Uma Charan Patnaik Engineering School
Berhampur

LECTURE NOTES

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Introduction

The term size refers to the physical dimension or magnitude of an object and the term reduction refers to the decrement or the process of decreasing the size. Thus, size reduction refers to the process of converting the object from one physical dimension of higher order to another dimension of smaller order. More precisely, size reduction is the operation carried out for reducing the size of bigger particles into smaller ones of desired size and shape with the help of certain external forces.

Comminution is another term used for size reduction.

OBJECTIVES OF SIZE REDUCTION

Size reduction of solids is carried out in almost all the process industries for a number of reasons. A few of them are

1. to increase the surface area, because in most chemical reactions and some unit operations (drying, adsorption, leaching, etc.) involving solid particles, the reaction/transfer rate is directly proportional to the area of contact between the solid and the second phase.
2. to produce solid particles of desired shape, size or size ranges, and specific surface.
3. to separate unwanted particles effectively.
4. to dispose solid wastes easily.
5. to mix solid particles more intimately, and
6. to improve the handling (storage and transportation) characteristics.

SIZE-REDUCTION METHODS

Various size-reduction equipment employ different actions to solid particles for size reduction, which is customer tailored. There are four basic ways to reduce the size of a material-impact, compression, attrition, and shear. Most of the size-reduction equipment employ a combination of all these size reduction methods. Apart from the above, another, but less popular, size-reduction method is cutting, which gives a particle of definite size and shape.

Impact

Here, the particle is subjected to a single violent force and in crushing terminology. it refers to the sharp, instantaneous collision of one moving object against another. Both objects may be moving, such as a cricket bat connecting with a fast-moving ball, or one object may be motionless, such as a rock being struck by a hammer blow. There are two varieties of impact-gravity impact and dynamic impact. In gravity impact, the free-falling material is momentarily stopped by the stationary object. Coal dropped onto a hard steel surface is an example of gravity impact. It is most often used when it is necessary to separate two materials which have relatively different friability. The more friable material is broken first, while the less friable material remains unbroken. Materials dropping in front of a moving hammer is an example of dynamic impact. When crushed by dynamic impact, the material is unsupported, and the force of impact accelerates movement of the reduced particles towards the breaker plate and/or other hammers. The use of dynamic impact is advantageous for size reduction of many materials, and it is specially needed when

1. a cubical particle is needed,
2. finished product must be well graded and must meet intermediate sizing specifications, as well as top and bottom specifications.
3. ores must be broken along natural cleavage lines in order to free and separate undesirable particles, such as mica in feldspars, and
4. materials are too hard and abrasive.

Compression

Here, the particle is broken by two forces and the size reduction is done between two surfaces, with the work being done by one or both surfaces. Jaw crushers using this method of size reduction are suitable for reducing extremely hard and abrasive rock. As a mechanical reduction method, compression is chosen

1. if the material is hard and tough,
2. if the material is abrasive,
3. if the material is not sticky.
4. where the finished product is to be relatively coarser in size, and
5. when the material will break cubically.

Attrition

Attrition is a method of size reduction by rubbing or scrubbing the materials between two hard surfaces. Attrition crushing is most useful when

1. the material is friable or not 10 abrasives, and
2. a closed-circuit system is not desirable to control the oversize.

Shear

Shear consists of a trimming or cleaving action rather than the rubbing action associated with attrition. It is usually combined with other size-reduction actions, e.g., single-roll crushers employ shear together with impact and compression. Shear method of size reduction is needed for

1. friable material,
2. primary crushing with a reduction ratio of 6 to 1, and
3. production of a relatively coarse product.

PRINCIPLES OF SIZE REDUCTION

Properties of Solids

For a particular size-reduction operation, the choice of machine to be used mainly depends on

1. the size and the quantity of material to be handled, and
2. the nature of the product required.

But the more important aspects about the feed material apart from its size and quantity are its properties such as hardness, toughness, stickiness, moisture content, friability, explosive nature, soapiness, crystallinity, and temperature sensitivity.

Hardness

The hardness of the material is its resistance to scratching and it affects the power consumption and the wear on the grinding machine. The Mohs Scale which was created in 1812 by the German mineralogist Friedrich Mohs, is commonly used to measure the hardness of minerals and many other solids.

Toughness

Toughness is the resistance of a material to impact. It is the reverse of friability or brittleness. Structure Granular materials (such as coal or rock) can be easily crushed while fibrous materials need tearing action.

Moisture Content

Materials do not flow well if the moisture content is higher (more than 3 to 4% by weight). They tend to cake and clog the machine which reduces the crushing effectiveness. Too dry a condition can result in excessive dust.

Explosive Nature

Explosive materials must be ground under wet conditions or in the presence of an inert environment.

Soapiness

Soapiness is the measure of the coefficient of friction, μ, of the surface of the material. If μ is low, the crushing will be more difficult.

Crystallinity

Every solid material has a specific crystalline pattern. The atoms in the crystal are arranged in a definite, repeating geometric pattern and there are certain planes in the crystal, called cleavage planes, along which the breakage occurs when sufficient pressure is applied on the solid.

Temperature Sensitivity

The heat generated during size reduction can result in loss of heat-sensitive components from solids. Softening or melting may also be important leading to clogging. In some cases, cryogenic crushing may be necessary using liquid nitrogen or, dry ice, e.g., in milling of spices or size reduction of meat.

Factors Affecting Size Reduction Process

Apart from the properties of solids, certain factors affecting the size-reduction process in terms of capacity and the performance are

