UTKALMANI GOPABANDHU INSTITUTE OF ENGINEERING, ROURKELA

LECTURE NOTES

PREPARED BY- SOVAN KUMAR SAHOO

SUBJECT- MECHANICAL OPERATION

DEPARTMENT OF CHEMICAL ENGINEERING

Class 1

In the process industries, this operation is usually carried out in order –

(i) to increase the surface in order to increase the rate of a physical or chemical process. In most reactions and unit operations (e.g., leaching) involving solid particles, the rate increases by increasing the area of contact between solid and second phase since the rate is proportional to the area of contact between the phases involved. In combustion process, the rate of combustion is proportional to the area presented to the gas. Thus, the rate of combustion of solid particles is high if the particles are of small size. In leaching, the rate of extraction increases because of the increased area of contact between the solid and the solvent.

II) to effect the separation of two constituents in cases where one is dispersed in small isolated pockets.

iii) to meet stringent specifications regarding the size of commercial products.

(iv) to accomplish intimate mixing of solids in a solid-solid operation since the mixing is more complete if the particle size is small.

(v) to improve dissolution rate, solubility, binding strength and dispersion properties. (vi) Many solid materials exist/present in sizes that are too large to be used directly. Thus, such materials must be reduced in size before use. Size reduction machines more commonly reduce the size of solids by (a) compression

CLASS2

Rittinger's Law • It states that the work required for the crushing operation is directly proportional to the new surface created. Mathematically, the law can be written as

P/•m = Kr(1/d- 1/D)…(2.1) where P = power required by machine

•m = feed rate to machine

Kr is constant (known as Rittinger's constant)

d,D= volume-surface mean diameter of the feed and product respectively.

Kick's Law • It states that the work required for crushing a given material is proportional to the logarithm of the ratio between the initial and final diameters. P •m = K_k ln (D/d) … (2.2) where K_k is a constant (known as Kick's constant) and D and d are the initial and final sizes respectively. • Since the energy required is directly related to the reduction ratio (D/d), the energy required to crush a given quantity of material from a 100 mm size to a 50 mm size is the same as that required to reduce the particle size from 12 mm to 6 mm. • Kick's law is more accurate than Rittinger's law for coarse crushing where the amount of surface produced is considerably less.

• Bond has proposed a law intermediate between Rittinger's and Kick's law for estimating the power required for crushing and grinding operations. • It states that the work required to form particles of size Dp from very large feed is proportional to the square root of the surface-to-volume ratio of the product (Sp /vp), Sp /vp = 6/ϕsDp .

Crushing Efficiency • It is defined as the ratio of the surface energy created by crushing to the energy absorbed by the solid. ηc = es (Ab – Aa) Wn …

where ηc = crushing efficiency Wn = energy absorbed by material, J/kg es = surface energy per unit area, J/m2 Ab = area of product, m2 Aa = area of feed, m2 .

Example 2.1 : A certain crusher accepts a feed material having a volume-surface mean diameter of 19 mm and gives a product of volume-surface mean diameter of 5 mm. The power required to crush 15 tonnes per hour is 7.5 kW. What will be the power consumption if the capacity is reduced to 12 tonnes per hour ?

Classification of size reduction equipments

1. Crushers (coarse and fine) (a) Jaw crusher (b) Gyratory crusher (c) Crushing rolls

2. Grinders (Intermediate and fine) (a) Hammer mills (b) Rolling-compression mills (i) Bowl mills (ii) Rolling mills (c) Attrition mills (d) Revolving mills (i) Rod mills (ii) Ball mills; pebble mills (iii) Tube mills
3. Ultrafine grinders (a) Hammer mills with internal classification (b) Fluid-energy mills (c) Agitated mills

