UNIT II- SIZE REDUCTION

Size reduction is applied to all ways in which particles of solids are cut or broken into smaller pieces. The objective of crushing and grinding is to produce small particles from larger ones. Smaller particles are desired because of their larger surface. In most reactions involving solid particles the rate is directly proportional to the area of contact with the second phase. In leaching, the rate of leaching is increased if the area of contact is more between solvent and the solid to be extracted. In addition the distance the solvent has to penetrate into the particles in order to gain access to more remote pockets of solute is also reduced. This factor is also important in drying porous solids, where reduction in size causes both an increase in area and a reduction in the distance, the moisture must travel within the particle in order to reach the surface. More intimate mixing of solids can be achieved if the particle size is small.

Solids may be broken by applying different forces. Four forces commonly used in size reduction machines are (1) Compression (2) Impact (3) Attrition or rubbing (4) Cutting.

Ex: Nut cracker, hammer, file, pair of shears.

Ex: Type of Force	Every Day Example	Typical Machine (Tools)
Compression	Cracking of net with a net cracker.	Jaw or Gyratory crusher.
Impact	Striking of stone with hammer, pounding.	Hammer mill and Impactor.
Attrition	Sharpening of knife on an emery wheel.	Rod mills and ball mills.
Shredding	Plaining of wood with Jack plane.	Cutters and shredders.

Compression is used for coarse reduction of hard solids to give relatively few fines. Impact gives coarse, medium or fine particles. Attrition yields very fine products from soft, non-abrasive materials. Cutting gives a definite particle size and sometimes a definite shape with few or no fines.

Requirements of an Ideal Crusher and Grinder:

1. It should have a large capacity.

2. Should consume less power per unit of product.

3. Should yield a product of single size or size distribution desired.

Unlike an ideal crusher or grinder an actual crusher or grinder does not yield a single size product. The product always consists of a mixture of particles. Some machines (especially in the grinder class) are designed to control the size of the largest particle in their products, but the fine sizes are not under control. In some types of grinders fines are minimized but they are not eliminated.

Classification of Equipment for Size reduction:

Coarse Crusher:

1. Jaw Crusher (Dodge and Blake)

2. Gyratory Crusher.

Intermediate Crushers:

1. Crushing rolls.

2. Hammer mills.

3. Edge runner.

Fine Crusher:

1. Ball mill.

2. Tube mill.

3. Ring roller mill.

Ultrafine Grinders:

1. Fluid energy mill.

2. Agitated mills.

Cutting Machines:

1. Knife Cutters.

Power requirement in Comminution:

The cost of power is a major expense in crushing and Grinding, so the factors that control this cost is important. During size reduction new surface is created.

Crushing Efficiency: 'η_c'

The ratio of the surface energy created by crushing to the energy absorbed by the solid is the crushing efficiency 'η_c'.

If e_s is the surface energy per unit area and A_{Wb} and A_{Wa} are the area of products and feed respectively and if W_n is the energy absorbed by unit mass of material.

$$\eta_c = \frac{e_s(A_{Wb} - A_{Wa})}{W_n}$$

The surface energy created by fracture is small in comparison with the total mechanical energy stored in the material at the time of rupture. Most of the mechanical energy stored is converted into heat. Crushing efficiencies are therefore low.

Mechanical Efficiency: 'η_m':

The energy absorbed by the solid w_n is less than that fed to the machine, part of the total energy input w is used to overcome friction in the bearing or other moving parts and the rest is available for crushing.

The ratio of the energy absorbed to the energy input is the mechanical efficiency η_m.

$$\eta_m = \frac{w_n}{w} = \frac{e_s(A_{w_b} - A_{w_a})}{\eta_c w} \Rightarrow w = \frac{w_n}{\eta_c} = \frac{e_s(A_{w_b} - A_{w_a})}{\eta_m \eta_c}$$

If $\overset{o}{m}$ is the feed rate, the power required by the machine

$$P = w\overset{o}{m} = \overset{o}{m}\,\frac{e_s(A_{w_b} - A_{w_a})}{\eta_m \eta_c}$$

w.k.t. A_{wb} and A_{wa} as $\dfrac{6}{\phi_a \int_P \bar{D}_{Sb}}$ and $\dfrac{6}{\phi_b \int_P \bar{D}_{Sa}}$

Substituting in the above equation

$$P = \frac{6\overset{o}{m}e_s}{\eta_c \eta_m \int_P}\left(\frac{1}{\phi_b \bar{D}_{Sb}} - \frac{1}{\phi_a \bar{D}_{sa}}\right)$$

Where $\bar{D}_{sb}$ & $\bar{D}_{sa}$ are the volume surface mean dia. of the product and feed respectively.

Laws of Comminution:

Rittinger's Law: (1867):

The law states that the work required in crushing is proportional to the new surface created.

$$P = W\overset{o}{m} = \overset{o}{m}\,\frac{e_s(A_{Wb} - A_{Wa})}{\eta_c \eta_m}$$

$$\frac{P}{\overset{o}{m}} = \frac{e_s(A_{Wb} - A_{Wa})}{\eta_m \eta_c} \quad \text{w.k.t} \quad A_W = \frac{6}{\Phi_s \int_P \bar{D}_{Ps}}$$

Substituting for A_W,

$$\frac{P}{\overset{o}{m}} = \frac{e_s 6}{\eta_m \eta_c \int_P} \left(\frac{1}{\Phi_b \bar{D}_{Sb}} - \frac{1}{\Phi_a \bar{D}_{Sa}} \right)$$

If Φ_a and Φ_b are equal and the mechanical efficiency is constant, crushing efficiency is constant. The various constants can be combined into a single constant K_R.

$$\frac{P}{\overset{o}{m}} = K_R \left(\frac{1}{\bar{D}_{Sb}} - \frac{1}{\bar{D}_{Sa}} \right).$$

Kick's Law: (1885):

Kick's law is based on stress analysis of plastic deformation within the elastic limit, which states that the work required for crushing a given mass of material is constant for the same reduction ratio that is the ratio of the initial particle size to the final particle size. This leads to the relation.

$$\frac{P}{\overset{o}{m}} = K_K \ln \frac{\bar{D}_{sa}}{\bar{D}_{Sb}}$$ where K_K is a constant.

A generalized relation for both cases is the differential equation.

$$d\left(\frac{P}{\overset{o}{m}}\right) = -K \frac{d\bar{D}_S}{\bar{D}_S^{\,n}}$$

n = 1 leads to Kicks law

n = 2 leads to Rittinger's law.

Both the laws have been shown to apply over limited ranges of particle size, provided K_K and K_R are determined experimentally by tests in a machine of the type to be used and with the material to be crushed. They thus have limited utility and are mainly of historical interest.

Bond crushing Law and Work Index: (1952):

A somewhat more realistic method of estimating the power required for crushing and grinding.

The law states that the work required to form particles of size D_P from a very large feed is proportional to the sequence root of the surface to volume ratio of the product, S_P/ D_P.

$$\frac{P}{\overset{o}{m}} \alpha \sqrt{\frac{S_P}{v_P}}$$ W.k.t $\Phi_S = \frac{6v_P}{D_P S_P}$ or $\frac{S_P}{v_P} = \frac{6}{\Phi_S D_P}$

$$\frac{P}{\overset{o}{m}} \alpha \sqrt{\frac{6}{\Phi_S D_P}} \qquad \text{or} \qquad \frac{P}{\overset{o}{m}} = \frac{K_B}{\sqrt{D_P}}$$

Where K_B is a constant which depends on the type of machine and on the material being crushed.

In the differential equation given earlier substitution of n = 1.5 and feed of infinite size will give this equation. To use above equation, a work index, W_i is defined and is the gross energy requirement in kWh / ton of feed needed to reduce a very large feed to such a size that 80 % of the product passes a 100 μm screen.

This definition leads to a relation between K_B and W_i, if D_P is in mm and P is in kW and $\overset{o}{m}$ is in tons / hour.

$$K_b = \sqrt{100 \times 10^{-3}}\ W_i = 0.3162\ W_i.$$

If 80 % of the feed passes a mesh size of D_{Pa} mm, the above equation can be written as

$$\frac{P}{\overset{o}{m}} = 0.3162\ W_i \left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right).$$

The work index includes the friction in the crusher and the power given by above equation is gross power.

Energy Utilization:

The energy supplied for crushing is utilized in the following ways

1. In producing elastic deformation of the particles before fracture occurs

2. In producing elastic deformation which results in size reduction.

3. In causing elastic distortion of the equipment.

4. In overcoming the friction between particles and between particles and machines.

5. In noise, heat and vibration in the plant.

6. In friction losses in the plant itself.

Relative Applicability of Law of Crushing:

Rittinger's law is applicable mainly to that part of the process where new surface is being created and holds most accurately for fine grinding where the increase in surface per unit mass of material is large.

Kicks law more closely relates to the energy required to effect elastic deformation before fracture occurs, and is more accurate than Rittinger's law for coarse crushing where the amount of surface produced is considerably less.

Bond's law is intermediate between Rittinger's law and Kick's law.

Alternate Derivation of Crushing Laws:

A number of empirical laws have been put forward to estimate the amount of energy required for size reduction. The following are the laws put forward. Kicks Law, Rittinger's Law, Bond's Law. All these laws can be derived from the basic differential equation.

$$\frac{dE}{dL} = - CL^{P} \qquad (1)$$

This equation states that the energy 'dE' required to effect a small change 'dL' in the size of unit mass of material is a simple power function of the size.

If P is put equal to (-2)

$$\frac{dE}{dL} = - CL^{-2}$$

$dE = - CL^{-2}dL$, integration gives.

$$E\Big|_{O}^{E} = \frac{-CL^{-2+1}}{-1}\Bigg|_{L_1}^{L_2}$$

$$E = C\left(\frac{1}{L_2} - \frac{1}{L_1}\right)$$

Writing $C = K_R fc$, where fc is the crushing strength of the material, we obtain Rittinger's law (1867).

$$E = K_R fc\left(\frac{1}{L_2} - \frac{1}{L_1}\right) \qquad (2)$$

Since the surface of unit mass of material is proportion to 1/L, the interpretation of this law is that the energy required for size reduction is directly proportional to the increase in surface

In equation (1) $\Rightarrow$ If P is put equal to – 1

$dE = - CL^{-1}\, dL$ integrating

$$E\Big|_O^E = - C \ln L\Big|_{L_1}^{L_2}$$

$$E = - C \ln L_2/L_1$$

$$E = C \ln L_1/L_2 \qquad \text{writing } e = k_k fc$$

$$E = k_k\, fc \ln L_1/L_2 \qquad (3).$$

Equation (3) is known as Kick's law this supposes that the energy required is directly related to the reduction ratio L_1/L_2 and that the energy required to crush a given amount of material from 2 cm to 1 cm size is the same as that required to reduce the size from ½ cm to ¼ cm.

In equation (2) and (3) K_R and K_k are known as Rittinger's constant and Kick's constant respectively. Both the constants are dimensional constants.

Bond's law is intermediate between Rittinger's and Kick's law put P = - $3/2$ in equation (1).

$$\frac{dE}{dL} = - C L^{-3/2}$$

$$dE = - C L^{-3/2}\, dL$$

$$\text{Integrating } E\Big|_O^E = \frac{C L^{-3/2+1}}{-1/2} = \frac{2C}{\sqrt{L}}\Bigg|_{L_1}^{L_2}$$

$$E = 2C \left(1/\sqrt{L_2} - 1/\sqrt{L_1} \right)$$

$$= 2C \sqrt{1/L_2} \left[1 - 1/q^{1/2} \right]$$

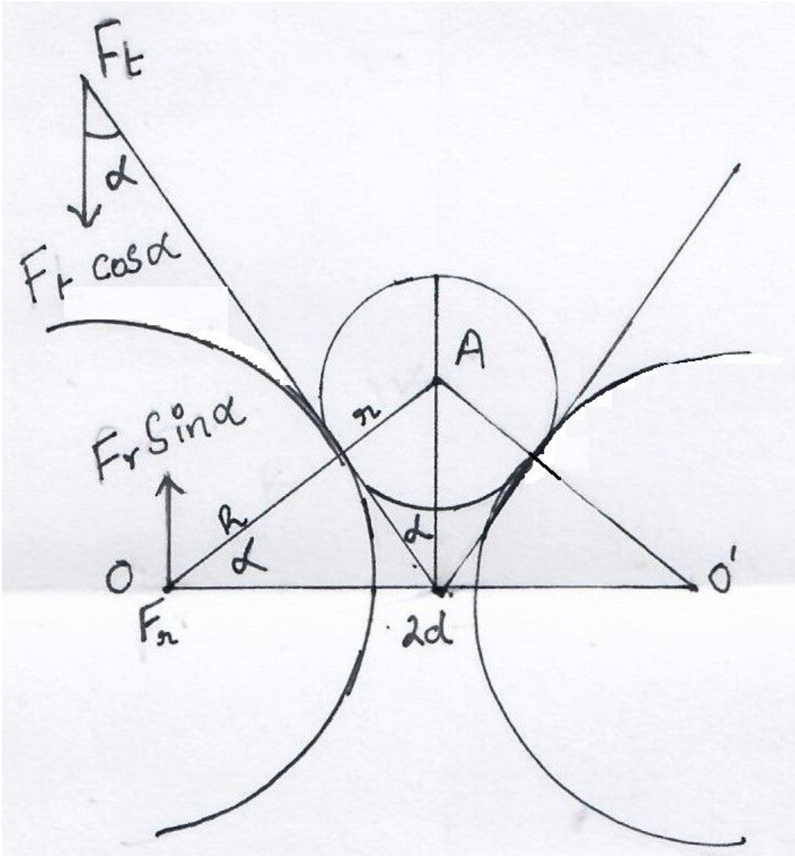
Where $q = \dfrac{L_1}{L_2}$ the reduction ratio

Writing C =5 Ei $\quad\quad\quad\quad 5 \times 2 = 10 = \sqrt{100}$

$$E = Ei\sqrt{\frac{100}{L_2}}\left[1 - \frac{1}{q^{1/2}}\right]$$

Bond terms Ei the work index and expresses it as the amount of energy required to reduce unit mass of material from an infinite particle size to a size of L_2 of 100 micron (i.e. $q = \infty$). The size of material is taken as the size of the square hole through which 80% of it will pass.
Bond's law is somewhat the more realistic in estimating power requirements of commercial crushers and grinders.