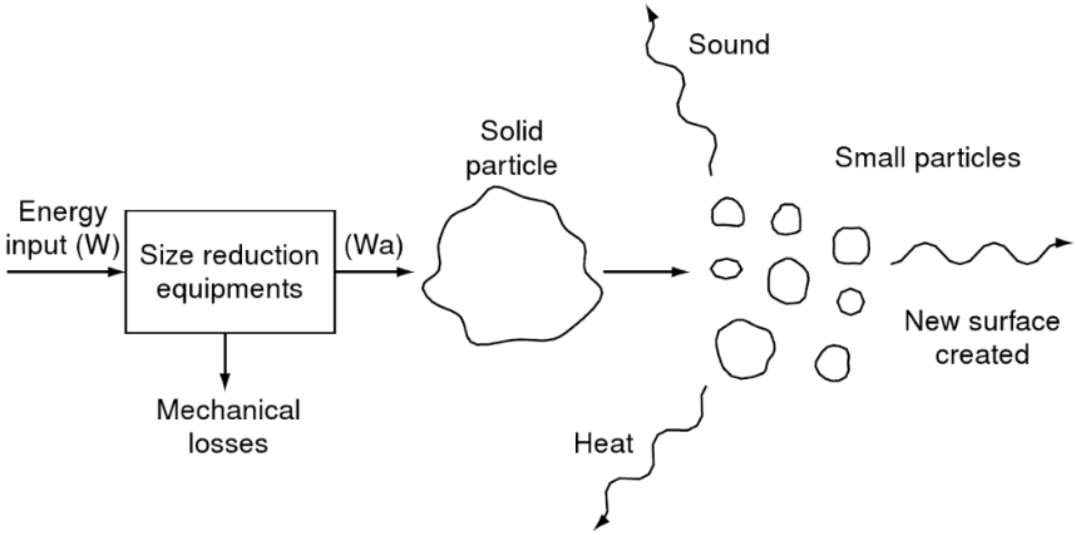
1. presence of moisture and sticky materials in equipments' feed,
2. presence of fines in the feed.
3. segregation of feed particles in the crushing chamber,
4. lack of feed control.
5. wrong motor size.
6. insufficient crusher discharge area.
7. insufficient capacity of the crushers' discharge conveyor,
8. materials being extremely hard to crush,
9. surface energy of solids,
10. power consumption, and
11. selection of an appropriate crushing chamber.

Energy and Power Consumption in Size Reduction

When external stress/force is applied for size reduction, the solid particles at first are twisted and strained. The work required to strain them is stored temporarily in the solids as the mechanical energy of stress. When additional force is applied to these already stressed particles, they are distorted beyond their ultimate strength and are suddenly broken into smaller particles, which ultimately generate new surfaces.

The unit area of solid has a definite amount of surface energy and when its size is reduced, the surface area per unit mass, specific surface, increases. This creation of a new surface requires work, which is supplied by the release of energy of stress at the time of rupture.

But, it is important to note that only a small portion out of the total energy supplied to the equipment is utilized for the creation of a new surface and most of the energy is lost to overcome the friction (in the bearings and other moving parts of the machine): as heat (because by the principle of conservation of energy, all energy of stress in excess of new surface energy created are converted to heat); and as sound. Thus, the energy efficiency is less and when most of the energy is lost, the cost of power becomes a major constraint. A schematic diagram for the creation of a new surface is shown in Figure



Schematic diagram for creation of a new surface

The crushing or grinding efficiency is one of the most important parameters in the subject of size reduction as the cost is represented in terms of energy, which draws much attention to the design engineers. But no such exact definition is available to define this entity.

Crushing Efficiency

We know that energy is required to effect size reduction/comminution, or in other words, comminution may be a process of conversion of energy from one form to another. The energy is utilized in the form of kinetic energy and the energy recovered is in the form of potential (surface) energy, heat, and sound. But only the potential energy is needed for use. Hence, the crushing efficiency can be defined as the ratio of the surface energy created to the energy absorbed (kinetic energy) by the solid.

In another way, this may be defined as the ratio of the energy absorbed by the solid to form heat and the energy input to the machine.

The crushing or grinding efficiency ranges from a value as low as 10^{-3} per cent to a maximum of one per cent. The remainder of the total energy input is converted to heat, sound, and the rest is wasted. It is of much interest to note that when wheat flour comes out of a flour mill, the temperature of the mass rises by 10 to 20° C.

The quantities needed to calculate the efficiency are

1. total energy input,
2. energy lost during size reduction,
3. total new surface created, and
4. specific surface energy.

The *total energy input* can be measured either by mechanical means or by electrical instruments. The energy lost is difficult to measure but it may be measured in terms of energy consumption.

Surface area may be determined from size distribution data or measured directly by flow through a powder bed or by the adsorption of gas molecules on the powder surface. Other methods such as gas diffusion, dye adsorption from solution, and heats of adsorption can also be used.

The *specific surface energy* of liquids can be measured with precision as it is numerically the same as the surface tension. But for solids, indirect methods based on mathematical utilization of physicochemical quantities only are available whose accuracy largely depends on the assumptions made in measuring it.

Laws of Comminution

It is almost impossible to find out the accurate amount of energy requirement in order to effect size reduction of a given material, mainly because

1. there is a wide variation in the size and shape of particles both in the feed and product, and
2. some energy is wasted as heat and sound, which can't be determined exactly.

But a number of empirical laws have been proposed to relate the size reduction with the energy input to the machine.

They are Rittinger's Law (1867). Kick's Law (1885), and Bond's Law (1952).

Rittinger's Law

According to this law, the work required for size reduction is proportional to the new surface area created. Mathematically, this law can be written as

$$W_R = \frac{P}{\dot{m}} = KE_S(A_{ssp} - A_{ssf})$$

where K = constant

Rittinger's law can be written as

$$\boldsymbol{W_R = \frac{P}{\dot{m}} = K_R\left(\frac{1}{\bar{D}_P} - \frac{1}{\bar{D}_F}\right)}$$

Where K_R is known as Rittinger's constant.

The inverse of Rittinger's constant is known as Rittinger's number.

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 predominant. Also, this law is applied in cases where the energy input per unit mas of material is not too high. This law is applicable for feed size of less than 0.05 mm.

Kick's Law

This law states that the work required for crushing a given mass of material is constant for a given reduction ratio irrespective of the initial size. The reduction ratio is the ratio of initial particle size to final particle size.

Mathematically,

$$\boldsymbol{W_K = \frac{P}{\dot{m}} = K_K\, ln\left(\frac{\bar{D}_F}{\bar{D}_P}\right)}$$

where, K_K = Kick's constant.

For example, if a given quantity material is being crushed from 100 mm to 20 mm or, from 30 m to 6 mm then in both the cases the energy requirement will be the same as the reduction ratio (100/20 = 30/6 = 5) is same for both the cases.

Kick's law is based on stress analysis of plastic deformation within the elastic limit. This law is more accurate than Rittinger's law for coarse crushing where the surface area produced per unit mass is considerably less. This law is applicable for feed size of greater than 50 mm.

Bond's Law

Neither of the two laws mentioned above (Rittinger's or Kick's) give the accurate energy requirement and both the laws are applicable over a limited range of particle size, and hence, they have limited utility. But in the year 1952, F C Bond suggested an intermediate law, which states that the work required to form particles of size D, from a very large particle size is proportional to the square root of the surface to volume ratio (S_P/V_P) of the product. This law is applicable for feed size between 0.05 and 50 mm.