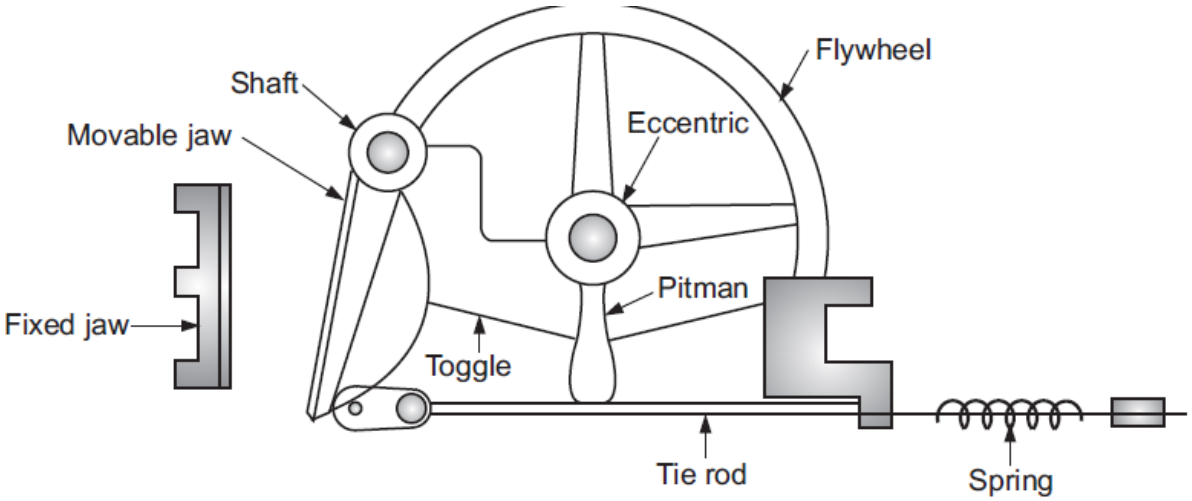
4. Cutting machines (a) Knife cutters, dicers, slitters.

Working of jaw crusher

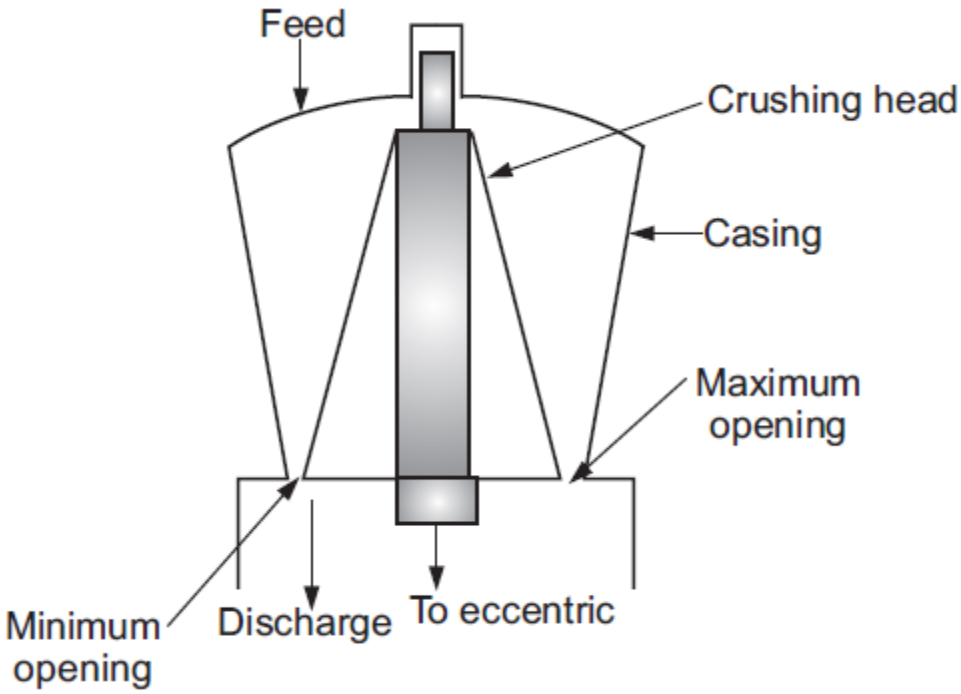
The Blake Jaw Crusher Principle : • It works on the principle of compression. It reduces size by compressive force. Construction : • A schematic diagram of the Blake jaw crusher is