Angle of NIP of Roll Crusher:



The angle of nip is the angle between the roll faces at the level where they will just take hold of a particle and draw it into the crushing zone.

In figure let O and O' be the centers of the two rolls of a pair, and let A be the centre of the spherical particle of material that has just been caught between the rolls. There is a certain force 'Fr' acting on the particle and this force makes an angle α with the line OO' and tends to expel the particle from the rolls. This force 'Fr' may be resolved into two components. There is also a force 'Ft' tending to draw the particles between the rolls. This force 'Ft' may be resolved into two forces. The force Ft cosα and Fr sinα are the two opposing forces. For the particle to be crushed Ft cosα should be greater than Fr sinα. The force 'Ft' depends on the force 'Fr' and on the coefficient of friction between the material to be crushed and the roll surface. If μ' is the coefficient of friction then Ft = μ'Fr.

In order that the particle shall be drawn between the rolls and crushed, it follows that μ' r cos α must be greater than r sin α or

$$\mu' \, r \cos \alpha > r \sin \alpha$$

$$\mu' > \tan \alpha$$

In other words the tan α must be less than the coefficient of friction. When μ' = tan α the particle is just caught between the rolls and ready to be drawn in to the crushing zone. The angle made is angle of nip and α is half the angle of nip. The coefficient of friction varies with different materials, but it has been found that an average value of the angle α taken from practice is about 16^o.

Relation between angle of NIP, Dia. of Rolls, radius of Feed and Product:

There is a definite relation between the diameters of rolls, feed and product. In the above figure let r is radius of the feed particle, R the radius of the roll and d the radius of the largest possible particle in the product (half the distance between the rolls). Then in the triangle OAO', angle O'OA is α

$$\text{Cos } \alpha = \frac{r+d}{R+r}.$$

For average conditions α is 16^o and cos α is 0.961 hence $0.961 = \frac{r+d}{r+R}$

Capacity of Roll Crushers:

It is assumed that the materials to be crushed moves like a continuous ribbon whose width is the width of the roll and whose thickness is the clear opening between the rolls. ∴ The theoretical volume of material crushed.

$$= \pi DN \times W \times 2d \quad m^3 / hr.$$

Where

D – Diameter of the roll, m

N – No. of revolutions / hr

W – Width of the rolls, m

2d – gap between the rolls, m

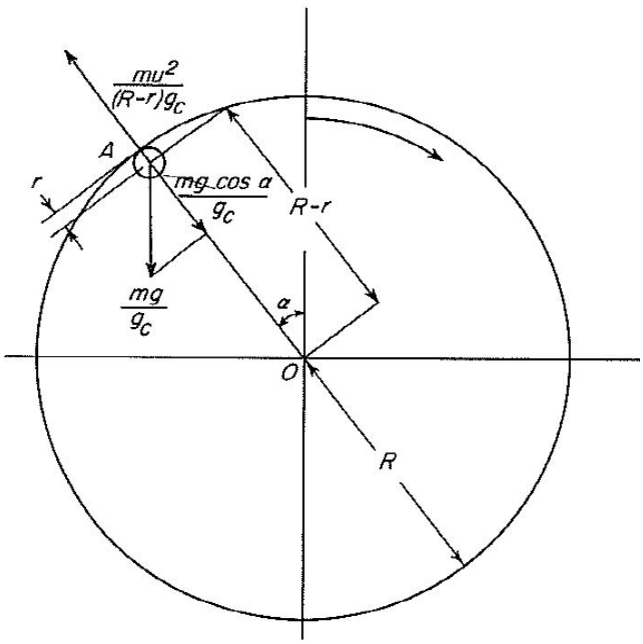
The mass of material crushed = volume × Density. The actual capacity is 1/3 rd to 1/10 th of this theoretical capacity.

Ball Mill:

Action in Revolving Mills (Tumbling Mills):

The load of balls in a ball or tube mill is normally such that when the mill is stopped, the balls occupy one half the volume of the mill. The void fraction in the mass of balls, when at rest is typically 0.40. The grinding may be done with dry solids, but more commonly the bed is a suspension of the particles in water. This increases both the capacity and efficiency of the mill. Discharge openings at appropriate positions control the liquid bend in the mill, which should be such that the suspension just fills the void space in the mass of balls.
When the mill is rotated, the balls are picked up by the mill wall and carried nearly to the top, where they break contact with the wall and fall to the bottom to be picked up again. Centrifugal force keeps the balls in contact with the wall, and also with each other during the upward movement. While in contact with the wall, the balls do some grinding by slipping and rolling over each other, but most of the grinding occurs at the zone of impact, where the free-falling balls strike the bottom of the mill.
The faster the mill is rotated, the farther the balls are carried up inside the mill and greater the power consumption. The added power is profitably used because the higher the balls are when they are released, the greater the impact at the bottom and the larger the productive capacity of the mill. If the speed is too high, however, the balls are carried over and the mill is said to be centrifuging. The speed at which the centrifuging occurs is called **Critical Speed**. Little or no grinding is done when a mill is centrifuging and operating speeds must be less than the critical.

The speed at which the outermost balls loose contact with the wall of the mill depends on the balance between gravitational and centrifugal forces. This can be shown as follows.



Forces on ball in ball mill:

Consider a ball at point A on the periphery of the mill. Let the radii of the mill and of the ball be R and r respectively. The center of the ball is then (R – r) meters from the axis of the mill. Let the radius AO form the angle α with the vertical. Two forces act on the ball. The first is the force of gravity mg, where m is the mass of the ball. The second is the centrifugal force mu^2 / R-r, where 'u' is the peripheral speed of the center of the ball and n is the rotational speed. The centripetal component of the force of gravity is mg $\cos\alpha$ and this force opposes the centrifugal force. As long as the centrifugal force exceeds the centripetal force, the particle will not break contact with the wall. As the angle α decreases, however the centripetal force increases and unless the speed exceeds the critical, a point is reached where the opposing forces are equal and the particle is ready to fall away. The angle at which this occurs is found by equating the two forces giving

$$mg \cos \alpha = mu^2 / R - r \quad \text{or} \quad \cos \alpha = u^2 / (R - r)\, g.$$

The speed 'u' is related to the speed of rotation.

$$U = 2\pi\, n\, (R - r)$$

Substituting for 'u' $\cos \alpha = \dfrac{4\pi^2 n^2 (R-r)^2}{g(R-r)}$

At critical speed, $\alpha = 0$, $\cos \alpha = 1$ and n becomes the critical speed N_c, then

$$N_C = \frac{1}{2\pi}\sqrt{\frac{g}{R-r}}$$

Tumbling mills run at 65 to 80 percent of the critical speed, with the lower values for wet grinding in viscous suspensions.

Cascading and Cataracting :

Cascading and Cataracting are the terms applied to the motion of the grinding media. Cascading applies to the rolling of balls or pebbles from the top to the bottom of the heap. Cataracting refers to the throwing of the balls through the air to the toe of the heap.

Advantages of Ball Mill:

1. The mill can be used wet or dry.

2. The cost of installation and of power is low.

3. The ball mill can be used with an inert atmosphere and therefore can be used for the grinding of certain explosive material.

4. The grinding medium is cheap.

5. The mill is suitable for materials of all degree of hardness.

6. It can be used for batch or continuous operation.

7. It can be used for closed or open circuit grounding.

Factors influencing the size of Product in Ball Mill:

1. The rate of feed:

With high rates of feed, less size reduction is effected since the material is in the mill for a short-time.

2. The properties of feed material (Size & hardness):

The larger the feed the larger will be the product under given operating conditions smaller size reduction is obtained with a hard material.

3. Weight of Balls:

A heavy charge of balls produces a fine product. The weight of charge can be increased by increasing the number of balls or by using a material of higher density. Since optimum grinding conditions are usually obtained when the bulk volume of the balls is equal to 50% of the volume of the mill, variation of the weight of the balls is normally effected by the use of materials of difference densities.

4. Diameter of Balls:

Small balls facilitate the production of fine materials but they do not deal so effectively with the large particles in the feed. The limiting reduction obtained with a given size of ball is known as free grinding limit. For most economical operation the smallest possible balls should be used.

5. The Slope of the Mill:

Increase in slope of the mill will increase the capacity of the plant because the retention time is reduced but a coarser production is obtained.

6. The speed of Rotation of the Mill:

At low speed of rotation, the balls simply roll over one another and little crushing is done. At slightly higher speeds they are projected short distances across the mill, and at still higher speeds they are thrown greater distances and considerable wear of the lining of the mill takes place. At very high speeds, the balls are carried right around in contact with the sides of the mill and no grinding takes place again.

7. The level of material in the Mill:

Power consumption is reduced by maintaining al low level of material in the mill, and this can be controlled most satisfactorily by making a suitable discharge opening for the product. If the level of the materials is raised the cushioning action is increased and the power is wasted by the production of an excessive quantity of undersize material.

Advantages of Wet Grinding:

1. The power consumption is less by about 20-30%.

2. The capacity of the plant is increased.

3. Removal of the product is facilitated and the amount of fines reduced.

4. Dust formation is eliminated.

5. The solids are more easily handled.

The disadvantages are that the grinding medium will generally be about 20% greater and it may be necessary to dry the product

Size range of feed and product of size Reduction Equipments:

Equipment	Feed Size	Product size
Coarse Crusher	60’’ – 1 $\frac{1}{2}$ ’’	2’’ – ¼ ‘’
Intermediate Crusher	2’’ – ¼ ‘’	¼ ‘’ – 200 mesh
Fine Crusher	¼ ‘’ – 1/8 ‘’	About 200 mesh
Ultra Fine	80 mesh	Down to 10^{-6}m.

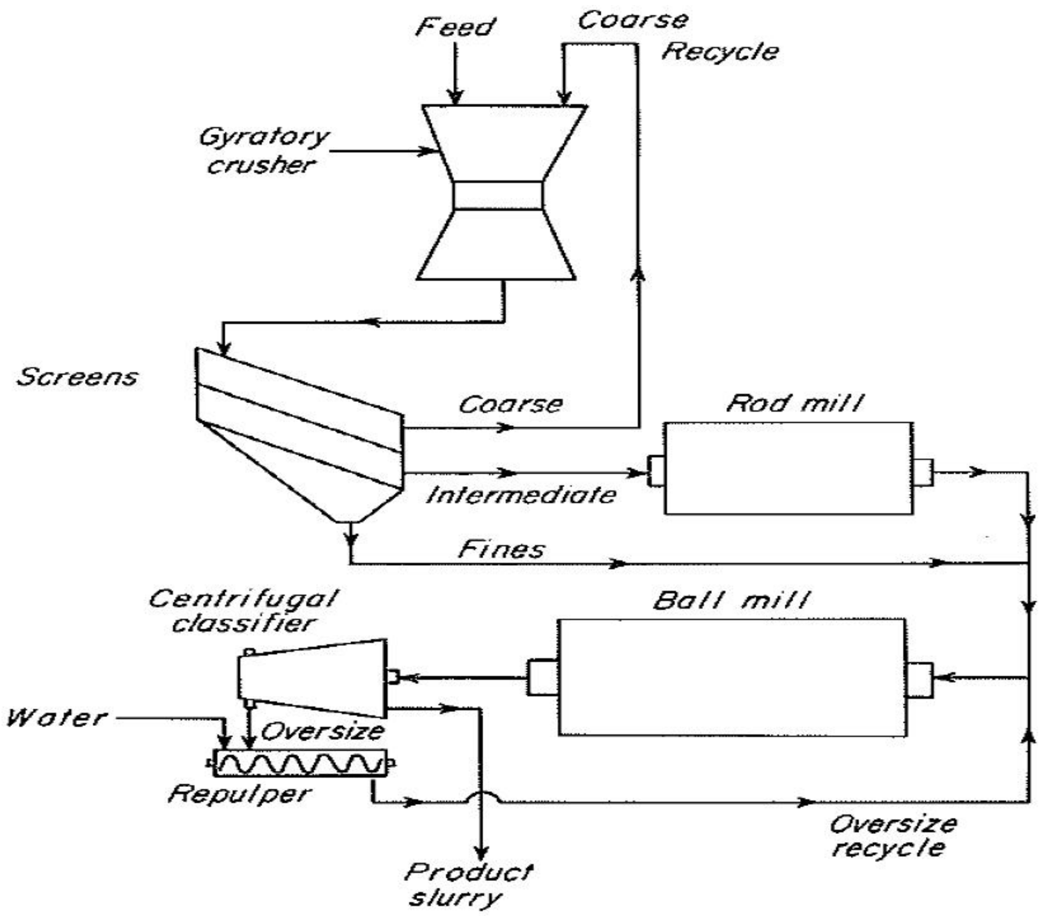
A greater size reduction ratio can be obtained in fine crushers than in coarse crushers.