Mathematically,

$$\boldsymbol{W_B = \frac{P}{\dot{m}} = K_B\left(\frac{1}{\sqrt{D_P}} - \frac{1}{\sqrt{D_F}}\right)}$$

where, K_B = Bond's constant.

The Bond's constant (K_B), is dependent on the type of machine used and on the material to be crushed. And it is found more accurately using work index, W_i, It is defined as the gross energy requirement in kilowatt hour per short-ton of feed (kWh / ton of feed) to reduce a very large particle to such a size that 80% of the product will pass through a 100-μm or 0.1-mm screen.

$$W_i = K_B\left(\frac{1}{\sqrt{D_P}}\right) \quad \Rightarrow \quad K_B = W_i\sqrt{D_P}$$

Now, if P is in kW, m is in tons per hour, and

1. D_p is in μm then $K_B = 10W_i$, and
2. D_p is in mm then $K_B = \sqrt{0.1}W_i = 0.3162W_i$

SIZE-REDUCTION EQUIPMENTS

Size-reduction equipments are classified on the basis of:

- the mode of operation,
- Method by which a force is applied

Classification of size-reduction equipments

Mode of operation

- Batch operated
- Continuous operated

Method by which a force is applied

1. **Impact**
   - Impact at one surface
   - Impact between particles

2. **Compression**
   - Crushing
   - Grinding

3. **Attrition**
   - Rubbing the materials between two surfaces
4. **Cutting**

Selection Criteria of Size-Reduction Equipments

While selecting a size-reduction equipment, the following criteria must be considered:

1. It should produce the materials of desired shape and size or the size distribution desired.
2. It should accept the maximum input size expected.
3. It should have a large capacity.
4. It should not choke or plug.
5. It should pass unbreakable materials without causing damage to itself.
6. It should operate economically with minimum supervision and maintenance.
7. The power input per unit weight of product should be small.
8. It should resist abrasive wear.
9. It should be dependable and have prolonged service life.
10. The replacement parts should be readily available at cheaper rate.
11. The initial fixed cost and the operating cost should be minimum.
12. It should be easy and safe to operate.
13. It should have easy access to internal parts for maintenance and last but not the least.
14. It should be a versatile one.

COARSE CRUSHERS

The coarse crushers (jaw, gyratory, and crushing rolls) employ mainly the compression action to large lumps of solid materials and are slow-speed machines. In these machines, the size reduction results from stresses that are applied to the solid particles to be crushed by some moving part in the machine and against a stationary part or against some other moving part. This compression action builds up strain within the particles to be broken, which results in fracturing whenever they exceed the clastic limit of the materials. And the coarse crushing is always conducted on dry materials.

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Jaw Crushers

Jaw crushers consist of two crushing faces (jaws) — one of them is fixed vertically to the frame, while the other one is movable, which is either pivoted at the top or at the bottom. Depending on the type of arrangement of the movable jaw, the jaw crushers are classified into two types — ***blake and dodge***. *In the blake type, the movable jaw is hinged at the top so that the greatest movement at the bottom is* *given to the smallest lumps. In the dodge type, the movable jaw is pivoted at the bottom giving minimum movement of jaw at the bottom by which more uniform products are obtained*. *But this type is less widely used because of its tendency to choke*.

Blake Jaw Crushers

Operating Principle

It works on the principle of compression and there are no rubbing or grinding actions, and it generally produces cubical products with minimum fines.

Construction and Working

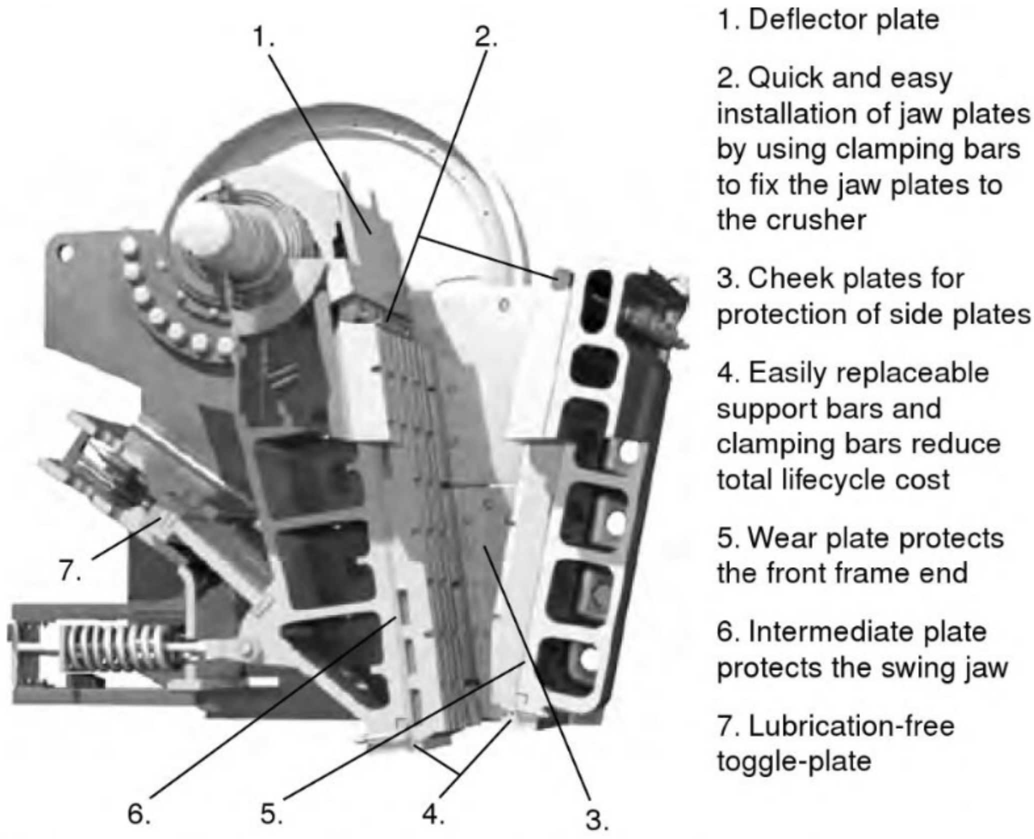
Generally, the Blake type of jaw crushers has cast-steel lined supporting frames for a vertical fixed jaw and for a movable jaw pivoted at the top such that they form a V-opening at the top. The crushing faces of the jaws are made of manganese steel so as to make them abrasion resistant. The movable jaw moves in a horizontal plane usually making an angle of 20 to 30 with the fixed jaw.