. It has a fixed jaw and a movable jaw. The movable jaw is pivoted at the top. The jaws are set to form a V open at the top. The swinging jaw (movable jaw) which reciprocates in a horizontal plane usually makes an angle of 20 to 30o with the fixed jaw (which is nearly vertical). Fixed jaw Movable jaw Shaft Toggle Eccentric Flywheel Pitman Tie rod Spring • The jaws are usually made of manganese steel or some other material that will withstand abrasion. The faces of the crushing jaws are usually corrugated for concentrating the pressure on relatively small areas. • In addition to the jaws, crusher consists of a pitman, toggles, flywheel, eccentric shaft, drawback rod and springs and frame. In this machine, an eccentric causes the pitman to oscillate in a vertical direction, and this vertical movement is communicated horizontally (reciprocating motion) to the movable jaw by the toggles. • The speed of operation should not be high or otherwise a large quantity of fines is produced as the material cannot escape quickly and gets repeatedly crushed. Since the crushing action is intermittent, the loading on the machine is uneven and due to this the crusher incorporates a heavy flywheel. • Since the maximum movement of the jaw is at the bottom (discharge), there will be little tendency

for the crusher to choke. Protection of Machine : • The machine is usually protected so that it is not damaged if accidental pieces of iron such as hammer heads, stray bolts, etc. enter into the crusher,



Hammer Mill Principle : Size reduction is achieved by impact and attrition.



Ball Mill Principle :

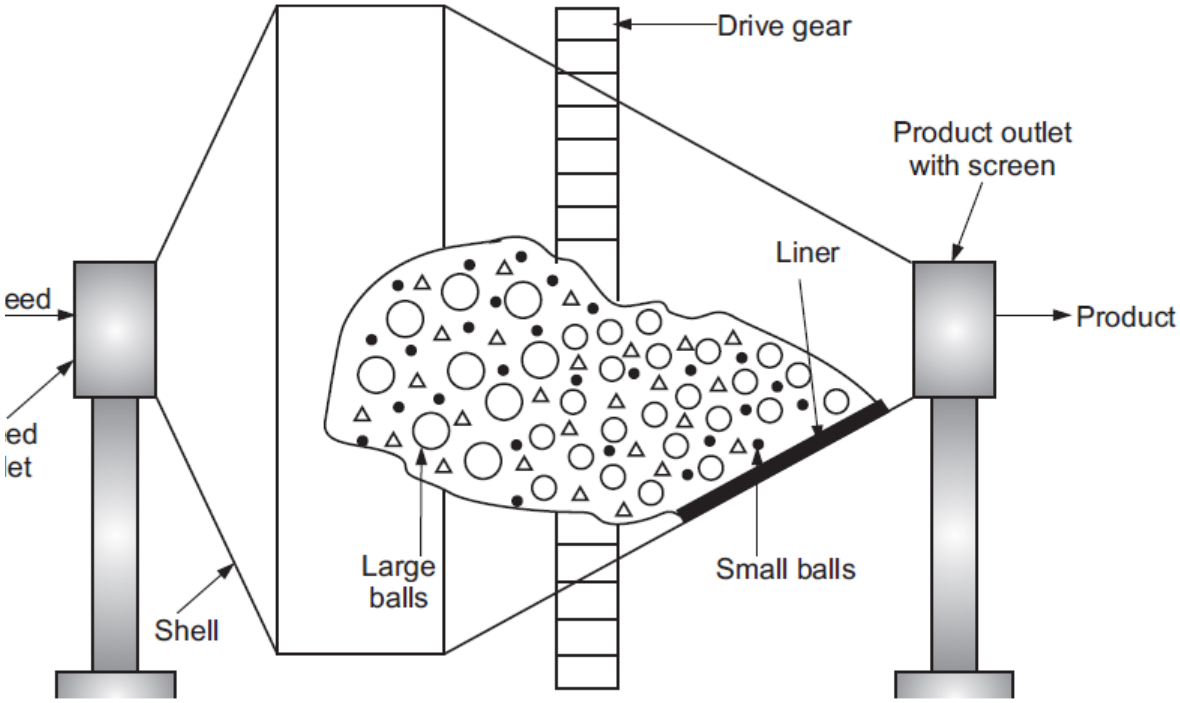
• It works on the principle of impact, i.e., size reduction is done by impact as the balls drop from near the top of the shell. Unit Operations-I 2.15 Size Reduction of Solids

