Paper No. : 04
Paper Title: Unit Operations in Food Processing
Module- 32: Fundamentals of Mixing

1. INTRODUCTION

Mixing (or blending) is a unit operation in which a uniform mixture is obtained from two or more components, by dispersing one within the other. Hence it is a process which involves manipulating a heterogeneous physical system, with the intent to make it more homogeneous. It has very wide applications in in many industries including food processing, pharmaceuticals, mining and powder metallurgy, and in processes involving physical and chemical changes. The larger component is called as the *continuous phase* and the smaller component as the *dispersed phase*. This process is generally used in food processing to combine ingredients to achieve different functional properties or sensory characteristics. In some foods, adequate mixing is necessary to ensure that the proportion of each component. Extruders and some types of size reduction equipment also have a mixing action.

Examples:

i. Texture development in dough and ice cream,
ii. Control of sugar crystallization
iii. Aeration of batters
iv. Chocolate products.

2. TYPES OF MIXING

I. Solid mixing
II. Liquid mixing

3. SOLID MIXING

3.1 Theory of solids mixing

In contrast with liquids and viscous pastes it is not possible to achieve a completely uniform mixture of dry powders or particulate solids.

The degree of mixing that is achieved depends on:

- The relative particle size, shape and density of each component
- The moisture content, surface characteristics and flow characteristics of each component
- The tendency of the materials to aggregate
- The efficiency of a particular mixer for those components.

In general, materials that are similar in size, shape and density are able to form a more uniform mixture than are dissimilar materials. During a mixing operation, differences in these properties also cause unmixing (or separation) of the component parts.

If a two-component mixture is sampled at the start of mixing (in the unmixed state), most samples will consist entirely of one of the components. As mixing proceeds, the composition of each sample becomes more uniform and approaches the average composition of the mixture. After a specific time of mixing, a number of small samples at random were picked up from the mixture and analyzed.

Let m_A gram of material A is thoroughly mixed with m_B gram of material B. The weight fraction of A in B in sample taken out from different locations of a mixer should ideally be equal to $m_A/(m_A+m_B)$. But in reality values of $m_A/(m_A+m_B)$ different among the samples. Variation in standard deviation σ of the values of $m_A/(m_A+m_B)$ is used as the measure for degree of mixing. Value of σ reduced gradually with increase in time of mixing. Generally, for mixing of solids, value of σ does not become zero even after very long mixing time. Let us designate the σ of a perfectly mixed sample, after very long time of mixing as σ_∞.

In order to estimate the values of mixing index M for two materials in mixer, it is necessary that the amount of A that is present in mixed samples of (A+B) is measured at different time of mixing.

Assuming that the rate of change of $(\sigma-\sigma_\infty)$ with time of mixing θ (min) will follow first order reaction kinetics, we can write,

$$-\frac{d(\sigma-\sigma_\infty)}{d\infty} = k\,(\sigma-\sigma_\infty) \quad \text{.... (1)}$$

Where, k(min^{-1}) is a constant, the value of which depends on type of mixer, speed of mixing blade, batch size of mixing materials and type of materials handled. Negative sign on the left hand side of Eqn (1) is due to the fact the value of $(\sigma-\sigma_\infty)$ decrease with in mixing time θ (min).

Consider that the initial value of σ is σ_i when mixing has been started and that its value becomes σ after θ min of mixing. σ_i is the standard deviation of the two unmixed components of samples. Under these conditions, solution of Eqn. (1) would give,

$$\frac{\sigma_i-\sigma_\infty}{\sigma-\sigma_\infty} = exp\,(k\theta) \quad \text{.... (2)}$$

Or $M = A\,exp\,(k\theta)$

Where,

$$M = \frac{\sigma_i-\sigma_\infty}{\sigma-\sigma_\infty} \quad \text{.... (3)}$$

And, A=1. M is called as mixing index. Eqn (2) shows that the value of m will increase exponentially with time of mixing.

When experimental data are analyzed and fitted to the equation: *M = A exp (k*∞), value of A normally does not come out to be equal to 1. Values of A and k can be estimated from the intercept and slope of the best fit straight line fitted between θ and $\log_e$ M data.

