4. SIZE REDUCTION

4.1. Introduction

The term “Size reduction” is applied to all the ways in which particles of solids are broken or cut to smaller pieces. Commercial products must sometimes meet very specific requirements as to the size and sometimes the shape of the product. On the other hand, particles are ground to increase the reactivity of solids in some industrial reactions. Also, this permits separation of unwanted large impurities by mechanical methods. Finally, it reduces the bulk of fibrous materials for easier handling.

Solids are broken in four different ways: by (1) compression, (2) impact, (3) attrition and (4) cutting. In general, compression is the main mode for coarse reduction, giving off only few fines, whereas impact can yield coarse or fine particles and attrition gives extremely fine particles. Cutting is only used whenever the product is to be of some definite shape with little or no fines.

4.2. Criteria for Size Reduction

Crushers and grinders are used for size reduction (also known as comminution). An ideal crusher or grinder should have a large capacity, consume as little energy as possible and the product particles should practically have the same size. In practice all these criteria are hardly met. As a matter of fact, the actual capacity of any crusher or grinder is always several times less than its ideal capacity, also the power required for crushing or grinding is much higher than the calculated theoretical power. Finally, it is not uncommon to have products having a very large particle size distribution. Sometimes, a screen can be put at the outlet of the crusher or grinder so as to remove the coarsest particles in the product but this provision cannot eliminate the too fine particles produced.

4.3. Power Required for Size Reduction

The theoretical energy required to break a solid to smaller particles is related to the energy required for the formation of new surfaces out of the originally available ones. The energy required to form a unit surface is termed “The specific surface energy, \(e_s\)”. If the original specific surface area is \(A_{w1}\) and that of the product is \(A_{w2}\), then the theoretical work required for size reduction is:

\[
W_{th} = e_s (A_{w2} - A_{w1}) \text{ J.kg}^{-1}
\]  

(4.1)

The actual work, \(W\) is much higher than the value that can be calculated from the above equation. Actually, \(W = W_{th} / \eta\), where \(\eta\) is an efficiency term in the range of 0.01 to 0.02. This is since most of the energy supplied is lost as thermal energy, which heats up the solid and the equipment besides the energy required to run the empty piece of equipment.

If the power used for grinding is to be calculated, we also have to take in account the power transmission mechanical losses (such as friction at bearings). This will have for
effect to further increase the value of $W$ by a factor of $1/\eta_{\text{mech}}$. so that the actual work is $W_{\text{th}}/\eta_{\text{mech}}.\times\eta$

Let the feed rate be $\dot{m}$, kg.s$^{-1}$. Hence the power required is:

$$p = \frac{m.\varepsilon_s.(A_{w2} - A_{w1})}{\eta_{\text{mech}}}$$  \hspace{1cm} (4.2)

Assuming that the sphericities of both the feed and the product are equal, and recalling
the definition of $D_{vs}$, **Rittinger**, in 1939, obtained the following equation to predict the power required in crushing and grinding operations:

$$P = m.K_s\left(\frac{1}{D_{vs2}} - \frac{1}{D_{vs1}}\right)$$  \hspace{1cm} (4.3)

Where 1 and 2 denote feed and product respectively.
This law, named after Rittinger, is best suited for grinding rather than crushing.

In case of crushing a classical law known as **Kick’s** law is best suited:

$$P = \dot{m}K\log\frac{A_{w2}}{A_{w1}}$$  \hspace{1cm} (4.4)

A more useful relation that can be used for both crushing and grinding has been obtained by **Bond** (1952). This law introduces two new concepts namely, **“The Bond diameter, $D_b$”** which is the screen opening such that 80% of the solids can pass through it and **“The Work index, $W_i$”** which is a constant value proper to each solid that represents the energy required to grind down a very large feed to such a size that 80% of it passes 100 mesh screen. The higher the value of the work index the harder it will be to grind the solid. Values of $W_i$ have been tabulated for a large number of materials.