Construction : • A ball mill consists of a hollow cylindrical shell rotating about its axis. The axis of the shell may be either horizontal or at a small angle to the horizontal. It is partially filled with balls. The grinding medium is the balls which may be made of steel, stainless steel or rubber. • The inner surface of the cylindrical shell is usually lined with an abrasion-resistant material such as manganese steel or rubber. The length of the mill is approximately equal to its diameter.

Open Circuit Grinding

 Open circuit grinding consists of one or more grinding mills arranged in series or parallel without classification equipment. This method discharges a final ground as it comes from a mill and there is no return of coarse discharge back to the mill.
 Some examples of open circuit grinding are : (i) Ball mill, (ii) Rod mill and

(ii) Combination of ball mill and rod mill.



1. Give the classification of size-reduction machines.
2. Name the four common ways of breaking solids in size-reduction machines.
3. Describe the construction of Blake jaw crusher.
4. Write in brief the construction and operation of ball mill.
5. What do you mean by closed-circuit grinding and open-circuit grinding ?
6. State why centrifuging is not desirable in a ball mill.
7. Define critical speed and give the formula for calculating the critical speed.
8. Define angle of nip and give the relationship between angle of nip, feed size, gap between rolls and diameter of rolls.
9. Draw a neat diagram of jaw crusher and name its parts.
10. State Rittinger's and Kick's law.

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Objective of size separation

operation :

The screening operation is industrially carried out in order to

(i) remove the fines from a feed material before a reduction equipment such as jaw crusher, ball mill or rod mill,

(ii) prevent an incompletely crushed material (oversize) from entering into other unit operations,

(iii) produce a commercial or process-grade material to meet specific particle size limits,

(iv) remove the fines from a finished product prior to shipping.

 An **ideal screen** is *the one which sharply separates the feed mixture in such a way that the smallest particle in the overflow is just larger than the largest particle in the underflow.* The ideal separation defines a cut diameter D_{pc} (a typical particle dimension) which makes the point of separation between the undersize and oversize fractions and is nearly equal to the mesh opening of the screen

Type of Screen Analysis

There are two methods of reporting screen analysis : (1) Differential analysis,

(2) Cumulative analysis.

 Differential Analysis : *The screen analysis in which the weight fraction of the material retained on each screen is reported in a tabular or a graphical form as a function of the mesh size/screen opening is called* ***differential analysis****.*

 Cumulative Analysis : *The screen analysis in which the cumulative weight fraction of the material retained (cumulative oversize) or passing through (cumulative undersize) each screen is reported in a tabular or a graphical form as a function of the screen opening is called* ***cumulative analysis.***

Definition and Derivation of the Effectiveness of a Screen

Material Balances over a Screen :

 Consider that the feed to a screen consists of materials A and B, where A is the oversize and B is the undersize material. Out of the total materials fed to the screen, some part of it is removed as overflow and remaining part of it is collected as underflow.

Let F be the mass flow rate of feed, (kg/h)

D be the mass flow rate of overflow, (kg/h)
B be the mass flow rate of underflow, (kg/h)
x_F be the mass fraction of material A in feed.
x_D be the mass fraction of material A in overflow.
x_B be the mass fraction of material A in underflow.
The mass fractions of material B in feed, overflow and underflow are $1 – x_F$, $1 – x_D$, and $1 – x_B$ respectively.
Overall material balance over a screen is
$F = D + B$ … (3.2)
Material balance of 'A' over a screen is
$x_F.F = x_D.D + x_B.B$ … (3.3)
From Equation (3.2), we have
$F – B = D$ … (3.4)