The jaw faces are of several patterns for gripping the material and for concentrating the pressure on smaller areas. The standard profile is suitable for both rock and gravel crushing, while heavy-duty profile is recommended for extremely hard materials. When a high production rate is needed, a corrugated profile is recommended.

Jaw crushers consist of eccentric, pitman, toggles, flywheel, shaft, draw back rod (tie rod), and spring. The eccentric causes the pitman to oscillate vertically, and this vertical motion of the pitman is transmitted to the movable jaw to have a back-and-forth motion horizontally by the toggles. The movable jaw is held against the toggle by a tie rod and spring.

The material to be crushed is fed through a hopper between the two jaw plates from the top. The materials caught between the upper part of the jaws are crushed to smaller size during the forward motion of the movable jaw. The crushed materials then drop down to the narrower space during the backward motion of the movable jaw and are re-crushed during the next forward motion. The materials come out of the bottom of the machine after sufficient size reduction.

It must be noted that the speed should not be so high that the materials get crushed several times and produce large quantity of fines.



Jaw Crusher

Gyratory Crushers

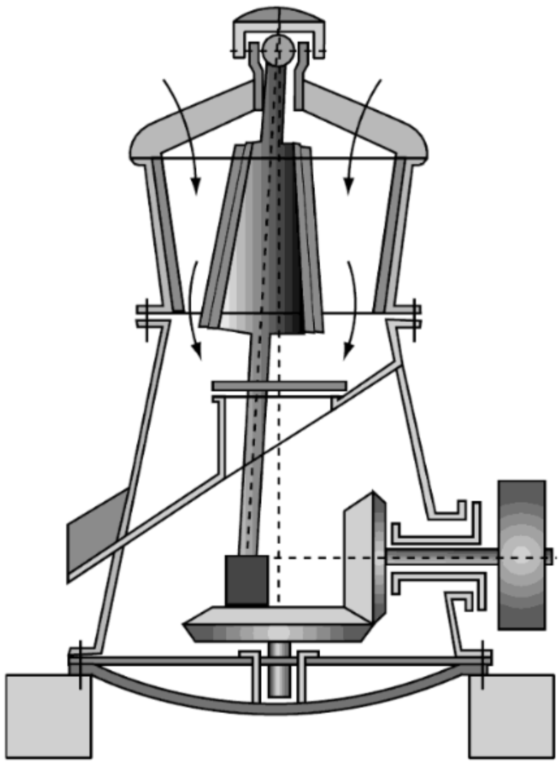
Gyratory crushers were developed more recently in order to have greater capacity over jaw crushers. The crushing process of gyratory crushers is similar to that of jaw crushers in that the maximum movement is at the bottom but the face is made to gyrate inside a stationary shell.

Operating Principle

Gyratory crushers, like jaw crushers, employ compressive force for size reduction.

Construction and Working

The gyratory crusher consists of two vertical conical shells, the outer shell having its apex in downward direction while the inner cone is positioned with its apex upward. The inner shell acts as the crushing head, which is in the form of a truncated cone and is mounted on an oscillating shaft. The upper end of this cone is held in a flexible bearing while the lower end is connected to an eccentric. The eccentricity causes the conical crushing head to oscillate between open side setting (oss) and closed side setting (css) discharge openings. Hence, the crushing action takes place around the whole of the cone and is continuous. The eccentricity also determines the capacity of gyratory crushers.



Gyratory Crusher

The material to be crushed is fed from the top and is crushed between the stationary outer shell and the crushing head. They are crushed several times before being discharged from the bottom. An additional crushing effect occurs between the compressed particles, resulting in less wear of the crusher materials. This is known as *interparticular crushing*.

As the crushing action is continuous, the fluctuations in stresses are smaller than that in the jaw crushers. Also, the load on the motor is uniform and the power consumption is less. These crushers have a large capacity per unit area of grinding surface if used to produce a small size reduction. Further, these crushers do not take large feed as the jaw crushers do and produce a more uniform product. Because of high initial investment, to optimize operating costs, and to improve the product shape, it is recommended to use gyratory crushers under choke-feed conditions. This can be done using a stockpile or a silo, which reduces the fluctuations of feed material flow.

Primary gyratory crushers form a critical transition between the mine or quarry and the plant. They reduce a wide range of feed to a manageable size suitable for further processing. Primary gyratory crushers are taller, heavier, and require a massive foundation than primary jaw crushers. Secondary gyratory crushers are normally used in the second crushing stage.

Roll Crushers

The history of roll crushers is more than 200 years old but in recent years they lost their popularity over jaw and gyratory crushers due to their poor wear characteristics with hard rocks. Depending on the number of rolls employed, roll crushers are of two types —*single-roll crushers and double-roll crushers*. The single-roll crusher is one of the oldest and the simplest crushers which are mainly used for primary crushing, whereas double-roll crushers are used for secondary crushing.

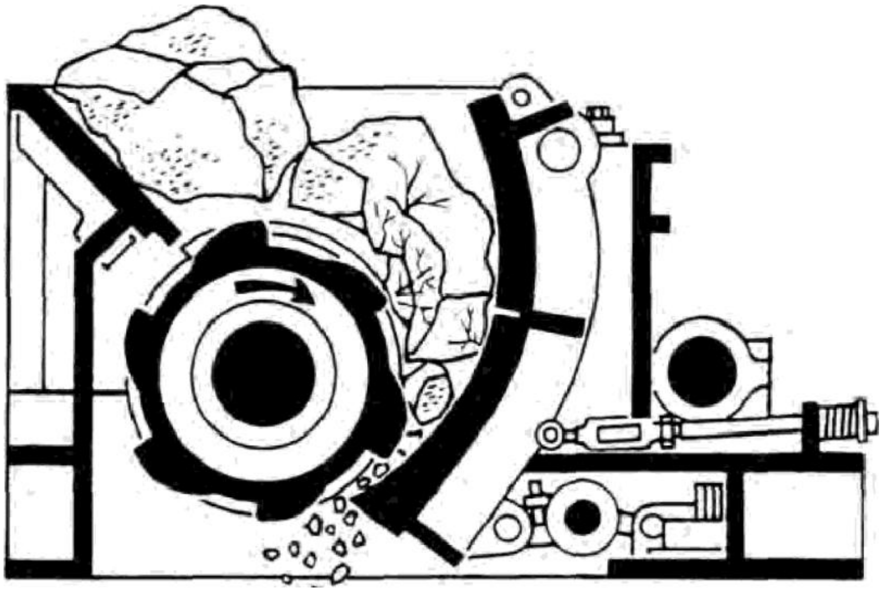
Single-Roll Crushers

Operating Principle

Single-roll crushers employ three different methods of size reduction — impact, shear, and compression.