Table (4.1) gives some values (in units of kWh.m$^{1/2}$t$^{-1}$)

<table>
<thead>
<tr>
<th>Material</th>
<th>Work index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>8.78</td>
</tr>
<tr>
<td>Cement clinker</td>
<td>13.45</td>
</tr>
<tr>
<td>Clay</td>
<td>6.30</td>
</tr>
<tr>
<td>Coal</td>
<td>13.00</td>
</tr>
<tr>
<td>Granite</td>
<td>15.13</td>
</tr>
<tr>
<td>Gravel</td>
<td>16.06</td>
</tr>
<tr>
<td>Limestone</td>
<td>12.74</td>
</tr>
</tbody>
</table>

The Bond’s equation is:

$$P = 36.W_i.\dot{m}.\left(\frac{1}{\sqrt{D_{b2}}} - \frac{1}{\sqrt{D_{b1}}}\right)$$  \hspace{1cm} (4.5)

The proper units to be used are: $\dot{m}$ in kg.s$^{-1}$ and $D_{b2}, D_{b1}$ in m.
The constant 36 is used whenever wet grinding is performed. **In case of dry grinding, this figure has to be multiplied by a factor of (4/3).** The values of power calculated by the previous formula represent the “theoretical power” required for size reduction. Actual powers can range from 2 to 20 times the calculated figures.

Example 4.1
In dry crushing of limestone, lumps of 50 mm size have their size reduced to 10 mm. Estimate the theoretical power required for a feed rate of 20 tph.

**Solution:**
According to Bond’s law, the power is:

\[
P = \frac{36 \times 20000 \times 12.74}{3600} \left(\frac{1}{\sqrt[0.01]{}} - \frac{1}{\sqrt[0.05]{}}\right) = 14100 \text{ W (19.2 hp)}
\]

Since dry operation is effected, this figure has to be multiplied by 4/3 to give a power consumption of **18800 Watt (25.6 hp)**.

Example 4.2
A batch crusher is run at constant power input. It was found that 30 minutes of operation were necessary to reduce the average particle size from 100 mm to 10 mm. How long would it take to reduce the particle size to 5 mm?

**Solution:**
1- Using Rittinger’s law:
   Since the amount to be crushed and the power are constant then the law can be rewritten as:

\[
\frac{P \times t}{m} = K \left(\frac{1}{D_2} - \frac{1}{D_1}\right)
\]

Hence,

\[
P \times 30 = M \cdot K \left(\frac{1}{10} - \frac{1}{100}\right)
\]  
(1)

\[
P \times 30 = M \cdot K \left(\frac{1}{5} - \frac{1}{100}\right)
\]  
(2)

Dividing (2) by (1), we get:
Total time, \( t = 63.3 \text{ min.} \)

2- Using Kick’s law:
Here also, the equation can be written twice to give:

\[
P \times 30 = \log \frac{100}{10}
\]  
(3)

\[
P \times t = \log \frac{100}{5}
\]  
(4)

Dividing, we get:
Total time, \( t = 39 \text{ min.} \)
3- Using Bond’s law, on the assumption that the average diameters can be identified with the Bond’s diameters:

\[ P \times 30 = 36 \times m \times W_i \times \left( \frac{1}{\sqrt{0.01}} - \frac{1}{\sqrt{0.1}} \right) \]  
(5)

\[ P \times t = 36 \times m \times W_i \times \left( \frac{1}{\sqrt{0.005}} - \frac{1}{\sqrt{0.1}} \right) \]  
(6)

Dividing, we get:

Total time, \( t = 48.2 \text{ min.} \)

This example shows the discrepancies that are associated with the application of the different formulae to predict power or, alternatively, the time required to achieve certain fineness. It also shows that the result predicted by Bond’s law is roughly an average value of those predicted by the two other formulae.

4.4. Industrial Size Reduction Equipment

Size reduction equipment is divided into Crushers, Grinders, Ultrafine grinders and Cutting machines. Crushers do the heavy work of breaking large pieces of solids into smaller lumps. Primary crushers are run on materials out of mine the size of which may reach more than one meter and breaking it into 150 – 300 mm lumps. A secondary crusher reduces those lumps to particles in the size range of 5 – 10 mm. Grinders reduce crushed feed to powder. The product from an intermediate grinder will usually pass a 40 mesh screen (about 0.35 mm) while most of the product of a fine grinder will pass 200 mesh screen (0.074 mm). Ultrafine grinders will accept a feed of a few mm in size and reduce it to a product of sizes in the range 1 – 50 μm. Cutters will deliver particles of definite shape and size, typically a few mm in length.