Value of σ_i of Eqn (2) can be estimated from the following equation

$$\sigma_{i=\sqrt{\mu(1-\mu)}} \quad \text{.... (4)}$$

Where, μ (fraction) is the weight of one of the components that is present in mixture before the mixing has been started. μ is called as population mean. Value of μ is calculated from the equation.

$$\mu = \frac{m_A}{m_A - m_B} \quad \text{... (5)}$$

Where m_A (g) is the weight of material A, which is mixed in m_B(g) of material B.

3.2 Factors affecting mixing

i. Particle size: easy to mix similar sized powders.
ii. Particle Shape: Ideal shape is spherical. Irregular shape leads to inter locking- once mixed difficult to segregate.
iii. Particle attraction: Due to electrostatic charges can leads to separation
iv. Material Density: Dense material moves downwards
v. Proportion of materials: Best mixing when ratio is 1:1.

3.3 Mechanism of solid mixing

Mixing of solid involves mainly three different types of mechanisms

i. Convective Mixing (Macro mixing)
ii. Diffusion mixing (Micro mixing)
iii. Shear Mixing

3.3.1 Convective Mixing (Macro mixing)

In this type of mixer, mixing is achieved by mechanical agitation. Parts of the bulk material are conveyed with respect to each other by the action of impellers or turbulent gas flow. Shearing occurs and may be considerable.

3.3.2 Diffusion mixing (Micro mixing)

In this type of mixer, homogeneity is achieved as a result of the random motion of the particles when the particle is in flow under the effect of gravity or vibration, without mechanical agitation. This mechanism is known as diffusion in which there is random movement of molecules. There is almost no shear. These mixers are particularly suitable for particulates that require gentle mixing, such as fragile agglomerates, but they do not perform well with cohesive powders.

3.3.3 Shear Mixing

In this type of mixing shear force occurs and it reduces the scale of segregation by thinning of dissimilar layers of solids.

3.4 Equipment for solid mixing

The different equipment involved in solid mixing involves drum blender, tumbler mixer, Paddle mixer, through mixers and vertical screw. The mechanism and applications of the mixers are mentioned below.

3.4.1 The drum blender

This belongs to the category of diffusive mixers. It consists of a horizontal cylinder rotating about its axis. Its mixing action is essentially diffusive. The powder to be mixed is placed inside the drum. As the drum rotates, the powder is lifted up, until the angle of repose is exceeded. At that point, the powder falls back on the rest of the bulk and enters a new cycle of lifting and falling. Diffusive mixing takes place during the residence of the powder in air, while falling. Continuous operation can be made possible by tilting the drum.

3.4.2 Tumbler Mixer

This belongs to the category of diffusive mixers. Tumblers mix free flowing solids that are used for powders and pastes. Tumblers provide "gentle" blending as material tumbles about a horizontal axis in an enclosed rotating unit. Hence this is used when there is a difference in the particle size and the density. Because the particles in a tumbler mixer hit against the walls and are then deflected to give good mixing.

They come in many of the different shapes as given below.

a) Barrel mixer
b) Cube mixer
c) Double cone blender
d) Twin- shell mixer- V-Shaped

Tumbler mixers also belong to the category of diffusive mixers. In the double-cone tumbler, the powder undergoes cycles of expansion and compaction as the vessel rotates. In the V-shaped tumbler, the powder is subjected to cycles of division and assembly. Convectional elements such as rotating or stationary flow distortion bars (intensifier bars) are sometimes installed in both types of mixers.

Factors considered in operating tumblers

i. Optimum speed should be used:
   Too low speed → sliding only
   Too high speed → centrifugation → segregation.
ii. The mixer should be charged with no more than 50% of its total capacity to provide the required space for the expansion for the powder bed movement of particles.