Methods of Operating Crushers:

The crushers may be operated under free crushing or choke feeding and also either open circuit or closed circuit grinding. If the crusher is fed at a low rate, the material crushed will leave the crusher immediately and this is called free crushing. If the crusher is fed at high rate of solid the material crushed cannot move freely through the crusher and stay in the crusher for longer time and get crushed again. This type of feeding is called Choke Feeding. During choke feeding energy is lost because of cushioning effect.

Open circuit and Closed circuit Operation:

In many mills the feed is broken into particles of satisfactory size by passing it once through the mill. When no attempt is made to return the oversize particles back to the machine for further reduction the mill is said to be operating in open circuit. This may require excessive amounts of power for much energy is wasted in re-grinding particles that are already fine enough. Thus it is often economical to remove partially ground material from the mill and pass it through a size separation device. The undersize becomes the product and the oversize is returned to be reground. The separation device is sometimes inside the mill, as in ultrafine grinders or as is more common, it is outside the mill. Closed circuit operation is the term applied to the action of a mill and separator connected so that the oversize particles are returned to the mill.



The above fig. shows a typical set of size reduction machines and separators operating in closed circuit. For coarse particles the separation device is a screen or Grizzly for fine powders it is some form of classifier.

The product from the Gyratory crusher is screened into 3 fractions, fines intermediate and oversize. The oversize is sent back to the Gyratory, the fines are fed directly to the final reduction unit, a ball mill. Intermediate particles are broken in a rod mill before they enter the ball mill. In the arrangement shown in the diagram the ball mill is grinding wet. i.e. water is pumped through the mill with the solid to carry the broken particles to a centrifugal classifier The classifier throws down the oversize into a sludge , which is re-pulped with more water returned to the mill. The undersize, or product, emerges from the classifier as a slurry containing particles of acceptable size. Although screens are simpler to operate than classifiers, they cannot economically make separations when the particles are smaller than about 150-200 mesh. It is the over grinding of precisely these fine particles that results in excessive consumption of energy. Closed circuit operation is therefore of most value in reduction to fine and ultra fine sizes, which demands that the separation be done by wet classifier or air separators. Energy must of course be supplied to drive the conveyors and separators in a closed-circuit system, but despite this, the reduction in total energy requirement over open circuit grinding often reaches 25%.

Crushers:

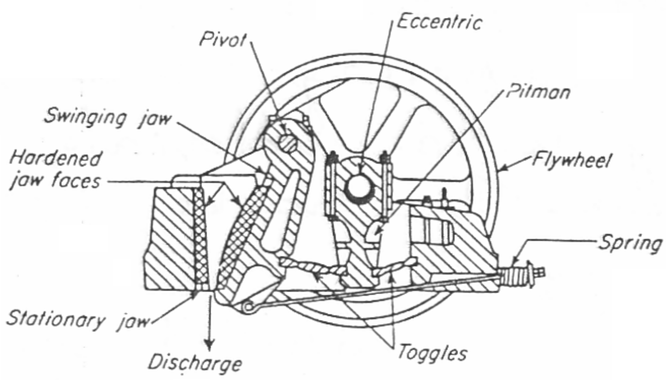
Crushers are slow speed machines for coarse reduction of large quantities of solids. The main types are JAW crushers and Gyratory crushers. These crushers operate by compressing and break large lumps of very hard materials. These are used to break the rocks and ores.

Jaw Crushers:

In a Jaw Crushers feed is admitted between the jaws set to form a ‘V’ open at the top. One jaw is fixed it is nearly vertical and does not move. This jaw is called fixed jaw. The other jaw is the swinging Jaw and this jaw reciprocates in a horizontal plane. The swinging jaw makes an angle of 20 to 30^{o} with anvil jaw. It is driven by an eccentric so that it applies great compressive force to lumps caught between the jaws. The jaw faces are flat or slightly bulged. They may carry shallow horizontal grooves. Large lumps caught between the upper parts of the jaws are broken, dropped into the narrow space below, and are recrushed the next time the jaw closes. After sufficient reduction they drop out the bottom of the machine. The jaws open and close 250 to 400 times/ min. They are 2 types of Jaw Crushers.

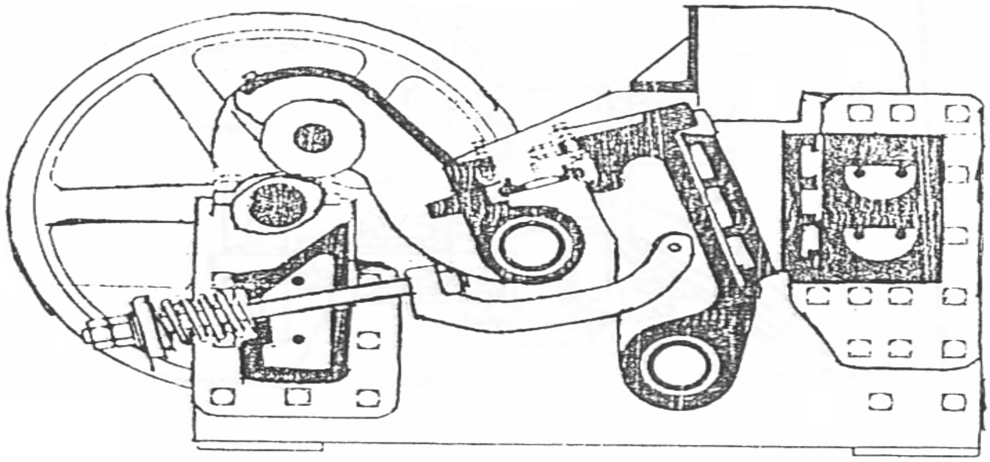
1. Blake Jaw Crushers:

The most common type of jaw crusher is Blake jaw crusher. In this machine an eccentric drives of a pitman connected to 2 toggles, one of which is pinned to the frame and the other to the swinging jaw. The pivot point is at the top of the moveable jaw. The greatest amount of motion is at the bottom of the V, which means that there is a little tendency for a crusher of this kind to choke.



The crushing faces are formed either of manganese steel or of chilled cast iron. The risk of breakage is reduced by grinding the back surface flat or packing with lead. The machine is usually protected so that it is not damaged if lumps of metal in advertently enter, by making one of the toggle plates in the driving mechanism relatively weak so that if any large stresses are setup, this is the first part to fail. Easy renewal of the damaged part is then possible.

Dodge Jaw Crusher:



Dodge crusher

In this type the moving jaw is pivoted at the bottom. The minimum movement is thus at the bottom and a more uniform product is obtained, but the crusher is less widely used because of its tendency to choke. The large opening at the top enables it to take very large feed and to effect a large size reduction. This crusher is usually made in smaller sizes than the Blake Jaw Crusher, because of the high fluctuating stresses that are provided in the members of the machine.

Gyratory Crusher:

This type may be looked upon as a Jaw crusher. Jaw crusher with circular Jaws, and materials is being crushed at all times. A conical crushing head Gyrates inside a funnel shaped casing, open at the top. The crushing head is carried on a heavy shaft pivoted at the top of the machine. An eccentric drives the bottom end of the shaft. At any point on the periphery of the casing, therefore the bottom of the crushing head moves towards and then away from the stationary walls. Solids caught in the 'V' shaped space between the head and casing are broken and re broken until they pass out the bottom. The crushing head is free to rotate on the shaft and turns slowly because of friction with the material being crushed.

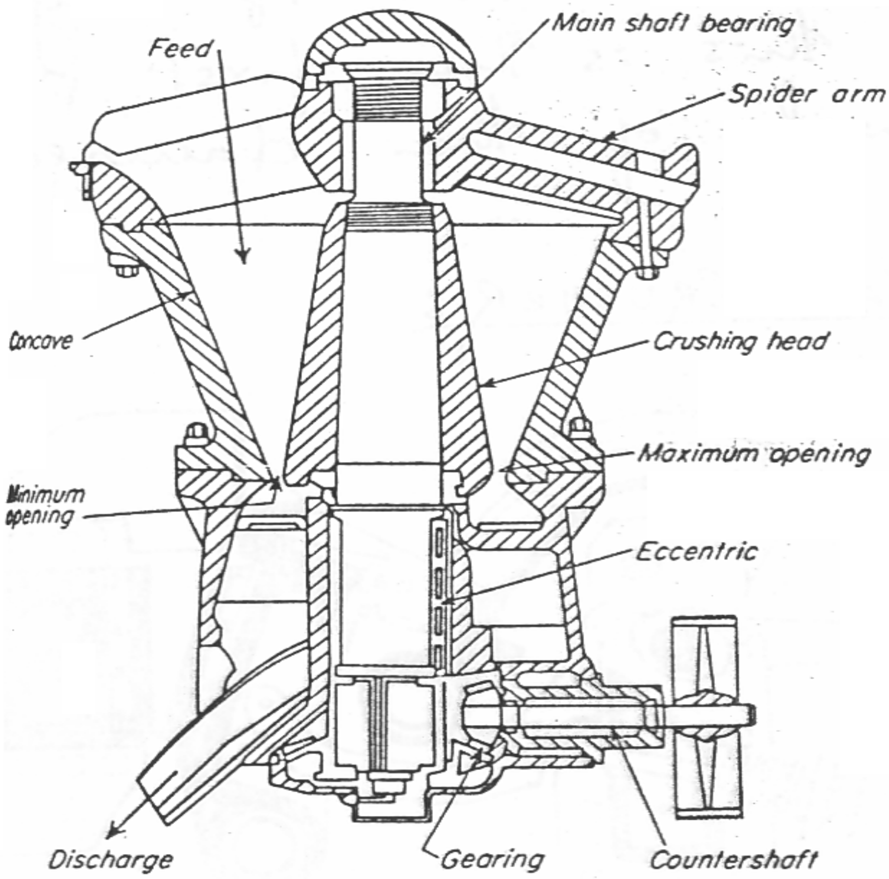
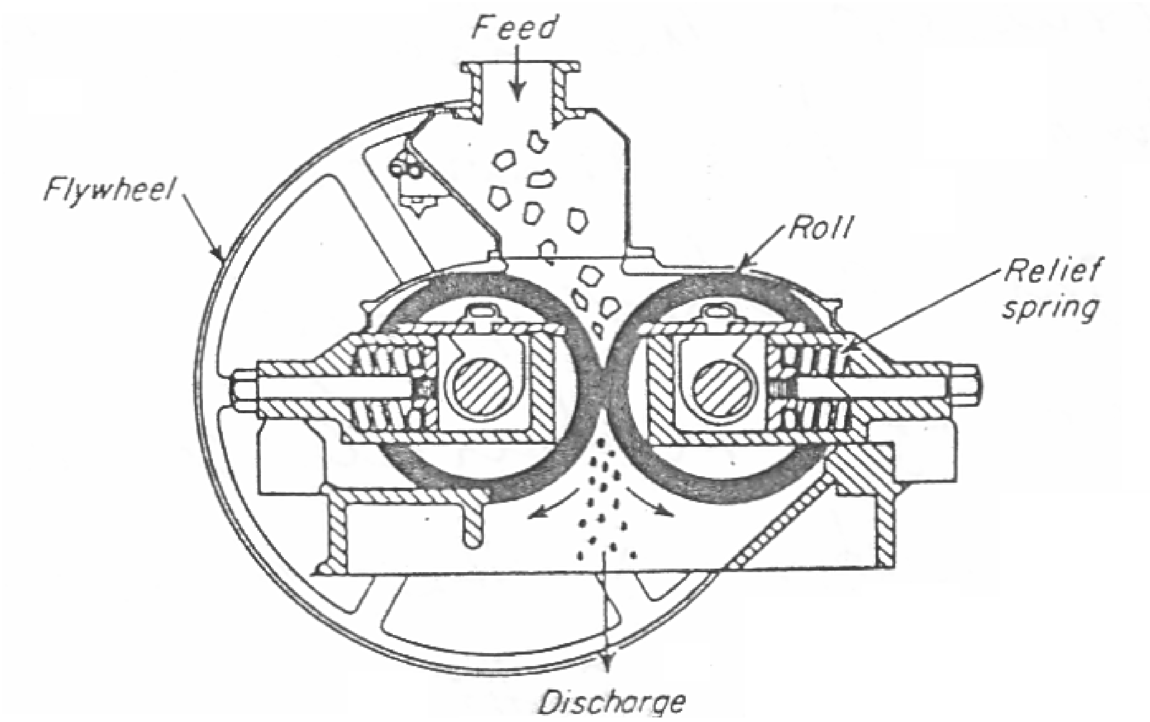


FIGURE 29.3
Gyratory crusher.

