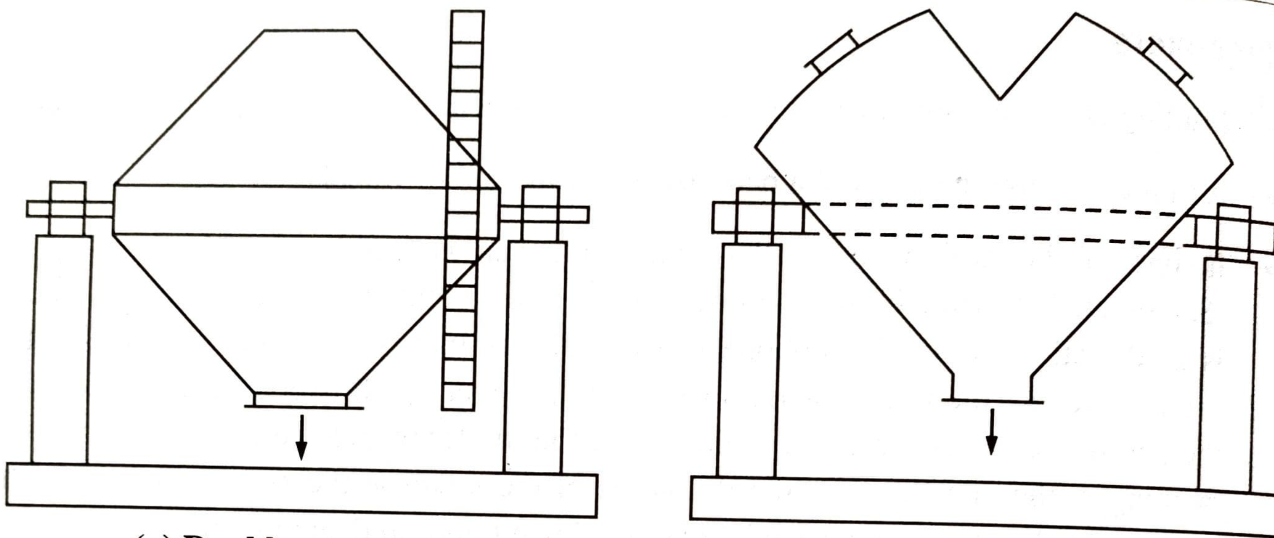


Fig. 6.22 : Muller mixer (Top view)

TUMBLING MIXERS / TUMBLERS

In tumbling mixers, the mixing results from repeatedly lifting and dropping the material and rolling it over.

A large number of materials are mixed by tumbling them in a partly filled container that rotates about a horizontal axis. Tumbling mixers such as double cone mixer and twin shell blender, shown in Fig. 6.23, are suitable for free flowing dry powders.



(a) Double cone tumbler (b) Twin shell tumbler

Fig. 6.23 : Tumbling Mixers

The double cone mixer [shown in Fig. 6.23 (a)] consists of a container made up of two cones, base to base with or without a cylindrical section in between. The mixer is mounted so that it can be rotated about an axis perpendicular to the line joining the points of the cones. The material to be mixed is charged to the mixer from above until it is 50 to 60% full. The ends of the container are closed and the solids are tumbled for a period of about 5 – 20 min. Finally, mixed material is dropped out from the bottom of the container into a conveyor or bin.

The twin shell blender [shown in Fig. 6.23 (b)] is formed out of two short cylinders. These cylinders are joined to form a V-shaped container (their axes are about 90° to each other) and rotated about a horizontal axis. It may contain internal sprays to introduce small amounts of liquid into the mix or mechanically driven devices to brake agglomerates of solids. Tumbling mixers are capable of handling large volumes, easily cleaned, and require a little less power than ribbon blenders.

SOLVED EXAMPLES

Example 6.1 : *A six-blade turbine agitator of diameter 60 cm is installed centrally in tank with flat bottom of diameter 180 cm, at a height of 60 cm from the bottom. The tank is filled with a solution of viscosity 10 C_p and of 1.45 g/ml density. The speed of agitation is 90 rpm. The tank is baffled. Calculate the power required.*

Data : Power number = N_p = 1.05 for $N_{Re} > 300$

Solution :

D_a = Impeller diameter = 60 cm

μ = Viscosity = 10 C_p = 0.10 poise

ρ = 1.45 g/cm³

N = Revolutions per second

$$= \frac{\text{Speed in rpm}}{60} = \frac{90}{60} = 1.5 \text{ rev. per second}$$

Reynolds number : $N_{Re} = \frac{N D_a^2 \rho}{\mu} = \left(\frac{100}{60}\right) \times \frac{(60)^2 \times 1.45}{0.10} = 87000$

So flow is turbulent.

For turbulent flow : N_P = Power number = C' = constant

and the power is given by

$$P = C' \rho D_a^5 N^3$$

where $N_P = C' = 1.05$

Substituting the values of various terms,

$$\begin{aligned} P &= 1.05 \times 1.45 \times (60)^5 (1.5)^3 \\ &= 3.9956 \times 10^9 \approx 4 \times 10^9 \ (\text{g.cm}^2)/\text{s}^3 \\ &= 4 \times 10^9 \ (\text{g.cm}^2)/\text{s}^3 \\ &= 4 \times 10^9 (10^{-3} \text{kg} \times 10^{-4} \text{m}^2)/\text{s}^3 \\ &= 4 \times 10^9 \times 10^{-7} (\text{kg.m}^2)/\text{s}^3 \\ &= 400 \ (\text{kg.m}^2)/\text{s}^3 \end{aligned}$$

Let us convert P in the units of power by g_c.

g_c [Newton's law conversion factor] has the units of 1 (kg.m)/(N.s²).

$$\therefore \quad P = \frac{400 \ (\text{kg.m}^2)/\text{s}^3}{g_c}$$

$$= \frac{400 \ (\text{kg.m}^2)/\text{s}^3}{1 \ (\text{kg.m})/(\text{N.s}^2)}$$

$$= 400 \ (\text{N.m})/\text{s}$$

$$= 400 \ \text{J/s} = 400 \ \text{W}$$

The power required is **400 W.** ... **Ans.**

Horse power [HP] required $= \frac{400}{746} = 0.536$ HP.

Important Points

- The term mixing implies taking atleast two separate phases and causing them to distribute randomly through one another.
- A substance which is uniform throughout in physical state and chemical composition is called a homogeneous substance or a phase.
- Mixing is a process in which two separate materials are taken and forced them to be randomly distributed through one another by mechanical means.
- Liquids are agitated for blending miscible liquids, dispersing a gas in the liquid and contacting or dispersing immiscible liquids.

- Axial flow impellers make an angle of less than 90° with the shaft and generate flow currents parallel to the axis of the shaft.
- Radial flow impellers have blades parallel to the axis of shaft and generate flow currents in tangential or radial directions.
- The methods used for prevention of swirling and vortex formation in agitated vessels are : off-centre mounting of the impeller, use of baffles and use of diffuser ring with turbines.
- Ribbon blenders are used for handling thin pastes and dry powders that do not easily.

Practice Questions

1. State the various types of impellers and draw a sketch of any one of them.
2. State the methods of avoiding vortex in an agitated vessel.
3. Draw sketches of flow pattern with propeller and turbine impeller.
4. Explain the construction two arm kneaders.
5. Draw sketches of different blades used in the kneading machines.
6. Explain in brief the construction of
   (i) Ribbon blender,
   (ii) Muller mixer.

□□□