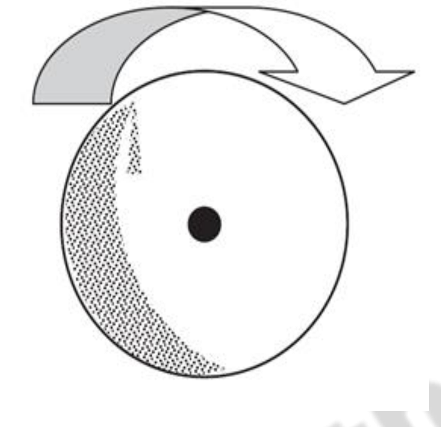
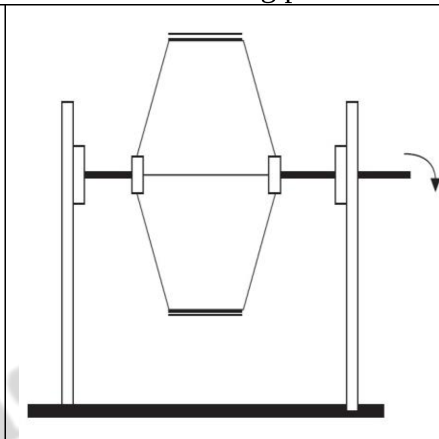
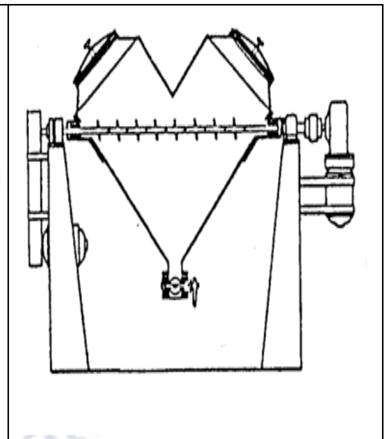
Using

Advantages of tumbling mixers:

i. Suitable for mixing friable materials because they produce mild forces causing gentle mixing.
ii. A perfect method for charging the powder into the mixer by adding the components together side by side.

iii. Can handle large volumes.
iv. Easy to clean, which allows for greater production flexibility.
v. Little wear on equipment.
vi. Gentle mixing for delicate particles
vii. High quality control is possible

Limitations
i. It cannot handle highly cohesive mixtures.
ii. This cannot be adapted to a continuous blending process.

		
Drum blender	**Double cone blender**	**V-Shaped blender**

3.4.3 Paddle mixer

This is a convective type mixer for particulate solids. This is a powerful mixer in which rotating elements mix the powder both by moving the bed and by fluidizing. A liquid component may be sprayed on the powder while mixing. Mixers of this type are available both for batch and continuous operation. In the developed version of the machine, the entire mixing chamber can be rotated upside-down for rapid discharge of the product, and then rotated back for charging a new batch.

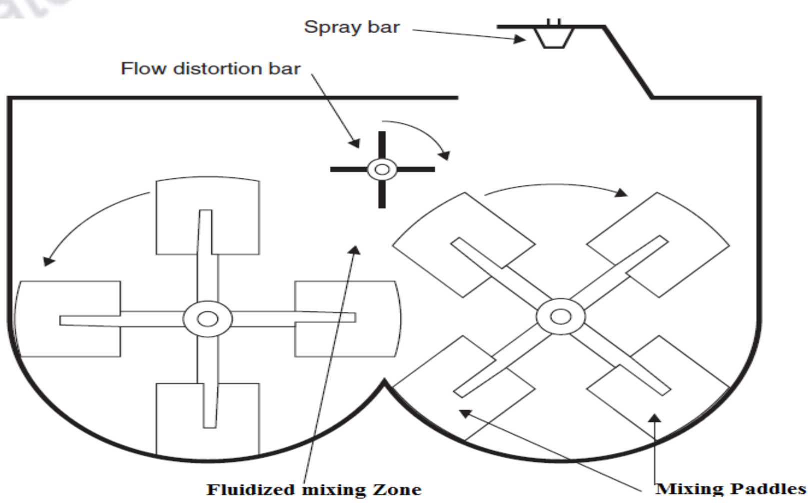


Fig: Paddle mixer

3.4.4 Trough mixers

This is also a convective type mixer for particulate solids. Trough mixers consist of conduct with a U-shaped cross-section and a longitudinal rotating shaft carrying various types of mixing elements. The agitating element may be a series of paddles or a screw like a screw conveyor. One of the best known of the trough mixers is the **ribbon mixer**.

Mixing Mechanism

- Convective effect of the ribbons.
- Shearing action.