The discharge from a Gyratory crusher is continuous instead of intermittent as in a Jaw crusher. The load on the motor is nearly uniform, less maintenance is required than the jaw crusher, and the power required per ton of material crushed is smaller. The capacity of the gyratory crusher varies with the jaw setting, the impact strength of the feed, and the speed of Gyration of the machine. The capacity is almost independent of the compressive strength of the material being crushed. This has a large capacity per unit area of grinding surface. This will not take such large feed as a jaw crusher with the same through put but it will give a rather finer and more uniform product. Because the capital cost is high, the crusher is suitable only where large quantities of material are to be handled.

Smooth Roll Crushers:

Two heavy smooth faced metal rolls turning m parallel horizontal axis are the working elements of smooth roll crusher.



Particles of feed caught between the rolls are broken in compression and drop out below. The rolls turn toward each other at the same speed. They have relatively narrow faces and are large in diameter so that they can 'nip' moderately large lumps. Roll speeds range from 50 – 300 rpm. Smooth roll crushers are secondary crushers with feeds 12 to 75 mm (1/2 to 3 in) in size and products 12 mm (1/2 in) to about 1 mm. (The limiting size D_p max of the particle that can be nipped by the rolls depends on the co-efficient of friction between the particle and the roll surface, but in most cases it can be estimated by using, $D_{p\,max} = 0.04\ R + d$.

R – Roll radius, d = ½ the width of the gap between the rolls.

Note:

$\cos\alpha = \dfrac{r + d}{r + R}$ can also be used

Where α - ½ the Angle of nip

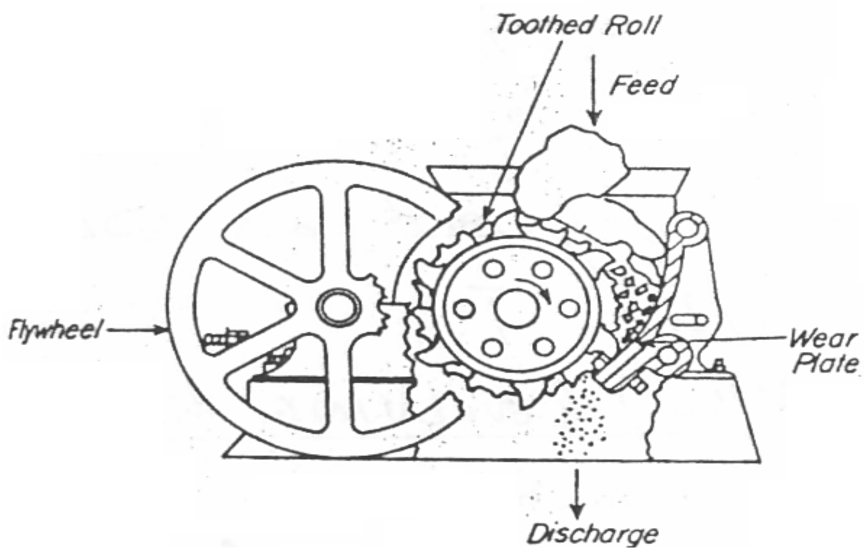
r – Roll radius

R – Particle radius

The maximum size of the product is approximately equal to 2d.

The particle size of the product depends on the spacing between the rolls, as does the capacity of a given machines. Smooth roll crushers give few fines of virtually no oversize. They opera more effectively when set to give a reduction ratio of 3 or 4 to 1 i.e., the maximum particle diameter of the product is one-third or one fourth that of the feed. To allow unbreakable material to pass through without damaging the machine, at least one-roll must be spring mounted. Roll crushers are suitable for effecting only for small size reduction in a single operation and it is therefore common to employ a number of pairs of rolls, one above the other.

Toothed Roll Crusher:

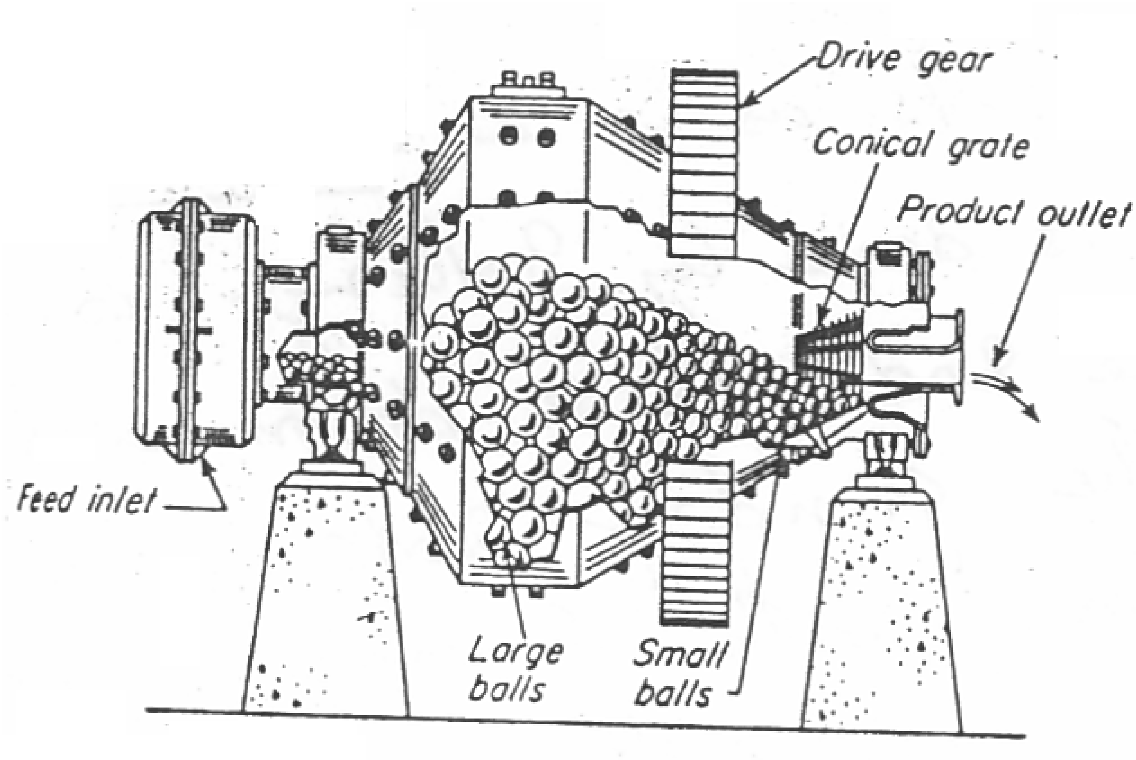


In many roll crushers, the roll faces carry corrugator, beaker bars or teeth. Such crushers may contain two rolls, as in smooth roll crushers, or only one roll working against a stationary breaker plate. A single roll toothed crusher is shown in fig. Many disintegrators contain 2 corrugated rolls turning at different speeds which tear the feed apart or a small high speed roll with transverse breaker bars on its face turning towards a large speed smooth roll.

Some crushing rolls for coarse feed carry heavy pyramidal teeth. Other designs utilize a large number of thin-toothed disks that saw through slabs or sheets material. Toothed roll crushers are much more versatile than smooth roll crushers, within the limitation that they cannot handle very hard solids. They operate by compression impact and not by compression alone as do smooth roll machines. They are not limited by the problem of nip inherent with smooth rolls and can therefore reduce much larger particles. Some heavy duty toothed double roll crushers are used for the primary reduction of coal and similar materials. The particle size of the feed to these machines may be as great as 500 mm (20 in); capacity = 500 tons/ hr. T.

Ball Mill (Tumbling Mill) Revolving Mill:

A cylindrical shell slowly turning about a horizontal axis and filled to about half its volume with a solid grinding medium forms a tumbling mill. The shell is usually steel, lined with high-carbon steel plate, porcelain, silica rock or rubber. The grinding medium is metal rods is a rod mill, lengths of chain or balls of metal, rubber or wood in a ball mill, flint pebbles or porcelain or zircon spheres in a peddle mill. For intermediate and fine reductions of abrasive materials tumbling mills are un equaled.



Tumbling mills may be continuous or Batch. In a Batch machine a measured quantity of the solid to be ground is loaded into the mill through an opening in the shell. The opening is then closed and the mill turned on for several hours it is then stopped and the product is discharged. In a continuous mill the solid flows steadily through the revolving shell, entering at one end through a hollow trunnion and leaving at the other end through the trunnion or through peripheral openings in the shell.

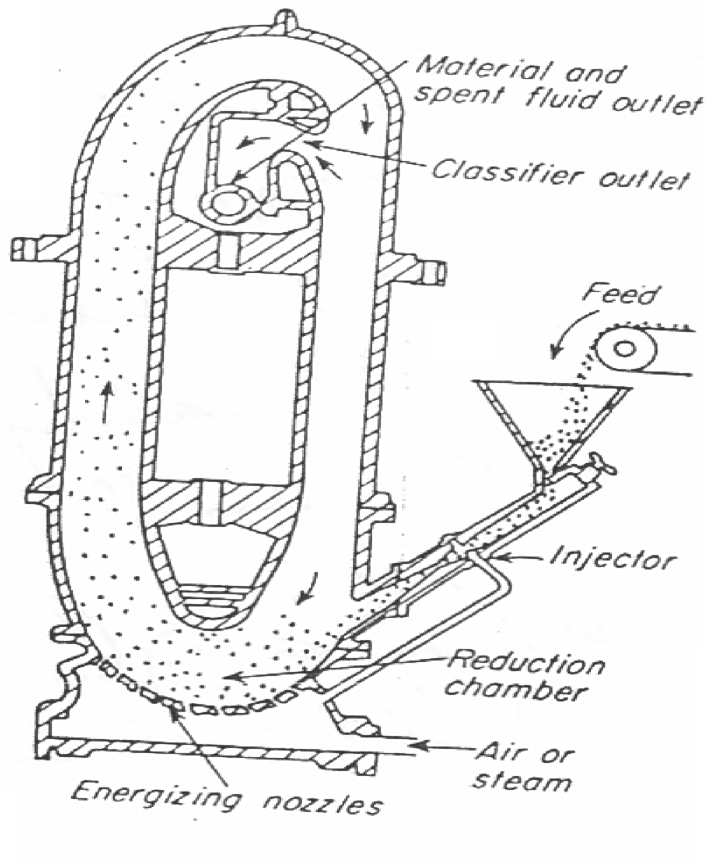
In all tumbling mills, the grinding elements are carried up the side of the shell nearly to the top from whence they fall on the particles underneath. The energy expended in lifting the grinding units is utilized in reducing the size of the particles. In some tumbling mills as in a rod mill. Much of the reduction is done by rolling compression and by attrition as the rods slide downward and roll over one another. The grinding rods are usually steel, 25 – 125 mm id dia. With several sizes present at all times in any given mill. The rods extend the full length of the mill. Rod mills are intermediate grinders, reducing a 20 mm feed to perhaps 10 mesh, often preparing the product from a crusher for final reduction in a Ball mill. They yield a product with little oversize and a minimum of fines.

In a Ball Mill or pebble mill most of the reduction is done by impact as the balls or pebbles drop from near the top of the shell. In a large ball mill the shell might be 3 m in dia. and 4.25 m long. The balls are 25- 125 mm in dia. The pebbles in a pebble mill are 50 – 175 mm in size. A tube mill is a continuous mill with a long cylindrical shell, in which material is ground for 2 to 5 times as long as in the shorter ball mill. Tube mills are excellent for grinding to very fine powders in a single pass where the amount of energy consumed is not of primary importance. Putting slotted transverse partition in a tube mill connects it into a compartment mill. One compartment may contain large balls, another small ball, and a third pebbles. Thus segregation of the grinding media into elements of different size and weight aids considerably in avoiding wasted work, for the large heavy balls break only the large particles, without interference by the fines. The small, light balls fall only on small particles, not on large lamps they cannot break.