The principal types of size reduction machines are:

1- Crushers:
   a- Jaw crusher
   b- Impact crushers
   c- Gyratory crushers
   d- Crushing rolls

2- Grinders:
   a- Hammer mills and other impact types
   b- Ball mills, Tube mills and Rod mills.
   c- Roller mills and bowl mills
   d- Attrition mills

3- Ultrafine grinders:
   a- Hammer mills with internal classification
   b- Fluid energy mills
   c- Agitated mills.

4- Cutting machines:
   a- Knife cutters.
In the following, some of these of machines will be considered in details:

4.4.1. **The jaw crusher** (Figure 4.1)

In a jaw crusher, feed is admitted between two jaws, a stationary jaw or anvil and a movable jaw, which reciprocates in a horizontal plane. It makes an angle of 20 - 30° with the stationary jaw. It is driven by an eccentric so that it applies great compressive force on the lumps caught between the jaws. Large lumps caught between the upper parts of the jaws are broken, drop in the narrower space below and are re-crushed the next time the jaws close. After sufficient reduction they drop out of the bottom of the machine. The jaws open and close from 250 to 400 times per minute. In the design shown in Figure (4.1), known as “Blake crusher” it is possible to regulate the maximum size of product by adjusting the maximum clearance between the two jaws at their lower parts using a spring. In this type, the pivot at which the movable jaw is fixed is located at the top of this jaw. This decreases the possibility of choking at the outlet of the crusher. Size reduction in jaw crushers occurs mainly by a compression mechanism and to lower extent by impact.

![Fig (4.1) A Blake Type Jaw Crusher](image)

4.4.2 **Impact crushers**

While in a jaw crusher breaking of feed lumps takes place mainly by compression, some crushers operate on an impact principle.

(i) The **Hazemag** crusher shown in Figure (4.2) is fed from a large inlet opening with large lumps that are thrown onto abrasion resistant apron blocks, usually made of high manganese steel (11 to 14%). Two rotors sustain particle motion towards the outlet opening. Size reduction essentially proceeds by impact on apron blocks. This crusher is of primary type often handling ore lumps that can reach 1 meter in size.

(ii) The **hammer crusher** (which can also operate as mill) contains a high-speed rotor turning inside a cylindrical casing. The shaft is horizontal and swing hammers are pinned to the rotor disk. As this latter revolves at peripheral speeds reaching 10 m.s⁻¹, these hammers direct themselves towards the radial directions of the disk and
hit the dropping feed breaking its particles to small fragments. The speed of revolution (rps) depends on the rotor diameter $D$. This is since:

$$v = \omega R = \pi n D$$  \hfill (4.6)

For example for a rotor diameter of 0.25 m, at a linear tip velocity of 8 m.s$^{-1}$, the speed of revolution will equal 10.2 rps (612 rpm).

Solid chunks are projected onto the internal walls of the casing and break into smaller pieces, which can still be subjected to more hammer action. Finally the outgoing solids are discharged after passing over a bottom screen. The rotor disks are 150 – 450 mm in diameter and can carry 4 to 8 hammers. Hammer crushers can handle solid feed in the $10^2$ mm size range and the discharged solids are in the size range of $10^1$ mm.

Alternatively, hammer mills can also be designed to work as intermediate crushers in which case, they will produce a product in the size range of $10^0$ mm. Figure (4.3)

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**Fig (4.2) Hazemag impact crusher**

**Fig (4.3) Hammer crusher**
4.4.3 Gyratory crushers (Figure 4.4)

Gyratory crushers are designated in size either by the gap and mantle diameter or by the size of the receiving opening. One common type, the gyratory cone crusher can be used for primary or secondary crushing. The crushing action is caused by the closing of the gap between the mantle line (movable) mounted on the central vertical spindle and the concave liners (fixed) mounted on the main frame of the crusher. The gap is opened and closed by an eccentric on the bottom of the spindle that causes the central vertical spindle to gyrate. The vertical spindle is free to rotate around its own axis. The crusher illustrated is a short-shaft suspended spindle type, meaning that the main shaft is suspended at the top and that the eccentric is mounted above the gear. Crushing is mainly due to compression and attrition mechanisms.