Construction

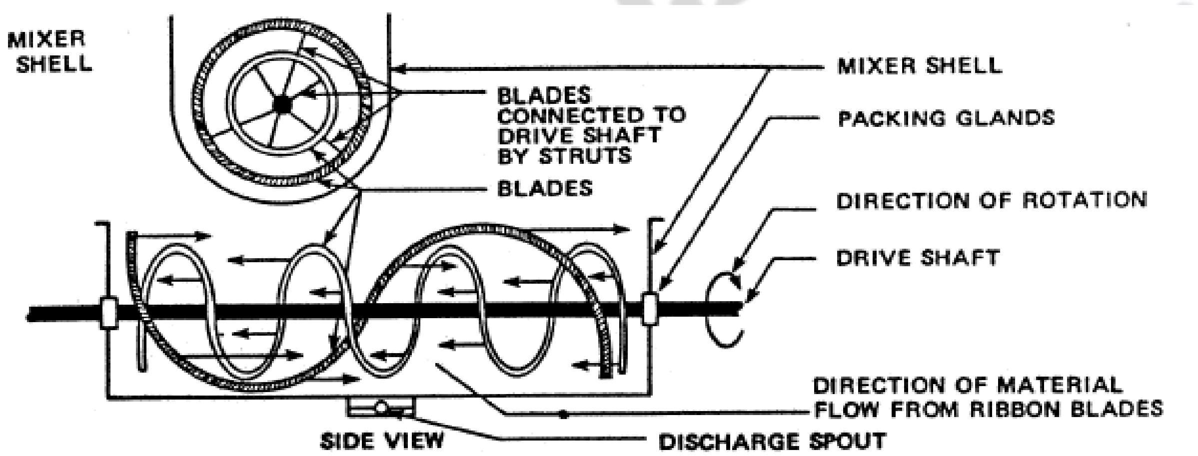


Fig: Trough Mixers

- It is a stationary cylindrical trough (shell) with semicircular bottom fitted with a longitudinal shaft, usually open at top.
- It has 2 spiral ribbons; an outer ribbon moves the material in one direction and an inner ribbon moves it in the opposite direction.
- The outer ribbon maintains a fairly close clearance with shell bottom; no stationary material remains adhered to shell.
- Top loading and discharge port.

Working

- Through fixed speed drive, ribbons are allowed to rotate.
- Helical blades move powders from one end to another.
- One blade moves material in one direction and other moves opposite.
- Close open trough to avoid dusting during dry blending.
- Due to high shear it effectively breaking up lumps and agglomerates.
- Once equilibrium achieved, powder mixture discharge from the bottom.

Application

- Finely divided solids
- Wet solid mass
- Sticky and plastic solids
- Also used for solid- Liquid and solid- semisolid mixing.

Advantages

- Headroom requirement is less
- Rapid break down of agglomerates
- Minimum dead spots

Disadvantages

- It requires high power.
- Produces size reduction for materials.
- Not suitable for fragile crystals

3.4.5 Vertical screw

It combines the 3 different mechanisms for mixing.

- Diffusive (conical vessel).
- Convective (helical conveyer).
- Shear mixing (rotating arm).

Advantages

- No dead points.
- Can be used for drying under vacuum.
- Double jacketed.

Disadvantage

- Expensive

4. LIQUID MIXING

4.1 Theory of liquid mixing

Liquid mixing promotes heat transfer between liquid and a heating source. This step is essential in the crystallization of drug substances. Uniform heat transfer in the solution yields crystals of same size. Liquid mixing is essential in the manufacture of number of dosage forms.

E.g.: Suspensions, Emulsions, Solutions, and Aerosols

The quality of mixing depends on the effective energy input by unit mass or unit volume of fluid. The relationship between mixing power and the type, dimensions and operation conditions of the mixer is expressed with the help of several correlations (McCabe and Smith, 1956). Most commonly, the mixing power correlations comprise the following dimensionless groups.

The results have been correlated in an equation of the form

$$\mathbf{(Po) = \mathit{K}(Re)^n(Fr)^m}$$

$$\mathbf{(Re) = (\mathit{D}^2\mathit{N}\rho/\mu)}$$

$$\mathbf{(Po) = (\mathit{P}/\mathit{D}^5\mathit{N}^3\rho)}$$

$$\mathbf{(Fr) = (\mathit{DN}^2/\mathit{g})}$$

Re = Reynolds Number
P0 = Power number relating drag forces to inertial forces
Fr = Froude number relating inertial forces to those of gravity
D = Diameter of the propeller,
N = Rotational frequency of the propeller (rev/sec),
ρ = density of the liquid,
M = the viscosity of the liquid and
P = the power consumed by the propeller.
If Reynolds number is 10 or lower (clearly laminar regime)