Segregation of the grinding units in a single chamber is a characteristic of the Conical Ball Mill. Feed enters from the left through a 60° cone into the primary grinding zone, where the diameter of the shell is a maximum. Product leaves through the 30° cone to the right. A mill of this kind contains balls of deficient sizes, all of which wear and become smaller as the mill is operated. Now large balls are added periodically. As the shell of such a mill rotates, the large balls move toward the point of maximum dia. and the small balls migrate toward the discharge. The initial breaking of the feed particles, therefore, is done by the largest balls dropping the greatest distance; small particles are ground by small balls dropping a much smaller distance. The amount of energy expended is suited to the difficulty of the breaking operation, increasing the efficiency of the mill.

Fluid Energy Mills:

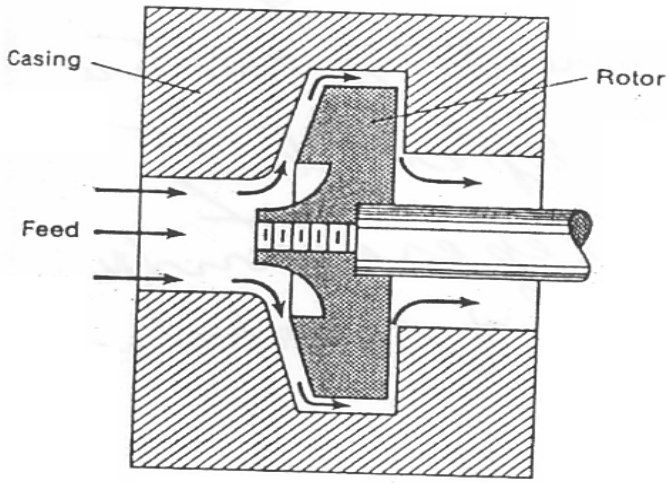
In these mills the particles are suspended in a high velocity gas stream. In some designs the gas flows in a circular or elliptical path; in others there are jets that oppose one another or vigorously agitate a fluidized bed. Some reduction occurs when the particles strike or rub against the walls of the confining chamber, but most of the reduction is believed to be caused by inter particle attrition. Internal classification keeps the larger particles in the mill until they are reduced to the desired size.



The suspending gas is usually compressed air of superheated steam, admitted at a pressure of 7 atm., through energizing nozzles. In the fig. shown, the grinding chamber is an oval loop of pipe 25 to 200 mm in dia. and 1.2 – 2.4 m high. Feed enters near the bottom of the loop through a venturi injector. Classification of the ground particles takes place at the upper bend of the loop. As the gas stream flows around this bend at high speed, the coarser particles are thrown outward against the outer wall while the fines congregate at the inner wall. A discharge opening in the inner wall at this point leads to a cyclone separator and a bag collector for the product. The classification is aided by the complex pattern of swirl generated in the gas stream at the bed in the loop of pipe. Fluid energy mills can accept feed particles as large as 12 mm but are more effective when the feed particles are no larger than 100 mesh. They reduce upto 1 ton/hr of non-sticky solid to particles averaging ½ - 10 μm in diameter, using 1 to 4 kg if steam or 6 to 9 kg of air per kilogram of product. Loop mills can process upto 6000 kg/hr.

Colloid Mills:

In this, intense fluid shear in a high-velocity stream is used to disperse particles or liquid droplets to form a stable suspension or emulsion. The final size of the particles or droplets is usually less than 5 μm. Often there is little actual size reduction in the mill; the principal action is the disruption of lightly bonded clusters or agglomerates. Syrups, mills, purees, ointments, paints and greases are typical products processed in this way. Chemical additives are often useful for stabilizing the dispersion.



In most colloid mills the feed liquid is pumped between closely spaced surfaces one of which is moving relative to the other at speeds of 50 m/ sec or more. In the fig. the liquid passes through the narrow spaces between the disk shaped rotor and the casing. The clearances are adjustable drum to 25 μm. Often cooling is required to remove the heat generated. The capacities of colloid mills are relatively low, ranging from 2 or 3 L/min for small mills upto 440 L/min for the largest units.

Knife Cutters:

A rotary knife cutter contains a horizontal rotor turning at 200 to 900 rpm in a cylindrical chamber. On the rotor are 2 – 12 flying knives with edges of tampered steel or stellite passing with close clearance over 1 – 7 stationary bed knives. Feed particles entering the chamber from above are cut several hundred times per minute and emerge at the bottom through a screen with 5 – 8 mm openings. Sometimes the flying knives are parallel to the bed knives. Sometimes depending on the properties of the feed they cut at an angle. Rotary cutters and granulators are similar in design. Cutters yield cubes, then squats or diamonds.

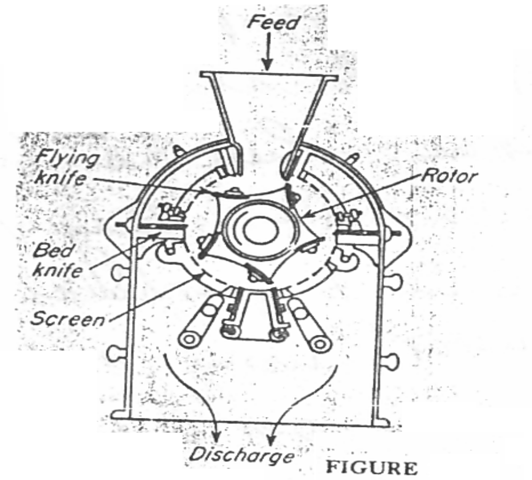


FIGURE
Rotary knife cutter.

CONVEYING OF SOLIDS

The term conveying is usually applied to transportation of solids. Although, in general, materials are handled in the fluid form wherever possible, many cases remain where solid materials must be transported. The choice of equipment for this purpose depends on a large number of factors, the most important of which are capacity necessary, shape and size of material, and whether the material is to be transported horizontally, vertically, or on an inclined plane.

In any case the equipment used is ordinarily designed on the basis of empirical experience rather than by any rational methods of calculation. This is largely because of the inherent variation in the properties of the materials transported and also the very wide range of processes where material handling is involved. Convenient classifications of some of the more important conveyors are

1. Belt conveyors
2. Chain conveyors
    - Scraper conveyors
    - Apron conveyors
    - Bucket conveyors
    - Bucket elevators
3. Screw conveyors
4. Pneumatic conveyors

Belt Conveyors:

The belt conveyor is essentially a very simple piece of equipment. It consists of an endless belt on which the solids are transported. Its component parts are built in a wide variety of forms, and the design and installation of such an apparatus are problems for a specialist. A belt conveyor must contain the following elements; first, the belt itself second, the drive; third, the supports; and, fourth, the lightener. In addition, unless the belt is to be loaded and unloaded by hand (which is done when package goods are being transported), feeding and discharge devices are necessary.

Belt construction:

The commonest form of belt is the rubber belt. It consists of a core, or carcass, of several plies, each impregnated with rubber and bounded together. Over the carcass is a covering of rubber that binds the whole together. The top cover is usually thicker than the underside. Special grades of rubber may be obtained to resist excessively abrasive conditions, temperatures higher than usual (up to 250°F), chemical attack, etc. Safe working stress on such belts runs from 25 to 40 lb./ in. per ply. Special constructions are available for temperatures above 250°F.

Cord belts follow the construction of cord tyres. The cords must be completely imbedded in rubber in forming the carcass. Cotton cord is common; nylon cord may be used for higher strengths. The safe working stress for cord belts may be 50 to 100 Ib. / in. per ply. The strongest (and most expensive) belts use steel wire instead of fabric cords. Such belts may have strengths up to 3000 lb. / in. per ply.

Belt-conveyor drives:

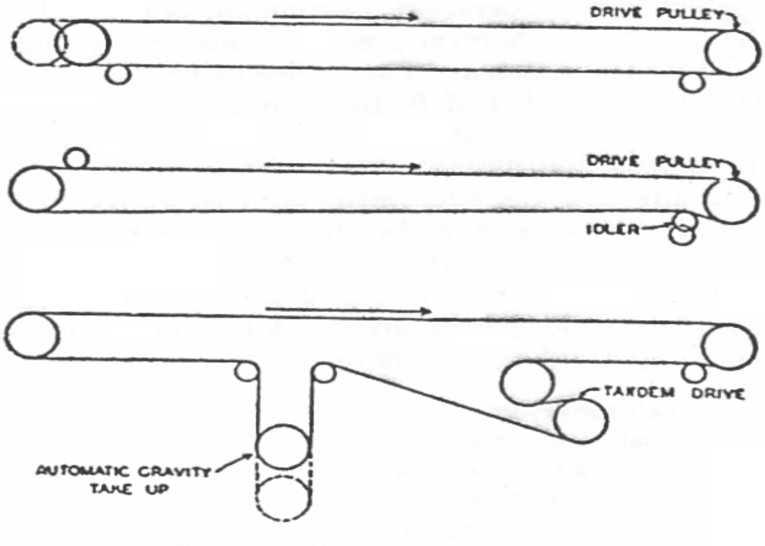


FIG. 16-1. Belt-conveyor drives.

Several methods of driving belt conveyors are shown in fig.16.1. The simplest possible drive is a bare steel pulley actuated by some source of power. This method is satisfactory where the power that must be transmitted is low enough to be carried by the friction of the belt on the pulley. In this type of drive, however, both the area of contact between the belt and the pulley and the coefficient of friction are small. The next step is to utilize pulleys covered with rubber or leather so that the coefficient of friction is increased. With either bare or lagged pulleys, an idler just behind the drive pulley can increase the area of contact from 180 to 220°. Where this does not meet the power requirements, tandem drives, whereby the belt is brought around one pulley and back over a second pulley (both driven), are used. Although the drive of the belt conveyor is ordinarily at the head or discharge end, it can be put at the tail or feed end. This latter arrangement involves a greater stress in the belt for a given power input and is therefore not used unless necessary.

Belt-conveyor supports:

The supports for the belt are rollers on shaft supports and are usually called idlers. They are built in a large variety of forms. The most expensive are carried on roller bearings equipped with pressure-grease-gun lubrication. The cheaper ones are carried on ordinary bushings and lubricated with grease cups. In general, the idlers are troughed so as to allow the belt to be depressed in the center and the edges to be raised. This permits a belt of a given width to carry more material per unit length without spillage. The belt return is ordinarily carried on lighter, non-troughing rolls and is sometimes mounted on the same base as the top idlers. An example of a belt-conveyor idler is shown in fig.

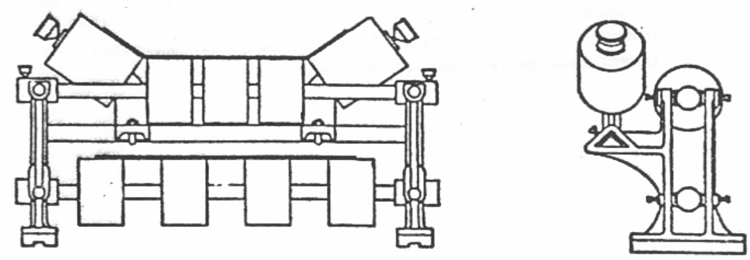


FIG. 16-2. Belt-conveyor idler.

Belt-conveyor take-ups:

For any but the shortest conveyors, changes in load or in weather, especially in temperature and humidity, result in a variation in belt length of sufficient magnitude to give an uneven tension if there is no provision for keeping the belt tight. Accordingly, a lightener or take-up must be installed to maintain an even tension on the belt under all conditions. Figure shows some common take-ups. The simplest take-up consists of a cast-iron bed with a traveling block moving along a screw. The block carries a plain bearing box. In the type shown in fig. (a), split journal box rides on a steel angle frame between two fixed support blocks. In this and similar types, the shaft of either the head or the tail pulley (preferably the latter) is mounted in a pair of these take-ups and the requisite tension applied by turning up the take-up screws by hand.