Substituting the value of D from Equation (3.4) into Equation (3.3), we get
$x_F.F = x_D (F – B) + x_B.B$ … (3.5)
$x_F.F = x_D.F – x_D.B + x_B.B$
$(x_D – x_F) F = (x_D – x_B) B$ … (3.6)
$$\frac{B}{F} = \frac{x_D – x_F}{x_D – x_B}$$
… (3.7)
Similarly, elimination of B from Equations (3.2) and (3.3) gives
$D/F = x_F – x_B / x_D – x_B$
… (3.8)
 The **effectiveness of a screen (screen efficiency)** is *a measure of the success of the screen in closely separating undersize and oversize materials*. In the case of a perfectly functioned screen, all the oversize material 'A' would be in the overflow and all the undersize material would be in the underflow.
 The **screen effectiveness** based on the **oversize material** is *the ratio of the amount of oversize material A that is actually in the overflow to the amount of oversize material A in the feed.*
Screen effectiveness
based on material A = $E_A = D.x_D / F.x_F$
$$= \frac{\text{Quantity of oversize in the overflow}}{\text{Quantity of oversize in the feed}}$$
… (3.9)
Similarly, the screen effectiveness based on the undersize material is given by
$$E_B = \frac{B (1 – x_B)}{F (1 – x_F)}$$
… (3.10)
The overall effectiveness of a screen can be given by
$E = E_A . E_B$ … (3.11)
where E is the overall effectiveness of a screen.
Substituting the values of E_A and E_B from Equations (3.9) and (3.10) into

Equation (3.11), we get

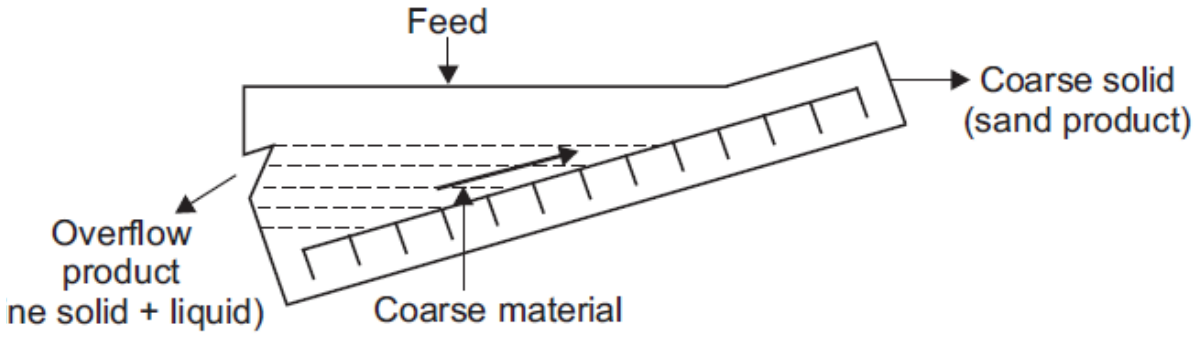
$E = \frac{D.B.\ x_D\ (1 - x_B)}{F_2\ x_F\ (1 - x_F)}$

… Substituting the values of D/F and B/F from Equations (3.8) and (3.7) into Equation (3.12), we get

$E = (x_F - x_B)\ (x_D - x_F)\ .\ x_D\ (1 - x_B)/(x_D - x_B)_2\ (1 - x_F)\ x_F$

Rake Classifier

 The rake classifier such as the Dorr classifier consists of a rectangular tank with a sloping/inclined bottom. The tank is provided with movable rakes (reciprocating rakes). The feed in the form of suspension (slurry) is introduced continuously near the middle of the tank. The lower end of the tank has a weir overflow (discharge weir) from which the fines that are not settled leave with the overflow liquid.



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Froth flotation processes are used for the separation of finely divided solids.

 Flotation refers to *an operation in which one solid is separated from another by floating one of them at or on the liquid surface*. In froth flotation, separation of a solid feed mixture depends upon differences in the surface properties of the materials involved. This technique is commonly used in mineral dressing. Mineral dressing refers to the method of treating ores at or near the mine site to produce one or more concentrates of valuable minerals and a tailings composed of waste or less valuable minerals.