$$Po \; \alpha \; \frac{1}{Re}$$

$$\text{Po*Re} = \frac{P}{N^2 d^3 \,\mu} = \text{constant}$$

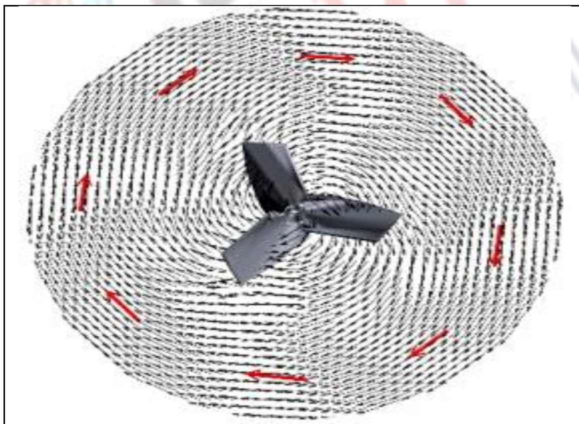
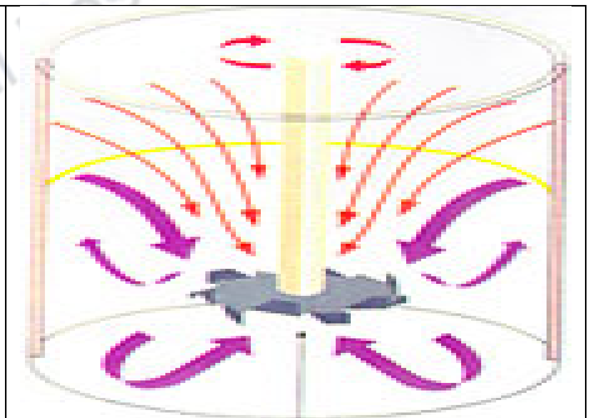
If Reynolds number is 10000 or higher (clearly turbulent regime)

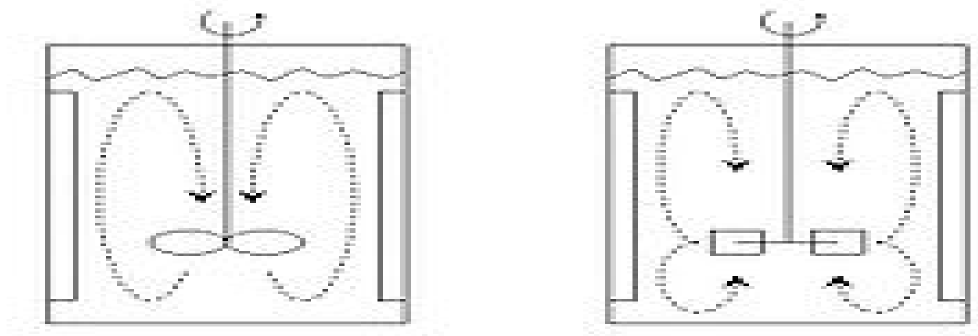
$$\text{Po} = \frac{P}{N^3 d^5 \,\rho} = \text{constant}$$

4.2 Flow Pattern during mixing

Flow pattern obtained in low viscosity liquids by a mixer involves the following types

i. A rotational velocity (tangential to the mixer shaft)
ii. A radial velocity which acts in a direction perpendicular to the mixer
iii. A longitudinal velocity (parallel to the mixer shaft)

	
Rotational velocity (tangential to the mixer shaft)	Radial velocity which acts in a direction perpendicular to the mixer



Longitudinal velocity (Parallel to the mixer shaft)

4.2.1 Tangential component or circular

Acts in the direction tangent to the circle of rotation around the impeller shaft. If shaft is placed vertically and centrally, tangential flow follows a circular path around the shaft and creates a vortex in the liquid.

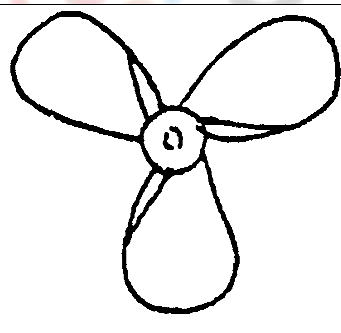
4.2.2 Radial component

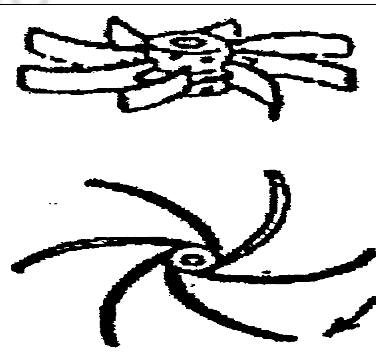
Acts in the direction vertical to the impeller shaft. Excessive radial flow takes the material to the container wall then material falls to the bottom and rotate as the mass beneath the impeller.