Construction and Working

Single-roll crushers are typically used as primary crushers. Single-roll crushers have a roll assembly consisting of a roll shaft and a fabricated roll shell with integral fixed teeth.



Single Roll Crusher

Entering the crusher through the feed hopper, the feed material is struck by the teeth of the revolving roll. While some breakage occurs here by impact, the rotation of the roll carries the material into the crushing chamber formed between the breaker plate and the roll itself. As the turning roll compresses the material against the stationary breaker plate, the teeth on the roll shear the material.

Sized materials fall directly out through the discharge end of the crusher which is completely open. As there are no screen bars, there is no re-crushing of the already sized materials, which helps to reduce the power demand while minimizing the fines. The clearance between the breaker plate and the roll determines the product size and this clearance is adjustable from outside the machine by a shim arrangement.

Double-Roll Crushers

Operating Principle

Here, the crushing is primarily accomplished by compression.

Construction and Working

Double-roll crushers consist of two heavy metal rolls of equal diameter placed horizontally which are rotated towards each other at same or at different speeds. The rolls are mounted on heavy shafts. One of the rolls is motor driven while the other roll rotates due to friction. The gap between the two rolls is adjustable because of two reasons—the product size is determined by the size of the gap between the rolls and to compensate for wear. The rolls have narrow faces and are large in diameter so that they can squeeze sharply (nip) the large lumps. The roll surfaces may be smooth, corrugated, or toothed.

The materials to be crushed are fed from the top. As the rolls rotate, they are nipped between them and get crushed by compression, and are discharged from the bottom. Compression crushing is extremely efficient, as energy is only used to crush those particles larger than the gap between the rolls. Fines are minimized because already crushed materials pass freely through the crusher with no further size reduction. Typical roll dimensions vary from 600 mm (24 in) in diameter with a 300-mm (12 in) width face to 2000 mm (78 in) in diameter with a 914-mm (36 in) width face. The speed of rolls varies from 50 to 300 rpm. These machines give a reduction ratio of 4 to 1 with few fines. Double-roll crushers accept feed sizes up to 150 mm, though larger feed can be effectively handled in certain applications.

Hammer Mills

Hammer mills are among the oldest, yet still the most widely used crushers. Hammer mills crush the materials in two stages—first, the size reduction occurs by dynamic impact and then the sizing occurs in the second zone, where small clearances exist between hammers and screen bars, by attrition and shear.

The advantages of Pennsylvania hammer mills are their ability to produce the specified top size without the need for a closed-circuit crushing system and to produce a cubical product with a minimum of flats. Large particles cannot escape the screen bars until sized, resulting in great product uniformity with a minimum of oversize.

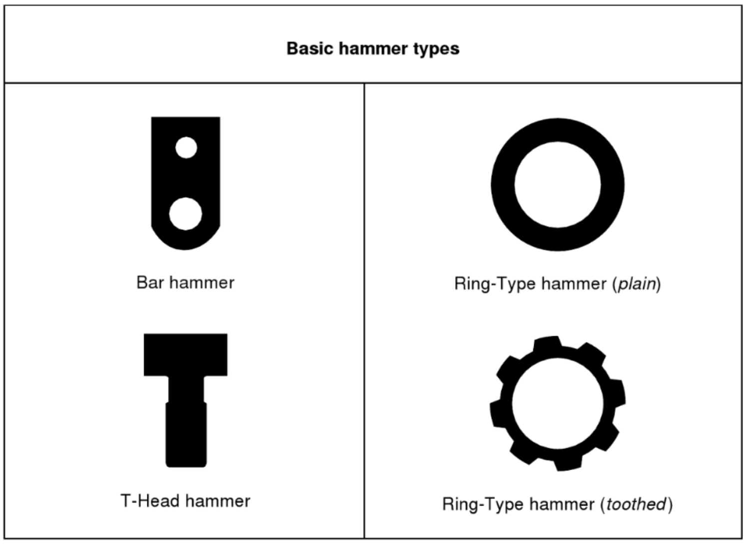
The product size can be controlled by several factors, such as

1. the feed rate,
2. the speed of rotation of disk,

3. the number and types of hammers used,
4. the clearance between the hammers and breaker plates, and
5. the size of screen opening

Hammer mills have high reduction ratios and have high capacities whether used for primary, secondary, or tertiary crushing. Due to excessive wear, these are not recommended for the fine grinding of very hard and abrasive materials. In hammer mills, the hammer design plays a significant role as the hammers do most of the work. The factors taken into consideration while designing the hammers are mass, general shape, the air paths created by hammer sweep, and heat treatment

The center of gravity determines the focus of impact and must be controlled to utilize the full mass of the hammer against the feed materials. The shape of the hammers is also important. The hammers may be of T-, bar-, or, of ring-shaped (plain and toothed) as shown in the figure. The hammer heads must be extremely hard and resistant to wear-this can be done by heat treating the hammer materials.



Hammer types

During rotation of hammers, a large current of air is produced which carries away a certain amount of fines. These must be directed away from the rotor disk and other vital parts to prevent premature wear.

Hammer mills are classified into reversible and non-reversible types based on the rotation of rotor in clockwise or counter-clockwise direction, or in both directions. Though their construction differs in many respects, their working and crushing actions remain similar.

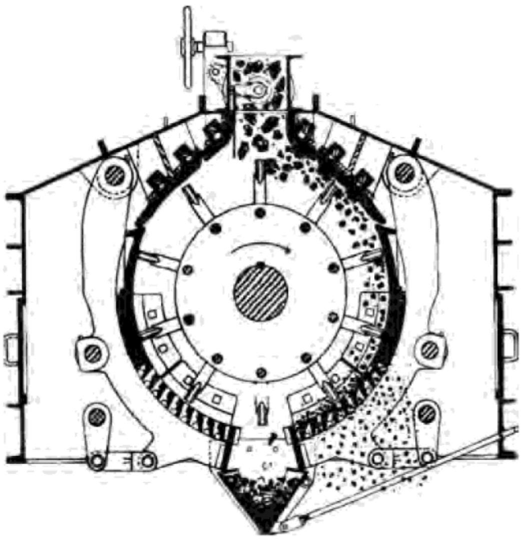
Construction and Working

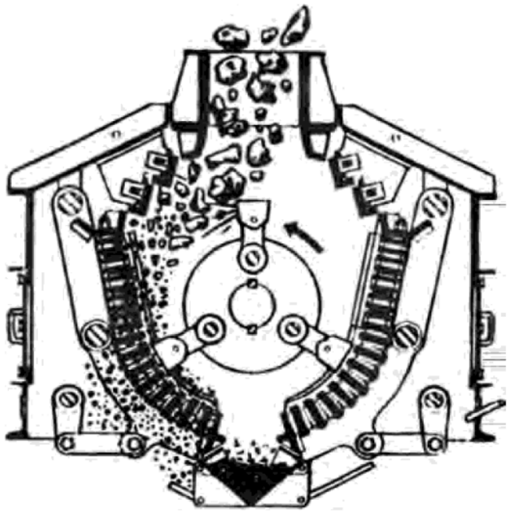
In general, the hammer mills consist of a cylindrical easing inside which a high-speed rotating disk (rotor) is incorporated, to which a number of swing hammers are pinned/hinged. A cylindrical screen or grating is attached to the bottom of the casing, which encloses all or, part of the rotor.