![Gyratory cone crusher](image)

**Fig (4.4) Gyratory cone crusher**

4.4.4. Crushing rolls (Figure 4.5)

This type of crusher represents what is known as an *intermediate crusher*. Typically, the feed consists of particles of size 10 - 75 mm and their product ranges from 1 to 10 mm. It consists of a pair of smooth face metal rolls turning on parallel horizontal axes. Particles of feed caught between the two rollers are crushed by compression and drop out below. The two rollers turn at the same speed towards each other. Common roller diameters range from 600 mm to 2000 mm while their face length range from 300 mm to 1000 mm. The rotational speed ranges from 50 to 300 RPM. The optimum operation of rollers takes place when they operate at a crushing reduction ratio of 3:1 or 4:1 ($D_{p\text{feed}}:D_{p\text{product}}$)

The roller diameter required for a certain crushing operation can be estimated whenever the maximum clearance between the two rollers is known; this corresponds to the maximum diameter of product. An important parameter to be dealt with is the **angle of nip, $n$** which 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. As seen from Figure (4.5) $\beta = 2\alpha$. 

45
Referring to Figure 4.5 (b), let a particle of radius $r$ be drawn between the two rollers. If the coefficient of friction between the crushed material and the crusher surface is $\mu$, then a necessary condition for particles to get admitted between the rollers is:

$$\mu > \tan \alpha$$

This inequality governs the permissible values of $\alpha$.

In Figure (4.4), let $D_1$ represent the diameter of the incoming particle and $D_2 = 2e$ that of the largest particle in crushed product. Also let $D$ be the roller diameter and $R$ its radius. We can deduce that:

$$\cos \alpha = \frac{R+e}{R+0.5D_1} = \frac{2R+2e}{2R+D_1} = \frac{D+D_2}{D+D_1}$$

The values of the angle of nip, $2\alpha$ usually vary from 20 to $30^\circ$. 

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**Fig 4.5 (a) Crushing Rolls**

**Fig 4.5(b) Angle of nip**
Example 4.3
Crushing rolls are used to reduce the size of a feed consisting of 20 mm diameter particles to a 5 mm product. The angle of nip is 30°. Estimate the diameter of the required rolls.

Solution:
Applying Eq. (4.8), one gets:
\[
\cos 30 = \frac{D+D_2}{D+D_1} = \frac{D+5}{D+20}
\]
From which \( D = 420 \) mm

4.4.5 Ball mills and related types
These types of mills constitute a special category also known as Tumbling mills. They are constituted of a cylindrical (or conical) shell rotating on a horizontal axis and are charged with a grinding medium of steel, porcelain, flint balls or steel rods. The main types in this category are:

a- The ball mill of length almost equal to its diameter
b- The tube mill of length greater than the diameter usually used when a finer product is desired.
c- The compartment mill which is a combination of the above types consisting of a cylinder divided into compartments separated by screens such that preliminary and final grinding take place in the first and in the last compartment respectively.
d- The rod mill in which the grinding medium consists of rods rather than balls and is known to deliver a more uniform size distribution.

These mills may be batch or continuous, they may achieve dry or wet grinding. A batch ball mill will simply consist of a cylinder (\( D \sim L \)) rotating round a central shaft mounted over two bearings brackets. The balls as well as the feed are charged through an opening in the lateral wall and discharge is made through an opening just opposite to the charging manhole. In case of wet grinding, the discharge opening is fitted with a valve to regulate the flow of slurry. Discharge often takes place by sweeping the ground slurry by means of a stream of compressed air. Figure (4.6) shows a batch ball mill used for dry grinding.

![Batch ball mill for dry grinding](image)
Continuous ball mills on the other hand are charged and discharged through hollow trunnions at both ends (Figure 4.7). If wet grinding is effected, then the slurry pours out of the discharge opening continuously. In case of dry grinding, the mill has to be air swept in order to remove the fine product. In that case, compressed air is blown at one end and is discharged at the other end entraining the fine product particles. These have to be separated from the main air stream.

Wet milling is used whenever the material is not water sensitive or will be used as a slurry on further processing (e.g. in the ceramic industry). This provides better homogenization, consumes less power and decreases the possibility of overgrinding.

Dry grinding, on the other hand, will be used whenever the material is to be processed in the dry state (e.g. in coal and cement industries).