 Froth flotation is used for treating the metallic ores that are finer than 48 to 65 mesh, or coal and certain non-metallics that are finer than 10 to 48 mesh. It is not possible to treat a coarser feed by froth flotation as the same cannot be suitably mixed and suspended by a floatation machine.

Principle of operation :

 Separation by froth flotation depends on differences in the surface properties of the materials.

 If the mixture is suspended in an aerated liquid (water), the gas bubbles will tend to adhere preferentially to the constituent which is more difficult to wet by the liquid (hydrophobic constituent) and so its effective density will be reduced to such an extent that it will rise to the surface (i.e., it will float on the surface of the liquid) and the material which has affinity for the liquid (hydrophilic material) gets surrounded by the liquid and it will simply sink, thus, achieving a separation. Frothing agents inducing the formation of a froth of sufficient stability are added to suspend or retain the particles in the froth on the surface before they are discharged.

[Hydrophobic – failing to mix with water – which will not wet by water and

Hydrophilic – having tendency to mix with water – which will get wet by water].

Promotors, Collectors, Modifiers and Frothing Agents :

 Almost all the minerals and inorganic solids are hydrophilic, as the surfaces of these solids get easily wetted by water. Hydrophilic solids are unflotable as air bubbles do not surround or cover them to form a particle bubble aggregate. However, these solids can be made hydrophobic (water repellent) with the help of reagents known as collectors or promotors. The collectors or promotors are the materials which selectively render the desired particles air-avid and water repellent.

(i) Promotors : These are materials which are adsorbed on the surface of the particles forming a unimolecular layer. A commonly used promotor is sodium ethyl xanthate.

(ii) Collectors : These are materials which form surface films on the particles. A commonly used collector is pine oil.

Types of Filtration : Cake Filtration and Deep Bed Filtration

 Basically, there are two types of filtration.

(i) Cake filtration, (ii) Deep bed filtration.

 In cake filtration, the proportion of solids in the suspension is large and most of the solid particles are collected in the cake which can later be detached from the filter medium.

 In deep bed filtration, the proportion of solids is very small and the particles of the solid being smaller than the pores of the filter medium will penetrate a considerable depth and ultimately get trapped inside the filter medium and usually no layer of solids will appear on the surface of the medium (e.g., water filtration).

medium

Slurry

Fig. 5.1 : Principle of filtration

Principles of Cake Filtration :

 In cake filtration, the feed to be handled (two phase mixture) is called **slurry**, the bed of deposited solids on a porous membrane (filter medium) is called **cake** and the clear liquid leaving the filter medium is called **filtrate.**

 A typical cake filtration operation is shown in Fig. 5.1. During the initial period of flow, solid particles are trapped within the pores of a medium forming a true filter medium. The liquid passes through the bed of the solids and through the filter medium. In the early stage of filtration, the rate of filtration is high. As the cake thickness increases, the rate of filtration decreases for a given pressure differential across the filter medium. This is due to the fact that as the cake gradually builds upon

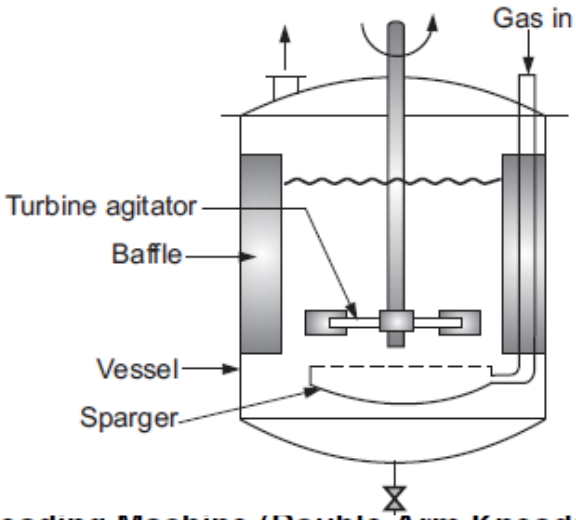
MIXING

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

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.



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.

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.