The material to be crushed is fed either at the top or at the center through a hopper, and is thrown out centrifugally and crushed either by hammers or against breaker plates fixed around the periphery of the casing. The material is beaten several times until it passes through the screen opening. Due to excessive wear, hammer mills are not recommended for fine grinding of very hard materials.

In reversible hammer mills, the rotor can run clockwise or counter-clockwise. Reversal of the rotor permits the operator to utilize the opposite face of the hammer for maximum hammer sharpness. Reversal also brings the opposite set of breaker plates and screen bars into use.

Reversible hammer mils are available in a great variety of sizes and are used for the size reduction of coal; fuels and sorbents in fluid-bed boiler applications: and rock, limestone, minerals, and chemicals. Reversible hammer mills for coal have more rows of hammers than found in the reversible hammer mills used for stone or rock. The reversible hammer mills for rock and minerals have massive breaker plates and screen bars than those used for crushing coal and have fewer rows of hammers than the coal version. The bottom of these mills is open and the sized material passes through almost instantaneously.

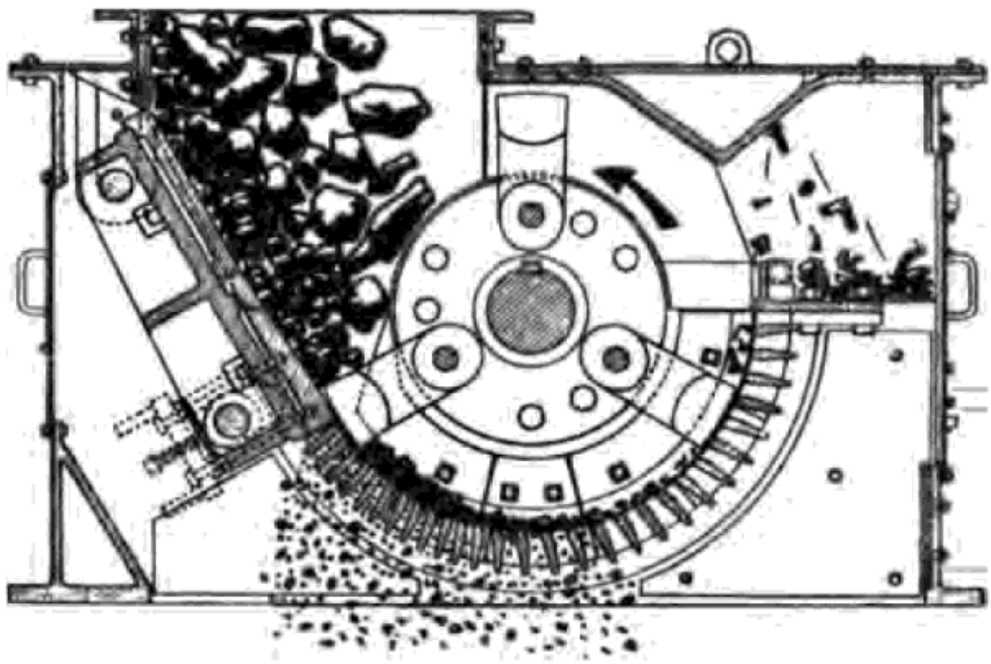




Reversible Hammer Mill for coal Reversible Hammer mill for

rock & minerals

Non-reversible hammer mills consist of a cylindrical grating below the rotor for product discharge. Size reduction starts by impact when the hammer strikes the material as it enters the crushing zone. Shattered fragments are swept down into the final crushing zone for further reduction at the pinch points between the hammers and screen bars. The oversize material remains in the machine until it is reduced sufficiently to fit through the screen bar openings. These crushers accept feed sizes of up to 750 mm (30 in).



Non-reversible Hammer Mill

The tighter the clearance between the screen bars and hammers, the smaller the particle size of the crushed product.

FINE GRINDERS

Ball Mills

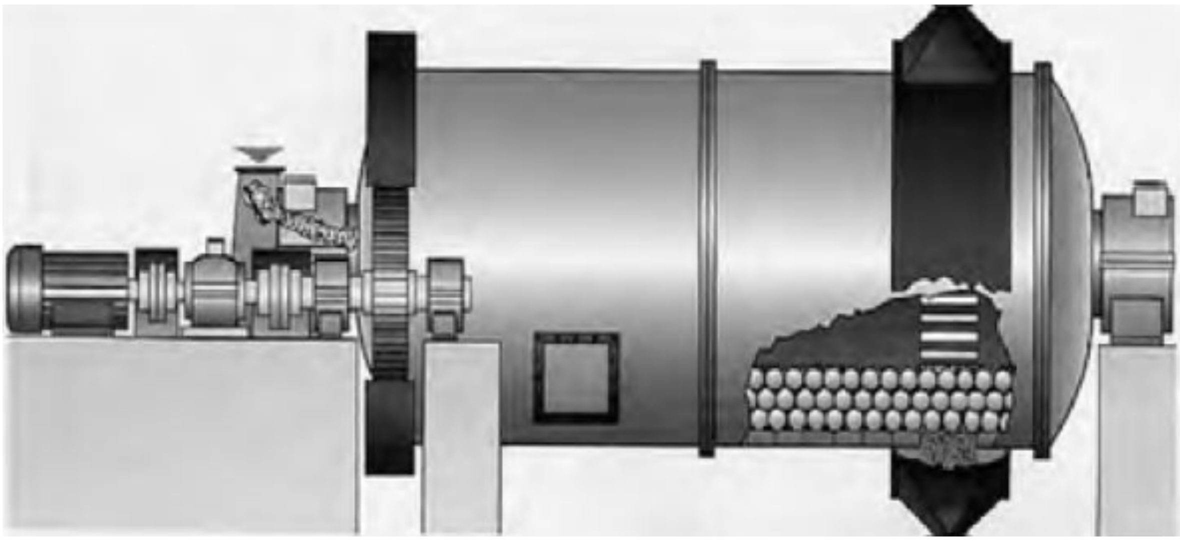
Ball mills are popular due to their low operating and maintenance costs regardless of whether the material displays Mohs hardness values of over 4 or is soft — such as limestone or barite.