Fig (4.7) A continuous ball mill

Speed of ball mill operation

The speed at which a ball mill is made to rotate plays an important role in determining the efficiency of the grinding operation. If the speed is too low, the balls may simply oscillate along the wall without serious grinding. There is, however, a maximum limit to the speed at which a ball mill can rotate. This is termed the critical speed $N_{\text{crit}}$ (RPM).

This speed is calculated as follows: During the mill operation, the balls move peripherally along the cylindrical wall and whenever the force of gravity overcomes the centrifugal force, a ball will simply fall down on the charged material performing the breaking operation by impact. If the speed is too high, then the ball may simply go on moving along the wall, the force of gravity being always less than the centrifugal force, a state known as Centrifugation.

The maximum speed is that at which a ball having reached the highest altitude (at the extremity of a vertical diameter) will now drop vertically. Under such condition, the force of gravity $mg$ is exactly balanced by the centrifugal force $\frac{mv^2}{R-r}$ (Figure 4.8)
Where:
\[ g = \text{acceleration of gravity} = 9.81 \, \text{m.s}^{-2} \]
\[ v = \text{peripheral velocity, ms}^{-1} \]
\[ R = \text{radius of mill, m.} \]
\[ r = \text{radius of ball, m.} \]

Hence \[ mg = \frac{mv^2}{R-r} \]

Or \[ v^2 = g.(R-r) \]

Since \( v = \omega.(R-r) \), we get:
\[ \omega^2.(R-r)^2 = g.(R-r) \]

\[ \omega = \sqrt{\frac{g}{R-r}} \]

Since \( \omega = \frac{2\pi N}{60} = \sqrt{\frac{g}{R-r}} \)

Substituting for \( D = 2R \) and \( d = 2r \), we get:
\[ N = \frac{42}{\sqrt{D-d}} \]  
(4.9)

Actual speeds are in the range of 65 – 75 % of the critical.

**Example 4.4**

Suggest suitable operating speed of a ball mill of 1 meter in diameter charged with 5 inch steel balls.

**Solution:**
\[ D = 1 \text{ m. and } d = 5 \times 0.0254 = 0.127 \text{ m.} \]

Substituting in Equation (4.9), we get \( N_{\text{crit}} \approx 45 \text{ RPM} \)

Since the operating speed is about 70\% of the critical speed, hence a reasonable speed is: \( N = 32 \text{ RPM} \)

**Size of Balls**

There is a general rule concerning the size of balls, that is, a coarser feed needs greater balls. In general, the ball diameter \( d_B \) (mm) is related to the size of the Bond diameter of product \( D_{b2} \) (micron) by:

\[
d_B = 1.13 \times \sqrt{D_{b2}} \times \frac{\rho_p W_i}{s \sqrt{D}} \tag{4.10}
\]

Where:

- \( W_i \) is the work index
- \( \rho_p \) is the particle density (g.cm\(^{-3}\))
- \( s \) is the ratio between actual and critical speed of mill (0.65 – 0.75)
- \( D \) is the mill diameter (m)

The diameters of the balls tend to decrease on prolonged operation due to wear and the worn balls have to be replaced by new ball charges.

**Ball and Material Charges**

The bulk volume of balls fed to a ball mill is usually expressed as a fraction of the volume of the mill \( (f) \). So that if the mill diameter is \( (D) \) and its length \( (L) \), then the bulk volume of balls is:

\[
V_{Bb} = \frac{\pi}{4} D^2 \cdot L \cdot f \tag{4.11}
\]

The bulk density of balls being obtained from \( \rho_{ball} (1 - \varepsilon) \), then the mass of balls is:

\[
M_b = \frac{\pi}{4} D^2 \cdot L \cdot f \cdot \rho_{ball} (1 - \varepsilon) \tag{4.12}
\]

In practice, the static porosity is about 40\% and the density of steel balls is about 7800 kg.m\(^{-3}\). Ball charges vary from 20-40\% for dry grinding and from 40 – 60\% for wet grinding.