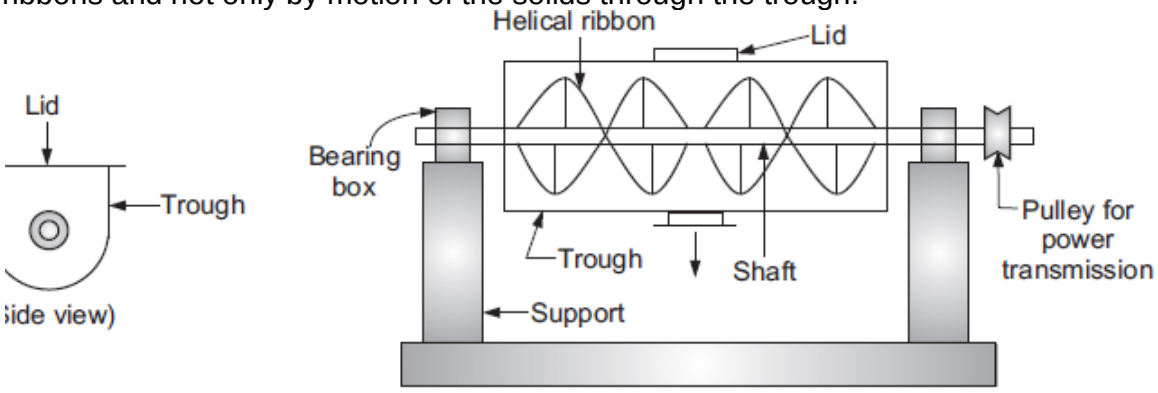


Fig. 6.20 : Ribbon blender

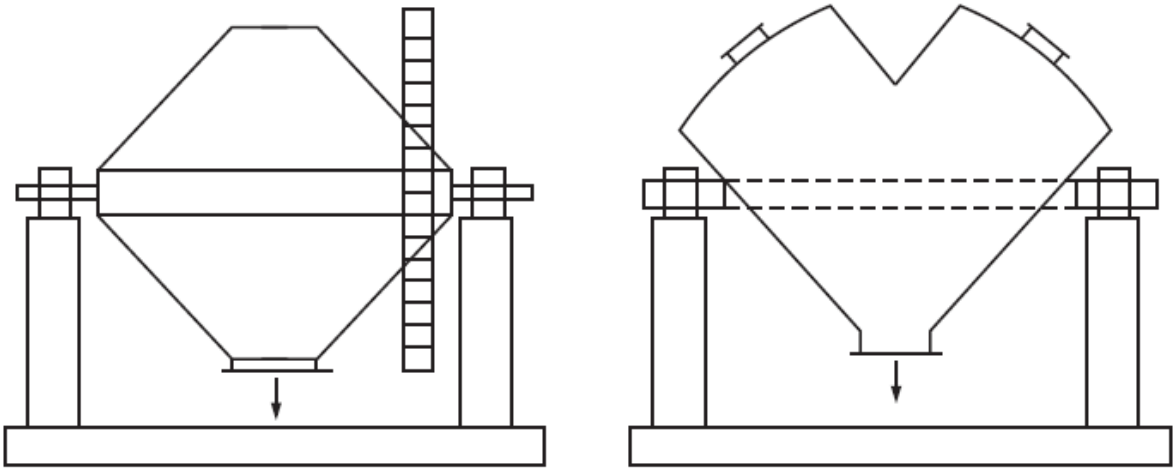
Ribbon blenders are used for batch or continuous mixing. In batch operated ribbon blenders, the solids are charged and mix until satisfactory and discharged from the bottom.

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.

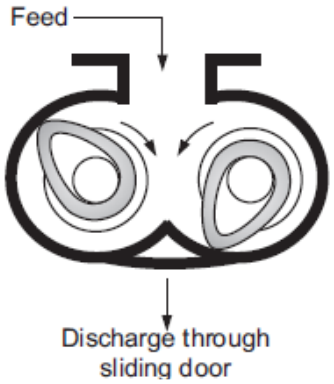
For light duty, the trough may be open or lightly covered, while for operation under pressure or vacuum, the trough is closed and heavy-walled. Ribbon blenders are very effective for handling thin pastes and dry powders that do not flow easily.