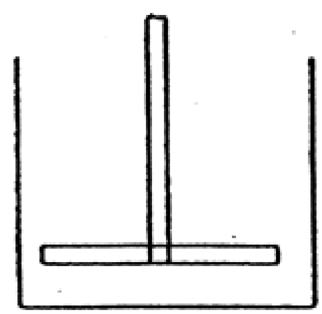
4.2.3 Axial component or longitudinal or vertical

Acts in the direction parallel to the impeller shaft. Inadequate longitudinal component causes the liquid and solid to rotate in layers without mixing. Adequate longitudinal pattern is best used to generate strong vertical currents particularly when suspending solids are present in a liquid.

4.2.4 Mixers for low or medium viscosity liquids







Propeller	**Turbine**	**Paddles**

4.2.4.1 Propeller

- It consists of number of blades, generally 3 bladed design is most common for liquids. Blades may be right or left handed depending upon the slant of their blades.
- Two are more propellers are used for deep tank.

- Size of propeller is small and may increased up to 0.5metres depending upon the size of the tank.

Small size propellers can rotate up to 8000rpm and produce longitudinal movement.

Advantages of propellers:

Used when high mixing capacity is required.

Effective for liquids which have maximum viscosity of 2.0pascals.sec or slurry up to 10% solids of fine mesh size.

Effective gas-liquid dispersion is possible at laboratory scale.

Disadvantages of propellers:

Propellers are not normally effective with liquids of viscosity greater than 5pascal.second, such as glycerin castor oil, etc.

4.2.4.2 Turbine

- A turbine consists of a circular disc to which a number of short blades are attached. Blades may be straight or curved.
- The diameter of the turbine ranges from 30-50% of the diameter of the vessel.
- Turbines rotate at a lower speed than the propellers (50-200rpm).
- Flat blade turbines produce radial and tangential flow but as the speed increases radial flow dominates. Pitched blade turbine produces axial flow.
- Near the impeller zone of rapid currents, high turbulence and intense shear is observed. Shear produced by turbines can be further enhanced using a diffuser ring (stationary perforated ring which surrounds the turbine).

  Diffuser ring increase the shear forces and liquid passes through the perforations reducing rotational swirling and vortexing.

4.2.4.3 Paddles

- A paddle consists of a central hub with long flat blades attached to it vertically.
- Two blades or four blades are common. sometimes the blades are pitched and may be dished or hemispherical in shape and have a large surface area in relation to the tank in which they are used.
- Paddles rotate at a low speed of 100rpm.
- They push the liquid radially and tangentially with almost no axial action unless blades are pitched.
- In deep tanks several paddles are attached one above the other on the same shaft.
- At very low speeds it gives mild agitation in unbaffled tank but as for high speeds baffles are necessary.

Uses of paddles:

Paddles are used in the manufacture of antacid suspensions, agar and pectin related purgatives, antidiarrheal mixtures such as bismuth-kaolin.

Advantages of paddles:

Vortex formation is not possible with paddle impellers because of low speed mixing.

Disadvantages of paddles:

Mixing of the suspension is poor therefore baffled tanks are required.

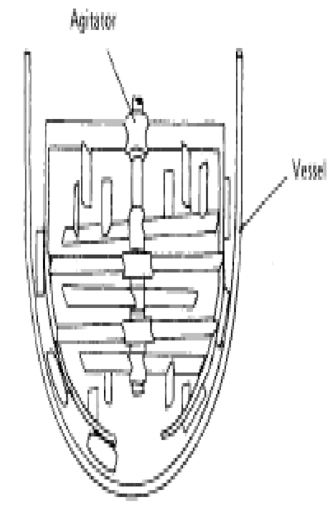
Impeller type	**Flow component**
Propellers	Axial
Turbines	Axial or tangential or both
Paddles	Radial and tangential
Paddles with pitch	Radial, tangential and axial