Material charge on the other hand, is based on the voids ratio between the balls in the static condition. A **common material to void ratio is 1**. This means that the solid feed just fills the pores between the grinding balls. Therefore, if the bulk density of solid feed is \( \rho_{Bf} \) then the mass of the feed charge can be calculated from the equation:

\[
M_b = \frac{\pi}{4} D^2 \cdot L \cdot f \cdot \rho_{Bf} \cdot \varepsilon \tag{4.13}
\]

**Example 4.5**

A ball mill of diameter = 1.5 m and length = 2 m is to be charged with 40\% of its volume alumina balls of specific gravity = 3.2. It is used to dry grind limestone of bulk
density = 1600 kg.m⁻³. Estimate the mass of balls and that of charge. (Void ratio between balls = 0.45)

**Solution:**

\[ D = 1.5 \text{ m}, \ L = 2 \text{ m}, \ \varepsilon = 0.45, \ \rho_b = 3200 \text{ kg.m}^{-3}, \ \rho_{bf} = 1600 \text{ kg.m}^{-3}, \ f = 0.4 \]

From equation (4.12):

\[ M_b = \frac{\pi}{4} \times 1.5^2 \times 2 \times 0.4 \times 3200 \times (1 - 0.45) = 2488 \text{ kg} \equiv 2.5 \text{ ton} \]

From equation (4.13):

\[ M_b = \frac{\pi}{4} \times 1.5^2 \times 2 \times 0.4 \times 1600 \times 0.45 = 1018 \text{ kg} \]

**Internal Lining of the Mill**

Owing to the often erosive character of the solids to be handled in a ball mill, it is customary to line the mill internally with an abrasion resistant material. This material should be, on the average, of close nature to the material of the balls so as not to abrade the balls causing contamination of the product. Whenever a moderately hard material is to be ground (such as limestone), the balls are made of alloy steel (usually of the high manganese type) and the linings of the mill are made from hard steel. If a soft material is processed, such as kaolin, then the balls are made of porcelain or alumina and the linings consist of alumina sheets. If a very hard material is involved, such as quartz, then the balls are made from flint gravel (A variety of silica). These balls are only spheroidal in shape but with continuous use they will eventually acquire a spherical shape. In that case, the linings are made of quartzite bonded grains strongly glued onto the internal surface of the mill. Recently, there has been an increasing trend to line mills with rubber linings since it can deal with versatile solids (Figure 4.9).

![Fig (4.9) Rubber lining with holders](image)

**Open and Closed circuit grinding**

In many cases the feed is ground to the required size inside the mill and no attempt is made to return oversize particles to the mill for further grinding. This is called **open circuit grinding**. This results in loss of power because of overgrinding already fine particles.

In case of fine grinding it is more economical to remove partially ground material from the mill and pass it through a separating device. This latter is sometimes integrated within the mill. For example, in tube mills there may be several compartments separated by screens. On the other hand, this device may be outside the mill. This is the case in **closed circuit grinding** where the oversize is separated in a classifier or a cyclone and recycled to the mill. Figure (4.10) shows such arrangement.
4.4.6 Vertical Roller Mills

Ball and tube mills are traditionally used in most chemical and allied industries for fine grinding. However, there is a growing trend toward the use of vertical roller mills (VRM) which simultaneously grind and classify the milled product. Figure (4.11) shows such a mill. In this type, two or three vertical rollers are used to grind a continuous feed stream on a rotating horizontal table. Compressed air is continuously fed upwards that transports the fine ground powder to a size classifier fixed on top of the mill. Oversized particles leave the classifier to drop on the grinding table.
4.4.7 Ultrafine grinders

**Disintegrators**
Desintegrators (or pulverizers) are used to continuously deliver a product of high fineness (particle size ~ few microns).

A pulverizing machine like the one shown in Figure (4.12) consists of a rotor running inside a 360° screen enclosure. The rotor includes a number of hammers designed to run at fairly close clearance relative to the inside of the cylindrical screen enclosing the disintegration chamber. The hammers are normally fixed rigidly to the shaft by keyways, pins or welding, but swing hammers are used when indicated.

**Fluid energy mills**
In the most common class of such mills the fluid streams convey the particles at high velocity into a chamber where two streams impact upon each other. Usually particles are conveyed with the jet where there is a high-energy release and a high order of turbulence which causes the particles to grind upon themselves and to be ruptured. Not all the particles are fully ground; so it is necessary to carry out a classifying operation and to return the oversize for further grinding. This happens at the upper bend in Figure (4.13) where the coarser particles are thrown outward against the wall while the fines accumulate at the inner wall. A discharge opening in the inner wall at this point leads to a cyclone and a filter for the product. Most of these mills utilize the energy of the flowing-fluid stream (usually air or steam) at 7 atm. to effect a centrifugal classification.