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 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.



- 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.

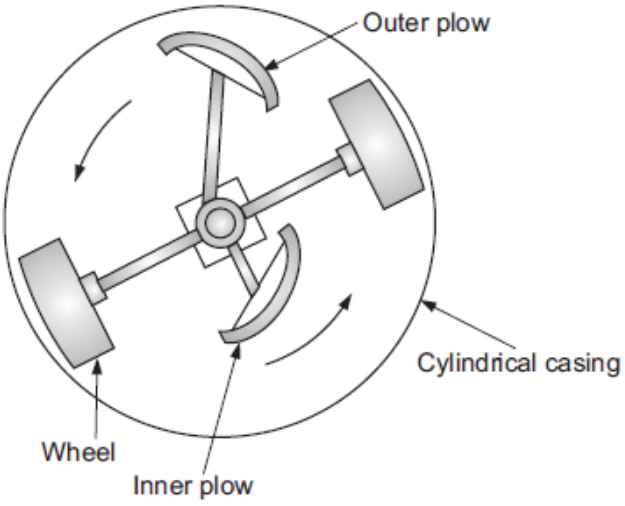


Fig. 6.22 : Muller mixer (Top view)

Transportation and storage

A conveyor is a conveyor is a conveyor, right? Wrong. There are two basic types of conveyors: powered and gravity Powered conveyors have some sort of external energy source to keep the items on the conveyor moving, typically by manipulating the conveyor surface. Gravity conveyors (as the name suggests) use the weight of the items being conveyed to propel them where desired.

Of course, there are plenty of limitations for gravity conveyors, but the flip side is that they don't have a motor system to maintain – or to fix in the event that it breaks down. Powered conveyors do run that risk, but can move all sorts of items (of just about any weight), even up an incline.

But the options don't stop with powered or gravity; there are many varieties of warehouse conveyor technologies.

- Aero-mechanical conveyor.
- Automotive conveyor.
- Belt conveyor.
- Belt-driven live roller conveyor.
- Bucket conveyor.
- Chain conveyor.
- Chain-driven live roller conveyor.
- Drag conveyor.

Bucket conveyors move products (typically aggregate or bulk) vertically via reciprocating buckets. The conveyor is made of an interconnected loop of troughs/buckets that stay level when moving from horizontal to vertical, preventing their contents from spilling out. The conveyor is loaded with material at the front, or "boot", and each bucket automatically deposits at the end of the run, also known as the discharge. This process is a fast and automatic method of vertical conveying, as the same buckets which pick up material are used to deposit it. The design of these machines depends heavily on the material being transported as well as the desired height that it must travel, but they are reliable and efficient if made correctly. They perform best when moving dry, light, or powder material and are typically not used to move wet or sludge-like substances, as any buildup in the buckets will cause discharging issues.

A **screw conveyor** or **auger conveyor** is a mechanism that uses a rotating helical screw blade, called a "*flighting*", usually within a tube, to move liquid or granular materials. They are used in many bulk handling industries. Screw conveyors in modern industry are often used horizontally or at a slight incline as an efficient way to move semi-solid materials, including food waste, wood chips, aggregates, cereal grains, animal feed, boiler ash, meat, and bone meal, municipal solid waste, and many others. The first type of screw conveyor was the Archimedes' screw, used since ancient times to pump irrigation water.

They usually consist of a trough or tube containing either a spiral blade coiled around a shaft, driven at one end and held at the other, or a "*shaftless spiral*", driven at one end and free at the other. The rate of volume transfer is proportional to the rotation rate of the shaft. In industrial control applications, the device is often used as a variable rate feeder by varying the rotation rate of the shaft to deliver a measured rate or quantity of material into a process.

Screw conveyors can be operated with the flow of material inclined upward. When space allows, this is a very economical method of elevating and conveying. As the angle of inclination increases, the capacity of a given unit rapidly decreases.

The rotating part of the conveyor is sometimes called simply an auger.