Operating Principle

The principle of size reduction in ball mills is impact of balls, which fall from the top of the shell on to the feed particles near the bottom of the shell.

Construction and Working

In general, ball mills consist of a hollow cylindrical or conical shell, made of steel or rubber-lined steel, with approximately half-full of steel balls, rotating about its axis, either horizontal or at a small angle to the horizontal. The grinding media is the balls, which may be made of steel or stainless steel. The material to be ground may be fed in through an opening at one end and the product leaves through a similar opening at the other end, which is covered with a coarse screen to prevent the escape of balls.



Ball Mill

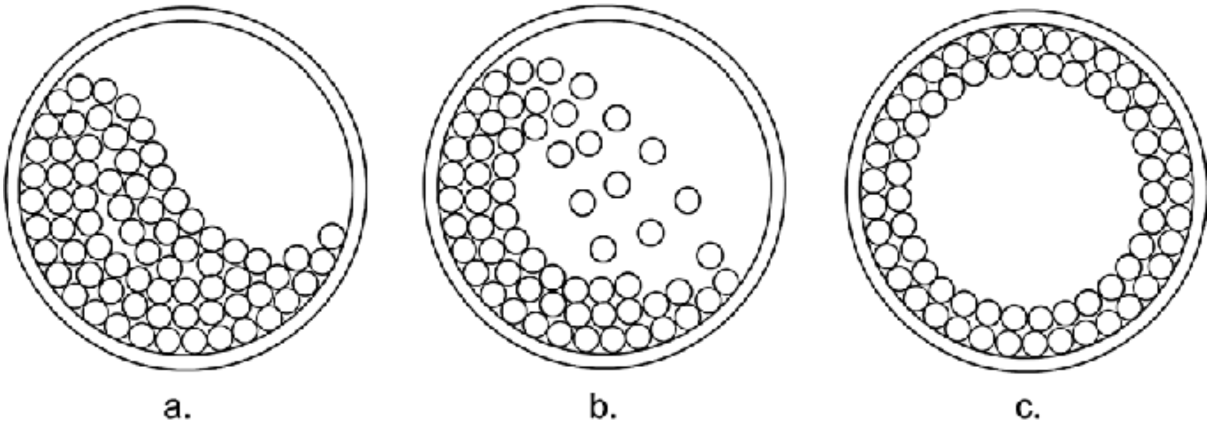
The inner surface of the mill is lined with an abrasion-resistant material such as manganese steel or rubber. For rubber-lined mills, less wear takes place than steel- lined mills. Another advantage in case of rubber-lined mills is that due to higher coefficient of friction between the balls and the cylinder, the balls are carried to a greater height in contact with the cylinder and thus drop on to the feed particles from a greater height causing the size reduction to be more effective.

The length of the ball mill is nearly equal to its diameter (L/ D ratio varies from 1 to 1.5:1). The balls occupy about 30 to 50 %of the volume of the mill. The diameter of the balls used varies between 12 to 125 mm. The optimum ball diameter is nearly proportional to the square root of the size of the feed and the proportionality constant is a function of the nature of the material to be ground.

The mill is rotated at low speed between 60-100 rpm through a drive gear. During grinding, the balls themselves wear (wear rate varies from 450 to 1350 g per ton of product) and are constantly replaced by new ones. So, at any point of time, balls of different ages and various sizes are found inside the mill. This is advantageous because the larger balls crush the coarse feed and the smaller balls grind the material to a finer product.

Theory

The speed of rotation is a crucial factor for ball mills. At low speeds of rotation, the balls are lifted and simply roll back over feed materials. Size reduction is caused by attrition and little crushing action takes place. Under this condition, the mill is said to be *cascading*.



Ball Mill operating at different speed – (a) cascading, (b) cataracting, (c) centrifuging

At slightly higher speeds, the balls are carried up further inside the mill and fall back due to gravity on to the feed particles at the bottom. Grinding takes place by impact and the mill is said to be *cataracting*. If the speed of rotation is increased further and further, a stage is reached when the balls are carried along with the inside walls of the mill due to higher centrifugal force and do not fall at all, and the mill is said to be *centrifuging*. The minimum speed at which centrifuging occurs is called the *critical speed of the mill*. At the critical speed, the balls will be at the uppermost position of the mill and there will be no resultant force acting on the ball as the centrifugal force will be balanced by the weight of the ball.