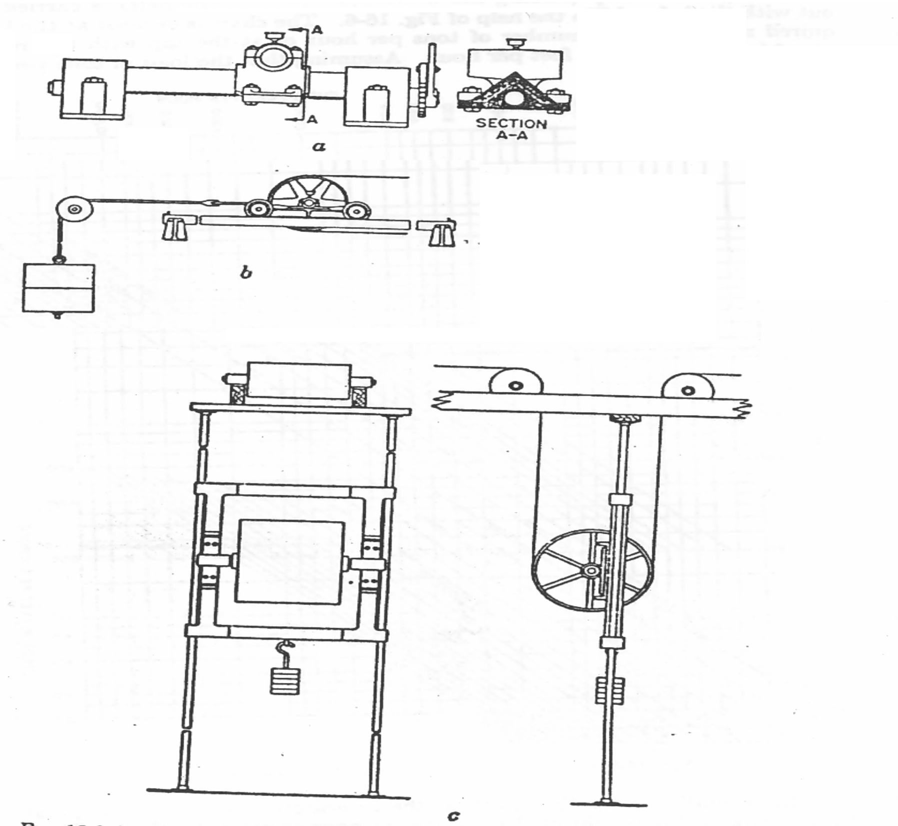


Fig. 16-3. Belt-conveyor take-ups: (a) steel angle frame; (b) horizontal gravity take-up; (c) vertical gravity take-up.

Feeders:

When a hopper is used, the slope of the side should be such that the horizontal component of the velocity of the material as it slides onto the belt is nearly the same as that of the belt itself. More elaborate feeding devices include short belt or apron conveyors discharging onto the main belt conveyor, shaking screens, rotary-drum feeders, reciprocating-plate feeders, and rotary – vane feeders. Diagram of typical examples of belt-conveyor feeders are shown in fig.

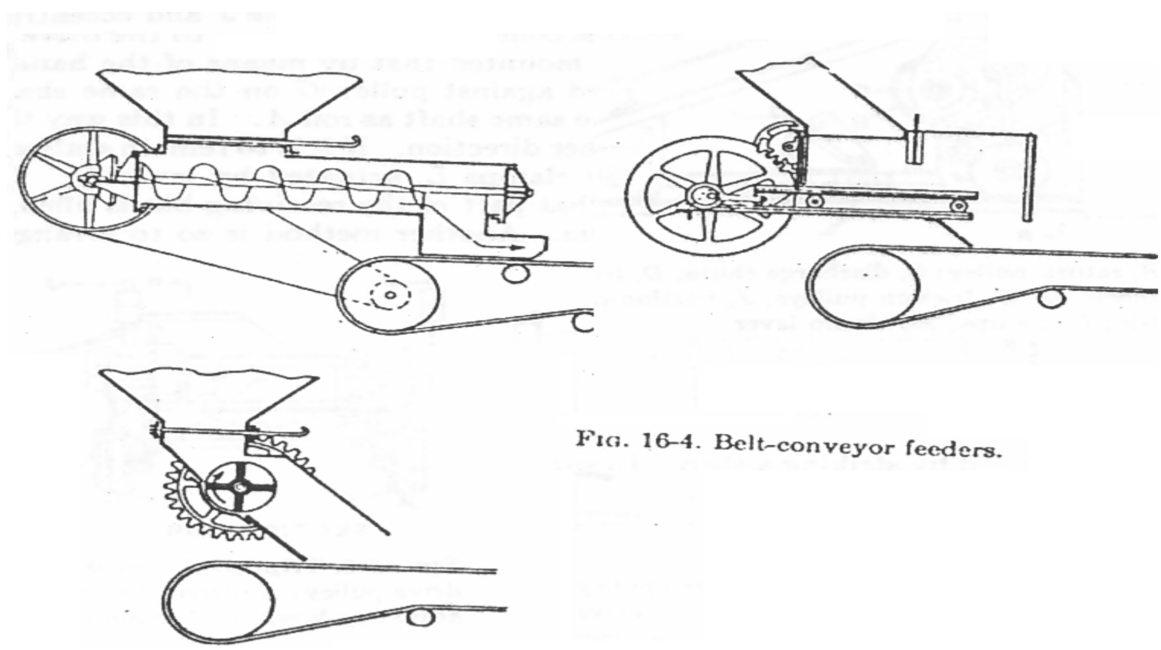


FIG. 16-4. Belt-conveyor feeders.

Discharge methods:

The method used to discharge a belt conveyor depends on whether or not the discharge is from the end of the conveyor or at some intermediate point, and whether or not the discharge is to be at a single point or to cover the entire length of a bin. For end discharge the belt is self-discharging. The belt material simply falls over the end. For discharge at intermediate points, however, some special devices are necessary. These methods may be listed as follows:

1. Scrapers 2. Tipping idlers 3. Trippers 4. Shuttle conveyors.

A scraper, as its name implies, is a plank or a strip of metal laid diagonally across a belt and diverting the material to one side. The tipping idler takes the place of one of the regular carriers but has its axis on an angle so that the material slides off the belt to one side as the belt passes over the tipping idler. This method is often very unsatisfactory, since a considerable section of belt must be tipped and the material is discharged over a considerable length of the belt rather than at a definite point.

A tripper consists essentially of two pulleys A and B in a frame. The pulleys are so mounted that the belt is doubled back for a shorted distance. The material coming to the tripper on the belt is dropped over the end of the belt as it is turned back, is caught in a chute, and diverted to one side or both sides. Trippers may be stationary, self-propelling, or hand-propelled, and the movable trippers allow the belt to be discharged at any point in its travel. Tracks must be provided along the side of the belt on which the tripper can run.

A shuttle conveyor is a short, movable conveyor, usually traveling at right angles to the main conveyor. The whole shuttle conveyor travels back and forth over the bin to be filled, automatically reversing the direction of the belt as the movement of the conveyor is reversed.

Belt-conveyor design-width and speed of Belt:

The complete design of large belt-conveyor installations should be undertaken only by one experienced in this field. This is because a belt conveyor is an expensive installation. Consequently, it should be engineered rather carefully. It is possible, however, to give simple rules by which the average engineer can get an approximate idea of his requirements for estimating purposes.

The capacity of a belt conveyor is determined by two factors: first, the cross section of the load, and, second, the speed of the belt. The cross section of the load is, in turn, determined by three factors: the width of the belt, the shape of the belt (i.e., whether it is flat or troughed), and the size of the material for relatively fine material the load will assume a fairly uniform cross section if properly fed.

Every manufacture of belt-conveyor equipment publishes approximate charts of formulas for the estimation of conveyor sizes and power requirements. Sometimes the width of the belt is determined by the size of the largest pieces rather than the actual weight of the average cross section of the load.

In general, belt conveyors should not be run at speeds much less than 200 fpm. The first cost of the whole conveyor is nearly the same no matter what its operating speed may be. At low speeds the weight of material conveyed per hour is too small to justify the expense. A narrower belt at higher speed will handle the same load at a lower first cost. On the other hand, speeds much over 500 fpm should be avoided, since they cause undue wear on the belt. Also at these higher speeds, fine material is expected to be blown off the belt.

Power requirements:

The power consumed by a belt conveyor may be divided into several items: (1) power necessary to move the load (2). Power necessary to move the belt itself (3) power necessary to overcome friction in the idlers (4) power necessary to operate trippers, and (5) power necessary to elevate material (in the case of inclined conveyors). The complete formulation of all these factors is somewhat complicated, especially since the various friction factors are not well known and the weight of the belt itself has not been determined at this stage of the design. The formulas given in the various manufactures catalogues involve considerable simplification. A graphic solution is normally done.

Width of belt, inch	**Horsepower for one tripper**	
	Plain bearings	**Roller bearings**
12	0.75	0.50
14	1.00	0.50
16	1.00	0.75
18	1.50	1.25

20	1.50	1.25
24	1.75	1.25
30	2.50	1.75
36	3.00	2.50
42	4.00	3.00
48	5.00	3.25
54	6.00	5.00
60	7.00	6.00

Weight of belt:

It is not sufficient to know the width of the belt, but its thickness must also be determined. This thickness depends on the maximum safe working stress that may be assumed for each ply of fabric per inch of width.

In order the drive the conveyor at all, a certain initial tension must be placed on the belt in order to prevent its slipping on the pulleys. When the conveyor is loaded, the conveying run is under a stress composed of (a) the initial tension, and (b) the tension equivalent to the power consumed. In order to calculate the tension in the conveying run it is necessary to know the initial tension, and this in turn is a function of the type of drive. With simpler drives a higher initial tension is needed to prevent slipping.

Table: Satisfactory Belt thickness:

Belt width	**Number of plies**
12''	3 – 4
18	3 – 5
24	4 – 7
30	5 – 8
36	6 – 9
42	6 – 10
48	7 – 12

The methods explained give approximate solutions and are for estimating purposes only. It should not be assumed that when these calculations have been completed the belt conveyor has been designed. There are many other factors that must be taken into consideration before a complete installation can be built. Errors or mistakes in the design of belt conveyors are not equally serious. Some cause excessive wear on the belt, some can be remedied after the conveyor is in service. The one error that cannot be remedied is to make the belt too narrow for the size of the material or the total capacity handled.

Chain conveyors-scraper or flight conveyors:

The scraper conveyor is the simplest and cheapest type of conveyor. Its advantages are its low first cost, its adaptability to a wide variety of conditions, its suitability for steeper inclines than the belt conveyor, and its ability to handle large pieces. The disadvantages of the scraper conveyor are its relatively heavy power requirement and heavy repair charges if the service is continuous. These conditions contrast sharply with the belt conveyer, which in particular may be characterized in just the opposite terms. Consequently, **where the load is heavy, the distance long, and first cost unimportant in comparison to power consumption and repairs, the belt conveyor is used. When the distance is short, the load light or intermittent, the first cost important, and power consumption relatively unimportant, the scraper conveyor is used.**

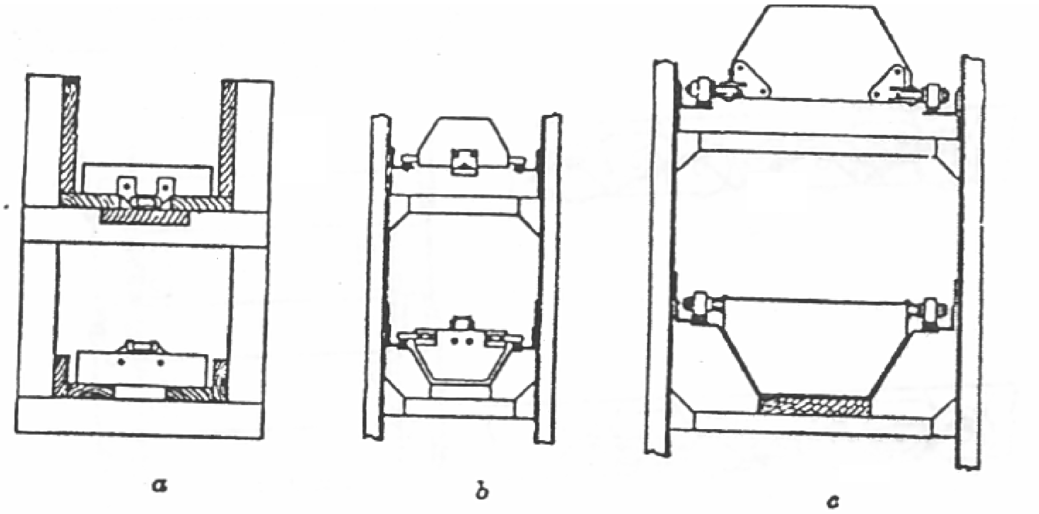


FIG. 16-11. Flight conveyors: (*a*) malleable chain, wood flights; (*b*) steel flights with wearing bars; (*c*) double roller chains, steel flights.

The simplest possible conveyor is one such as shown in fig.a. A malleable detachable chain has blocks of wood fastened to these attachments to act as scrapers. The conveyor runs in a wooden trough. In fig. a the upper run is the conveyor and the lower run is the return. Such a conveyor might be used for sawdust, chips, or any other light material that would not be injured by having the chain running in the material conveyed. The lower run might have a solid bottom and be used for conveying if it were desirable to keep the chain out of the material handled. In this case the top run would be the return.

More elaborate constructions employ steel frames and wearing bars for the flights, as shown in fig.b. However the same chain and the same attachments are used, but the flights are of sheet, steel, the trough is of sheet steel, and the frame is built of angle iron. Wearing bars are riveted to the corners of the flights so that the flight itself does not bear on the trough. A still more elaborate form, using roller pintle chain, is shown in fig.c. Since this is a double-chain conveyor, it will handle heavier loads for the same weight of chain.