TYPES OF MIXER FOR LOW VISCOSITY LIQUID

	Paddles	Turbines	Propellers
Example	Simple Paddle	Curved – Blade	Standard 3- Blade
Size	Diameter of paddle is 50 -80% of the inside diameter of vessel	Diameter of turbine is 30-50% of the inside diameter of vessel.	Diameter of propeller is much smaller in diameter than paddles or turbines
Uses	Suitable for: mixing low viscosity liquids.	Suitable for: mixing viscous liquids, thin pastes and emulsions.	Suitable for: Mixing heavy susps., mixing of thin liquids Dissolution of solids.
Rotation speed	20 - 120 r.p.m. (low speed)	120 - 200 r.p.m. (moderate speed)	400 – 1750 r.p.m. (high speed)
Flow type	Tangential & radial	Tangential & radial	Tangential & axial
Viscosity	Up to 1000 cp	Up to 100.000 cp	Up to 5000 cp

4.2.5 Mixers for high viscosity Liquids and pastes

In high- viscosity liquids, pastes or dough, a different action is needed i.e. kneading, folding, and shearing.

		
Fig: Sigma blade mixing (Ref: toposmondialcorp. blogspot.com)	**Fig: Planetary mixer (Ref: www. pharmaequipments .org)**	**Fig: Anchor & gate agitator**

4.2.5.1 Sigma blade mixing

Principle – shear. Inter meshing of sigma blades creates high shear and kneading action.

Construction and working:

- It consists of double tough shaped stationary bowl.
- Two sigma shaped blades are fitted horizontally in each tough of the bowl.
- These blades are connected to a fixed speed drive.
- Mixer is loaded from top and unloaded by tilting the entire bowl.
- The blades move at different speeds , one about twice than the other, which allows movement of powder from sides to centers.
- The material also moves top to downwards and gets sheared between the blades and the wall of the tough resulting cascading action.
- Perforated blades can be used to break lumps and aggregates which creates high shear forces.
- The final stage of mix represents an equilibrium state.

Uses of sigma blade mixer:

- Used in the wet granulation process in the manufacture of tablets, pill masses and ointments,
- It is primarily used for liquid – solid mixing, although it can be used for solid – solid mixing.

Advantages of sigma blade mixer:

- Sigma blade mixer creates a minimum dead space during mixing.
- It has close tolerances between the blades and the sidewalls as well as bottom of the mixer shell.

Disadvantages of sigma blade mixer:

- Sigma blade mixer works at a fixed speed.

4.2.5.2 Planetary mixer

Principle:

Mechanism of mixing is shear. Shear is applied between moving blade and stationary wall. Mixing arm moves around its own axis and around the central axis so that it reaches every spot of the vessel. The plates in the blades are sloped so that powder makes an upward movement to achieve tumbling action also.

Construction:

- Consists of vertical cylinder shell which can be removed.
- The blade is mounted from the top of the bowl.
- Mixing shaft is driven by planetary gear and it is normally built with variable speed drive.

Uses :

- Break down agglomerates rapidly.
- Low speeds are used for dry blending and fast for wet granulation.

Advantages:

- Speed of rotation can be varied at will.
- More useful for wet granulation process.

Disadvantages:

- Mechanical heat is buildup within the powder mix.
- It requires high power.
- It has limited size and is useful for batch work only.

4.2.5.3 Anchor and gate agitator

- These are primarily used with high-viscosity fluids in unbaffled tanks.
- It scrape fluid off the tank wall and off the impeller.
- They generate a complex flow pattern and have a pumping action similar to that of a displacement pump.

TYPES OF MIXER FOR HIGH VISCOSITY LIQUID

TYPES	MECHANISM	USES	ADVANTAGE	DISADVANTAGE

SIGMA BLADE	Intermeshing of sigma blades creates high shear & kneading action 14-60 rev/min	Used in the wet granulation process in the manufacture of tablets, pill masses and ointments, It is primarily used for liquid – solid mixing, although it can be used for solid – solid mixing**.**	Creates minimum dead space during mixing Tolerance b/w blades & sidewall as well as bottom	Works at fixed speed
PLANETARY MIXER	Shear is applied between moving blade and stationary wall	Break down agglomerates rapidly. Low speeds are used for dry blending and fast for wet granulation.	Speed of rotation can be varied at will. More useful for wet granulation process.	Mechanical heat is buildup within the powder mix. It requires high power. It has limited size and is useful for batch work only
ANCHOR & GATE AGITATOR	generate a complex flow pattern and have a pumping action similar to that of a displacement pump.	Primarily used for high viscosity liquids and pastes	scrape fluid off the tank wall and off the impeller. used with high-viscosity fluids in unbaffled tanks.	Power is dissipated in the product as heat so mixing efficiency should be high to reduce mixing time

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