Open-Circuit and Closed-Circuit Grinding

- In many machines, the feed material is reduced to satisfactory size by passing it once through the machine.
- If the material is passed only once through the machine (crushing or grinding), and no attempt is made to return the oversize material to it for further reduction, the process is known as open-circuit grinding.
- If the partially ground material from the machine is sent to a size separation unit, from where the undersize is withdrawn as the product and the oversize material is returned to the machine for reground, the process is known as closed-circuit grinding.
- In case of coarse particles, the size separation unit is a screen or grizzly while it is some form of classifier in case of fine powders. Closed-circuit grinding though useful for any crusher, it is commonly employed to machines yielding a fine product.
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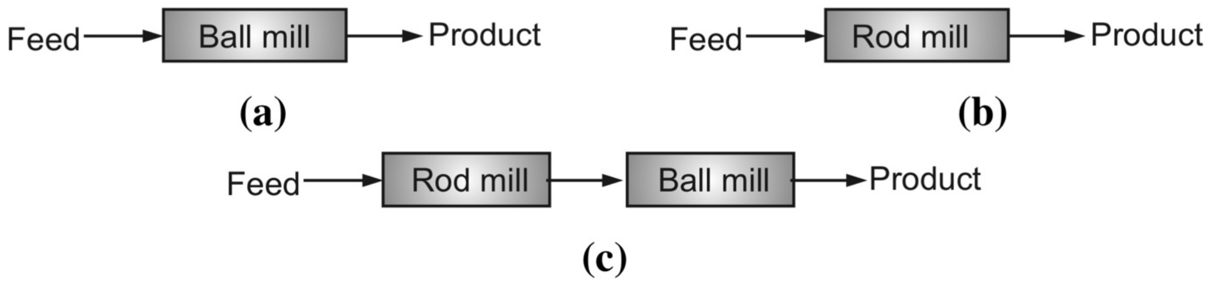
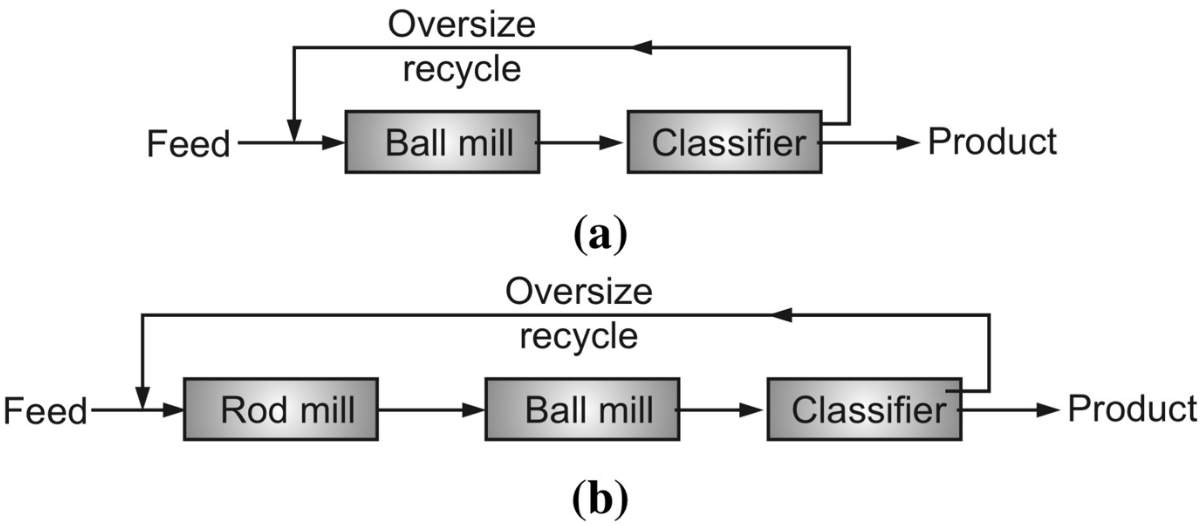
Open-Circuit Grinding



Open circuit grinding systems

- 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:
    a. Ball mill
    b. Rod mill and
    c. Combination of ball mill and rod mill.
- Some conditions that favour open circuit grinding are:
    a. Small reduction ratios and
    b. Coarse reduction of particles.
- Advantages of open circuit grinding are:
    a. Simplicity of operation,
    b. Minimum equipment requirements.

Closed-Circuit Grinding



Closed circuit grinding systems

- Closed circuit grinding consists of one or more grinding mills with classification equipment. The mills discharge ground product to classifier which returns the coarse product from it to the mill for further grinding.
- Some examples of closed-circuit grinding are:
    a. Ball mill and classifier
    b. Rod mill, ball mill and classifier.

Some advantages of closed circuit grinding are:

1. higher capacity,
2. lower power consumption per ton of product,
3. suitable for reduction to fine and ultrafine sizes,
4. avoids coarse material in the final ground product by returning it to the mill,
5. eliminate overgrinding by removing fines early.

Some conditions that favour closed circuit grinding are:

1. larger reduction ratios and
2. fine reduction of particles.

Dry and Wet Grinding

Dry Grinding

Dry grinding is a process that uses dry materials or gas to break down particles. In this method, the material to be ground is placed in a grinding chamber with a rotating abrasive wheel. The abrasive wheel grinds the material by removing small chips from the surface.

Advantages of Dry Grinding

- Low cost: Dry grinding is a cost-effective method as it does not require the use of water or other solvents.

- No contamination: Dry grinding does not produce a slurry, which reduces the risk of contamination.
- Versatility: Dry grinding can be used for various materials, including metals, plastics, and ceramics

Disadvantages of Dry Grinding

- Heat generation: Dry grinding generates a significant amount of heat, which can cause thermal damage to the material.
- Dust: Dry grinding produces dust, which can be hazardous to workers' health.
- Limited particle size reduction: Dry grinding is not suitable for reducing particles to a small size, as it may cause material agglomeration

Wet Grinding

Wet grinding is a process that uses water or other liquids to break down particles. In this method, the material to be ground is placed in a grinding chamber with the liquid and a rotating abrasive wheel. The liquid acts as a lubricant and cooling agent, which helps to reduce the heat generated during the process.

Advantages of Wet Grinding

- Efficient particle size reduction: Wet grinding can reduce particles to a smaller size compared to dry grinding.
- No dust: Wet grinding does not produce dust, which reduces the risk of contamination and improves worker safety.
- Cooling effect: The liquid used in wet grinding acts as a cooling agent, which prevents thermal damage to the material.

Disadvantages of Wet Grinding

- High cost: Wet grinding is a more expensive method compared to dry grinding as it requires the use of water or other liquids.
- Potential contamination: Wet grinding may introduce impurities into the material due to the use of water or other liquids.
- Limited application: Wet grinding is not suitable for all materials, such as those that are sensitive to water or those that may be damaged by moisture.

Both dry and wet grinding processes have their own advantages and disadvantages. Dry grinding is preferred in situations where there is limited moisture content or when the material is hard and abrasive. Wet grinding, on the other hand, is ideal when the material is soft and has high moisture content.

When it comes to choosing between dry and wet grinding processes, it ultimately depends on the specific application and material being processed. Factors such as particle size, cost, and energy efficiency must be considered before making a decision.

In summary, dry grinding produces fine particles and is best suited for hard, abrasive materials. Wet grinding produces smaller particles and is ideal for softer, more delicate materials. Both processes have their own unique advantages and disadvantages, and it is important to choose the right method for your application to achieve the desired result.

Free and Choke Grinding

Free grinding refers to a situation where the material being ground flows freely through the grinding machine without any significant blockages, while "**choke grinding**" means the material is fed into the grinder at a rate that exceeds its capacity, causing a buildup and potential jamming due to excessive material trying to pass through at once; essentially, the machine is choked with material.

Free grinding:

- Optimal grinding process with smooth material flow.
- Allows for efficient crushing and particle size reduction.
- Usually achieved by carefully controlling the feed rate of material into the grinder.

Choke grinding:

- Inefficient grinding due to material buildup and potential machine damage.
- Can lead to uneven particle size distribution.
- Occurs when too much material is fed into the grinder at once, exceeding its capacity.