Design of scraper conveyors:

The capacity of scraper conveyors on material weighing about 50 lb./ cu. ft. and operating on a level is as follows:

Size of flights, in	**Weight per flight, lb.**
4×10	15

4 × 12	19
5 × 12	23
5 × 15	31
6 × 18	40
8 × 18	60
8 × 20	70
8 × 24	90
10 × 24	115

On other materials the capacity will be proportional to the weight per cubic foot. The speed of scraper conveyors is usually about 100 fpm. A conveyor running up an incline has the following percentage capacity of that of a corresponding horizontal conveyor:

Incline, degree	**Capacity, per cent of Horizontal**
20	77
30	55
40	33

Apron conveyors:

Apron conveyors are used for the widest variety of purposes but usually for heavy loads and short runs. They range from forms that can be improvised for simple cases up to elaborate and expensive conveyors that would be purchased from manufactures who specialize in this field.

The simplest apron conveyor (fig .a) consists of two chains made up entirely of malleable detachable links carrying A attachments. Wooden bars are fastened to these attachments between the chains, and the whole conveyor drags on the support. This forms a practically continuous moving platform. For heavier loads or longer runs, malleable chains consisting alternately of A links and D links might be used with rollers on the D links (fig. b). The next step would be roller pintle chain with A attachments. For still heavier work or rougher usage, steel plates might be used instead of the wooden bars. In the simplest cases, these plates may be used instead of the wooden bars. In the simplest cases, these plates may be flat, but, where the conveyor is to be used for loose solids rather than packages, the plates may overlap and be stamped to the proper radius so that they will cover each other as the chain goes over the sprockets (c). More elaborate types involve the use of long-pitch straight side chains that carry steel with a depression stamped in each (d). This style of conveyor, when carried to the extreme case, becomes practically a series of horizontal buckets (e). In these latter styles, the inner side bar of the chain is developed to a considerable height to form the side of the conveyor, and this makes possible larger capacities.

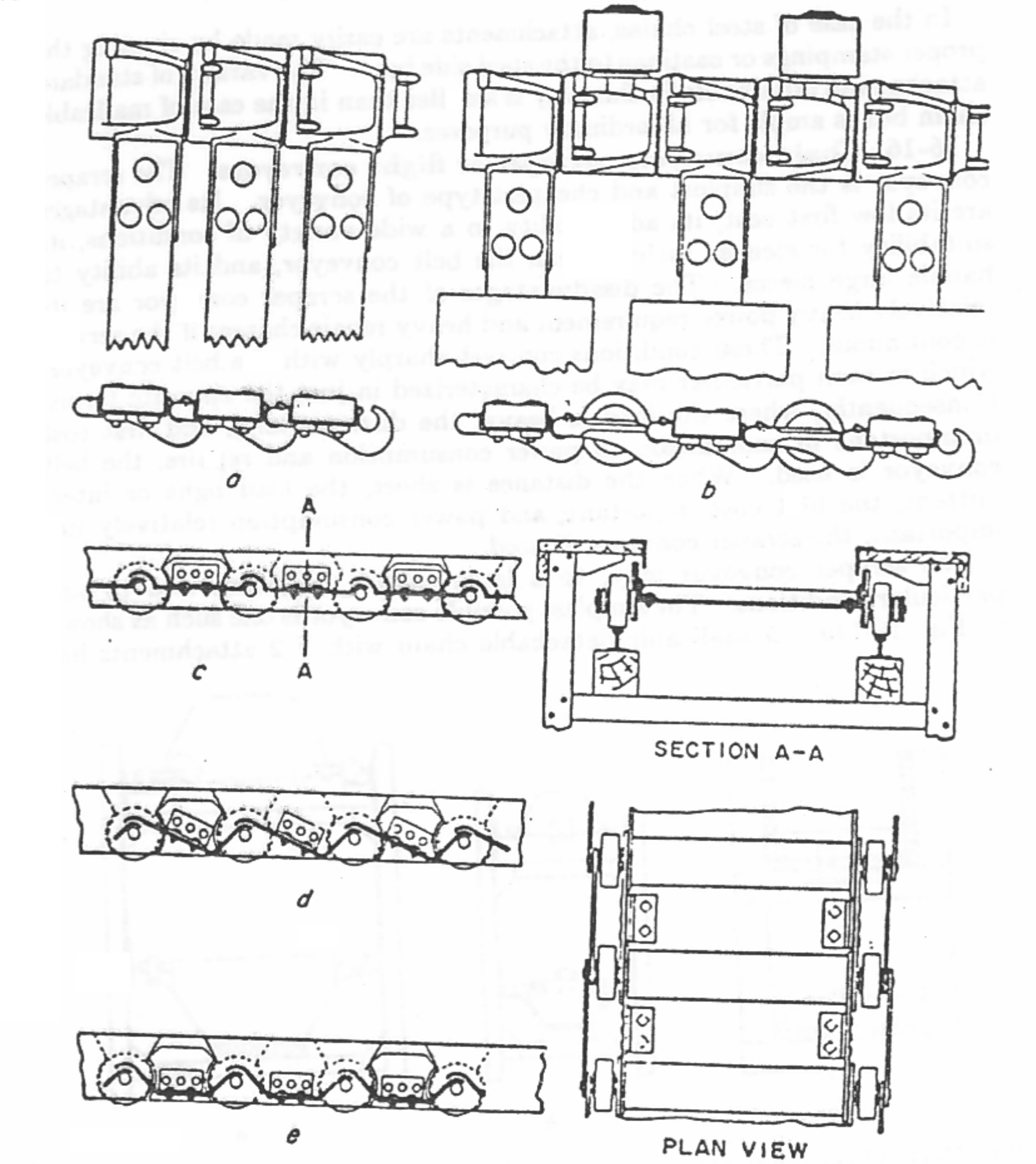


FIG. 16-12. Apron conveyors: (a) malleable detachable chain with A attachments, chain dragging; (b) malleable detachable chain with alternate A and D attachments, chain on rollers; (c) overlapping flat steel plates riveted to long-pitch straight-side roller chain; (d) overlapping stamped plates; (e) recessed plates.

Bucket conveyors:

The deep apron conveyors, as has been said, develop gradually into a type known as bucket conveyors. The simpler bucket conveyors consist merely of deep steel stampings with over lapping edges carried on log-pitch straight-side steel chain. If the buckets are sufficiently deep, there is no distinction in construction between the horizontal conveyor and a sharply inclined bucket elevator. Very elaborate forms of bucket conveyors are used for handling coal in power houses and other places where the most expensive type of conveyor is justified. In this case, cast-iron or stamped-steel buckets are pivoted between two long-pitch straight-side steel chains. They are so constructed that on the horizontal runs the buckets overlap each other, and the feed to such a conveyor may therefore be a continuous stream of material. The buckets are so pivoted that on the vertical runs they hang freely between chains, and the conveyor acts as an elevator. A tripper may be located at any point in the horizontal run to discharge the buckets by inverting them over any desired portion of the bin. Such conveyors are often arranged so that they receive coal near the end of the bottom run, elevate it to the coal bunkers, discharge it at any point in the run over the bunkers, and handle ashes on the bottom run. They are elaborate and expensive installations.

Elevators: A belt, scraper, or apron conveyor may be used to lift material as well as convey it, provided that the lift is short in comparison with the horizontal run, so that the angle of the conveyor to the horizontal is not great. Belt conveyors are seldom run at angles greater than 15 to $20^{o,}$ and scraper conveyors seldom over 30^{o}. If the lift must be more abrupt than this, or if a straight vertical lift is necessary, some form of elevator is used. The usual type of elevator consists of a series of buckers carried either on chains or on a belt.

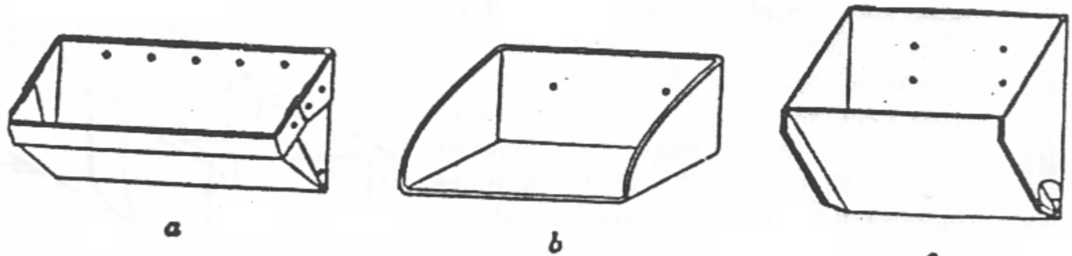


Fig. 16-13. Elevator buckets: (a) Minneapolis type; (b) buckets for wet or sticky materials; (c) stamped-steel bucket for crushed rock.

Buckets may be of many forms, and some types are shown in fig. The Minneapolis-type bucket (a) is almost universally used for grain and any other dry, pulverized material. For materials that tend to be sticky, flatter buckets (b) are used; and for large lumps and heavy material, such as coal or crushed stone, the heavier stamped-steel buckets (fig. c) are employed.

Belt or chain bucket elevators handling light materials may be operated at a speed of 150 to 250 fpm. At this speed the material is usually thrown from the buckets at the top of the elevator so that a spout placed to clear the head sprocket will receive all the discharge. For heavier loads or lower speeds, the so-called perfect discharge may be used. In this design an idler sprocket bends the chain back under the head sprocket so that the buckets turn completely upside down over a spout placed just under the head sprocket. In the case of elevators for heavy materials using overlapping buckets, the buckets are so shaped that the back of one bucket acts clear of the head sprocket at very low speeds.

Elevators may be run without any casing around them. It is more common, however, to enclose the elevator completely; and the casing may be of wood or sheet steel, as conditions may dictate. Occasionally, a separate casing is made around each leg of the elevator, but it is far more common to enclose the whole structure in a single casing.

Screw conveyors-flights:

An important type of conveyor for transporting material in the form of finely divided solids or pasty solids is the screw conveyor. This apparatus consists essentially of a spiral blade revolving around an axis in the bottom of a U-shaped trough.

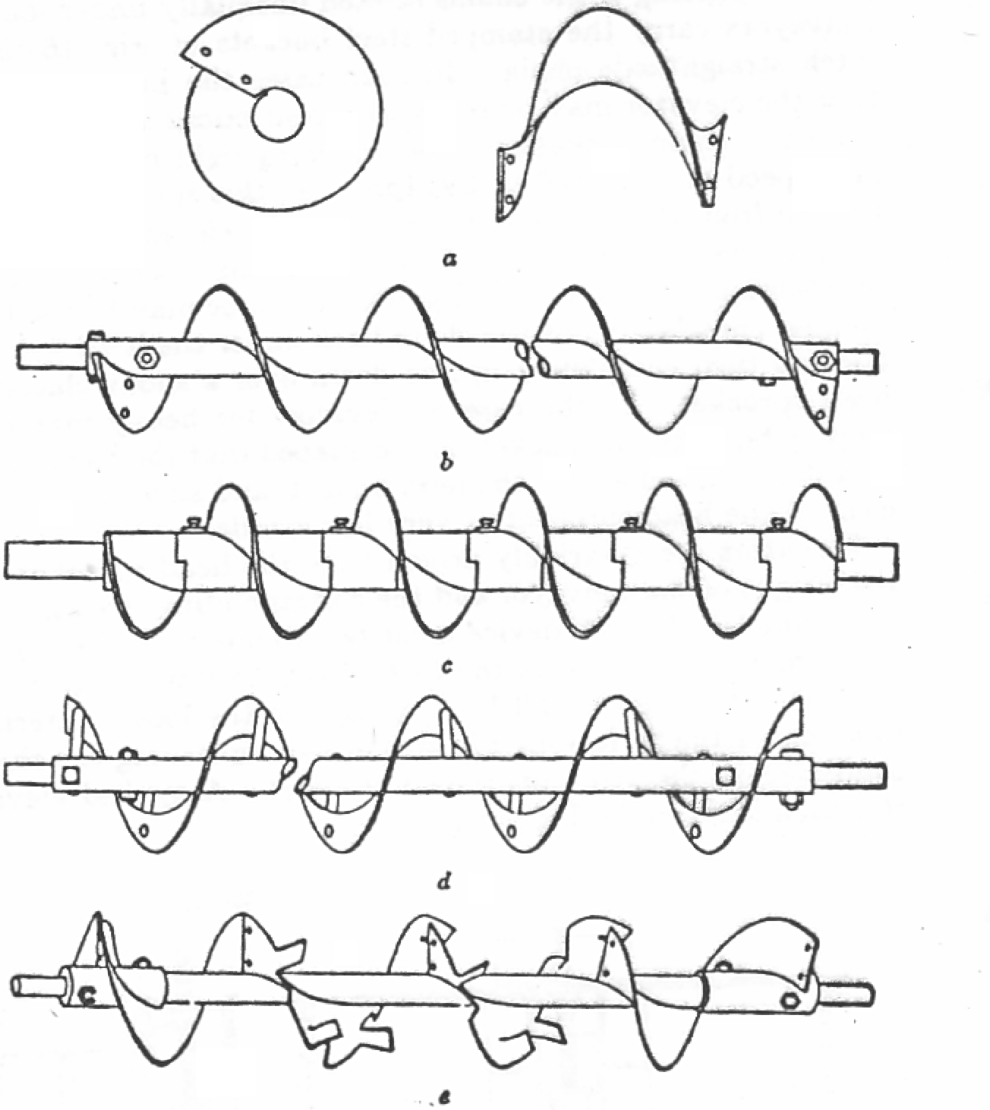


FIG. 16-15. Screw-conveyor flights: (a) sectional; (b) helicoid; (c) cast iron; (d) ribbo (e) cut flights.