![Fig (4.12) A pulverizing machine](image)
4.5 Size Reduction Practice

Because of the large number of equipment involved it is necessary to make the proper choice when a given material is to be crushed and / or ground. This depends on several factors among which are:

4.5.1 Grindability

The measure of the grindability of a material under specified grinding conditions is the volume of material removed per unit volume of wheel wear. This definition requires a specific testing apparatus working under some standard conditions of load and rotating speed. Usually, the Bond work index can be taken as an accurate indicator for grindability.

4.5.2 Nature of the material to be ground

A different type of equipment is necessary when shifting from a hard coalescent material to a material of flaky nature. Also, if the required product is to have a spheroid shape, then it is not recommended to use vertical mills for that purpose. This is since their product tends to assume a flaky shape.

4.5.3 The capacity of the grinding unit

Some crushers or grinders are more suited than others for small capacities.

4.5.4 The required fineness

If the material is to be ground to a very fine product it is usual to use internal classification or closed circuit grinding to avoid material loss.

Table (4.2) summarizes the crushing and / or grinding equipment used in for size reduction of some common materials.
Table (4.2): Size reduction equipment for some specific purposes

<table>
<thead>
<tr>
<th>Material</th>
<th>Crushing</th>
<th>Grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>Roller mill</td>
<td></td>
</tr>
<tr>
<td>Oil pressed cakes</td>
<td></td>
<td>Attrition mill</td>
</tr>
<tr>
<td>Starch</td>
<td></td>
<td>Hammer mill</td>
</tr>
<tr>
<td>Iron ore</td>
<td>Impact crusher</td>
<td>Rod mill – Ball mill</td>
</tr>
<tr>
<td>Clays</td>
<td>Jaw or impact crusher</td>
<td>Roller mill – Ball mill</td>
</tr>
<tr>
<td>Talc</td>
<td>Jaw crusheer – Crushing rolls</td>
<td>Closed circuit dry ball mill</td>
</tr>
<tr>
<td>Limestone, dolomite</td>
<td>Jaw or impact crusher</td>
<td>Roller mill – Tube mill</td>
</tr>
<tr>
<td>Silica – Feldspar</td>
<td>Impact crusheer</td>
<td>Quartzite lined ball mill</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Jaw or Gyratory or Impact crusheer</td>
<td></td>
</tr>
<tr>
<td>Phosphate rock</td>
<td>Jaw crusheer</td>
<td>Roller mill</td>
</tr>
<tr>
<td>Cement raw materials</td>
<td>Jaw crusheer</td>
<td>Tube mills</td>
</tr>
<tr>
<td>Cement clinker</td>
<td></td>
<td>Tube mills – Roller mill</td>
</tr>
<tr>
<td>Gypsum</td>
<td>Impact crusheer</td>
<td>Tube mill for calcined product – Roller mill</td>
</tr>
<tr>
<td>Asbestos</td>
<td>Jaw crusheer with vacuum elimination of fine debris</td>
<td>Hammer mill with vacuum elimination of fine debris</td>
</tr>
<tr>
<td>Coal, Anthracite, Charcoal</td>
<td></td>
<td>Hammer mill – Ball mill (Internal classification)</td>
</tr>
<tr>
<td>Dry colors, Dyes</td>
<td></td>
<td>Hammer mill</td>
</tr>
<tr>
<td>White pigment (Titania)</td>
<td></td>
<td>Ball or Pebble mill – Roller mill</td>
</tr>
<tr>
<td>Sulphur</td>
<td></td>
<td>Roller mill with inert gas classification</td>
</tr>
<tr>
<td>Gums – Resins</td>
<td>Crushing rolls</td>
<td>Hammer mill – Roller mill</td>
</tr>
<tr>
<td>Hard rubber</td>
<td>Heated crushing rolls with screening and recycle</td>
<td></td>
</tr>
<tr>
<td>Peanut shells</td>
<td></td>
<td>Hammer mill</td>
</tr>
</tbody>
</table>