The screw element is called a flight and may be sectional, helicoids, ribbon etc. The sectional conveyor is made up of short sections, each of which is stamped as a circular disc, cut along one radius, and then given the proper twist to develop the spiral. Each disc provides for one full turn of the conveyor, and the various turns are riveted together. However (b) is made from a single long ribbon that is twisted and warped into a spiral shape and then welded to the central shaft. The shaft is standardized and is schedule 80 pipe. For service where temperature or abrasion necessitates cast iron, cast-iron flights are assembled on a standard shaft.(fig. c). For sticky materials, ribbon flights (fig. d) are used. For mixing, the flights of (fig. e) are used. These are made by cutting into a standard flight and bending back the part of the helix between the cuts.

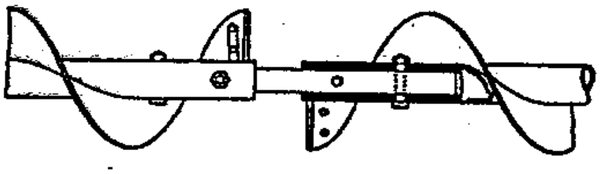
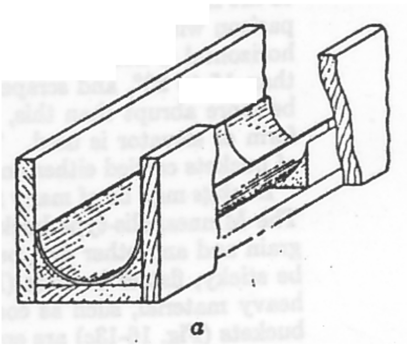


FIG. 16-16. Screw-conveyor coupling.

For the simplest and least expensive type of screw conveyor, when a length of conveyor is purchased, it is supplied with it one simple hanger, one coupling for joining of spiral, and a half-round linear. The standard coupling consists of a short section of solid shaft fitting into the hollow conveyor shaft (fig.). Then conveyor pipe is reinforced at the ends, and a part of the coupling shaft acts as the journal. For more expensive and more elaborate conveyors there are available better-grade hangers, various types of spiral, different constructions of trough, more elaborate and more expensive bearings, and many other accessories.

Screw-conveyor troughs:

The trough is ordinarily made of sheet steel. Standard sections come in lengths of 8.10, and 23 ft. In the simplest type (16.17 a), only the half-round section at the bottom of the trough is made of steel and the straight sides are formed by the wooden trough in which the conveyor is installed. The steel linear for this type of trough is regularly supplied with each length of conveyor flight. Figure 16.17.b shows a more elaborate trough in all-steel construction.



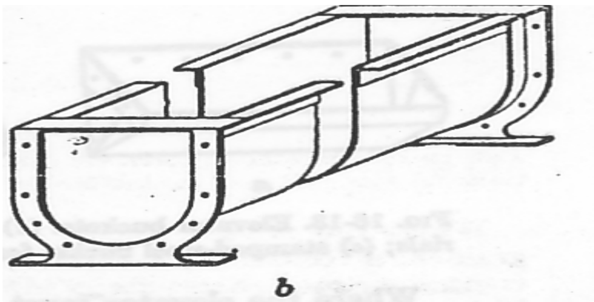
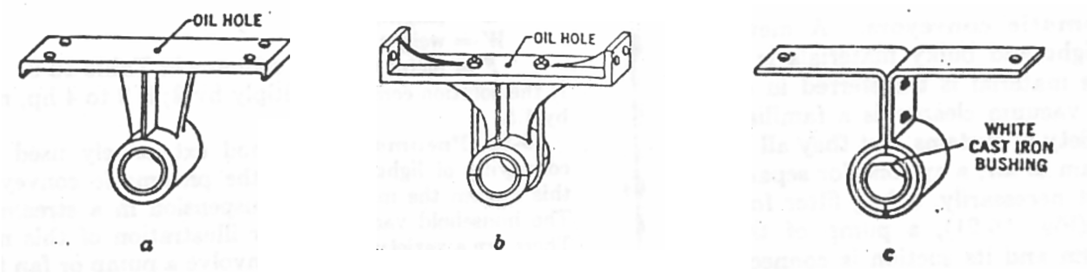


FIG. 16-17. Screw-conveyor troughs: (a) wood trough with steel liner; (b) all-steel trough.

It is necessary that the shaft be suspended in suitable bearings in order to be kept in alignment. Two of the bearings are carried in the end plates of the conveyor, but hangers must also be provided along the length of the trough. Ordinarily there is a hanger for each section. Figure 16.18 shows a few types of hangers. Figure 16.18 a is one of the simplest and cheapest forms. Figure 16.18 b has a spilt bearing and fits inside a steel trough. More elaborate forms have adjustable bearings and better lubrication. Since the material that is being transferred through the conveyor is in contact with the bearings of the hanger, often oil or grease is objectionable because of contamination, and wood bushings soaked with oil or bushings made of white cast-iron (fig. c) run without lubricant are used.



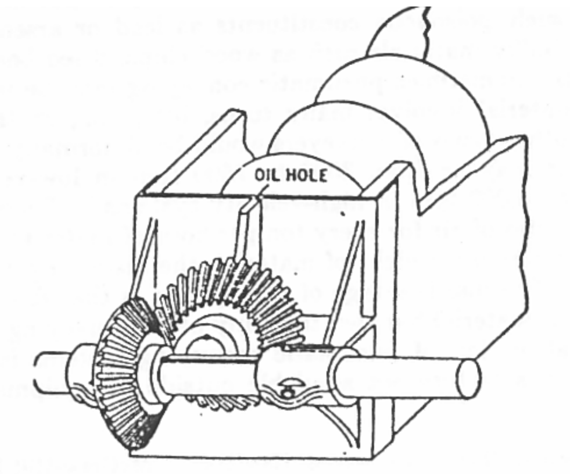


FIG. 16-19. Screw-conveyor box end—drive end.

The types of construction used in the ends of the conveyors or box ends also exhibit a great variety. In general, the drive end (fig.16.19) is different in construction from the discharge end, in order to bring the shaft through and connect it to the drive which is usually by bevel gears. As in all other types of conveyors, the selection of suitable parts is determined by the expense that is justified by the scale of operation, severity of services, value of the material, and other peculiarities of the problem at hand.

Pneumatic conveyors:

A method extensively used for the conveying of light and bulky materials is the pneumatic conveyor. In this system the material is transferred in suspension in a stream of air. The household vacuum cleaner is a familiar illustration of this method. There are a variety of systems. But they all involve a pump or fan for producing the stream of air, a cyclone for separating the particles, and usually, but not necessarily, a bag filter for removing the dust. In the simplest from, a pump of the cycloid type produces a moderate vacuum and its suction is connected to the conveying system. The material is sucked up through a nozzle which may be fixed or movable (usually the latter). The stream of air with the solid in suspension goes to a cyclone separator, and then to the pump. Where the material carries dust that would injure the pump, that would be harmful if discharged into the air , or that is the desired product, a bag filter is placed between the separator and the pump.

This system of conveying is primarily indicated for materials that must be kept as clean as possible, such as grain; and also to protect from such poisonous constituents as lead or arsenic. It is also suitable for bulky materials such as wood chips, dried beet pulp, and similar materials. Sometimes pneumatic conveying may be used where the path of the material involves many turns, lifts,

etc., so that the installation costs of other types of conveyers would be abnormally high. The velocity of the air may be from 3000 to 7500 fpm in low-velocity systems and 10,000 to 20,000 fpm in high-velocity systems. There will be used from 50 to 200 cfm of air for every ton per hour of material handled depending on the nature and weight of material, the distance conveyed, the vertical lift, etc. The disadvantage of this system is that it requires more power per unit of material handled than any other conveying system.

The calculation of pneumatic conveying systems is entirely empirical and involves factors not available outside of equipment manufactures files.

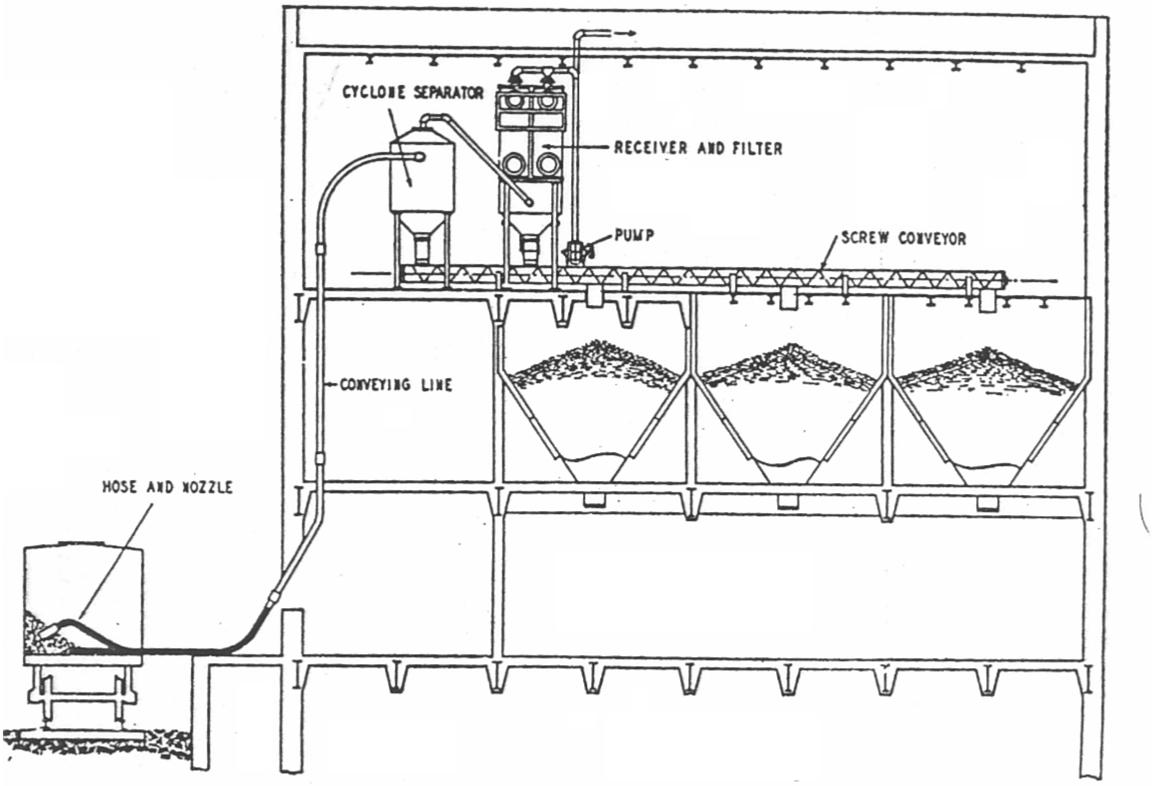


FIG. 16-21. Pneumatic conveying system and auxiliary equipment.

General Field of conveyors:

Several statements as to the use of particular conveyors have been made above from time to time, but table 16.7 gives a fair summary.

Table: General Fields of Usefulness or Convector types

	Belt conveyor	Apron conveyor	Flight conveyor	Drag chain	Screw conveyor
Carrying paths	Horizontal to 18^o	Horizontal to 25^o	Horizontal to 45^o	Horizontal or slight incline 5-10^o	Horizontal to 15^o may be used up to 90^o but capacity falls off rapidly.
Capacity range, tons / hr., material weighing 50 lb./cu. ft.	2160	100	300	20	150
Speed range, fpm	600	- 00	150		100 rpm
Location of loading point	Any point	Any point	Any point	Any point	Any point
Location of discharge point	Over end wheel and intermediate points by tripper or plow.	Over end wheel.	At end of trough and intermediate points by gates.	At end of trough	At end of trough and intermediate points by gates.
Handling abrasive materials	Recommended.	Recommended.	Not recommended.	Recommended with special steels.	Not preferred.