SIZE REDUCTION

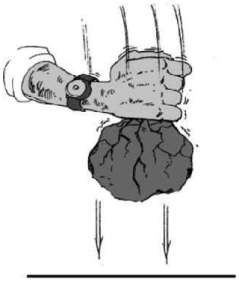
Size Reduction

- **Size reduction :** The process of converting the object from one physical dimension of higher order to another dimension of smaller.
- **Communition** is another term used for size reduction

Objectives of Size Reduction

- To increase the **surface area**
- To get the desired **shape, size or size ranges** and **specific surface** particles
- To separate **unwanted particles** effectively
- To dispose **solid waste** easily
- To **mix** solid particles more **intimately** and
- To improve the **handling (storage and transportation)** characteristics

Methods



Impact (hammer)

Impact

- The particle is subjected to a **single violent force**.
- **Instantaneous collision** of one moving object against another
  - Both objects may be moving, Ex: Cricket bat connecting with a fast moving ball
  - One object may be motionless, Ex: Rock being struck by a hammer below

Gravity impact: The free falling material is momentarily stopped by the stationary object

Ex: coal dropped onto a hard steel surface

- Most often used when it is necessary to separate relatively different friable materials

Friable: Something that is crumbly is easily broken into lot of little pieces

- The more friable is broken first, while the less friable remains unbroken

Dynamic impact: Ex: Materials dropped in front of a moving hammer

- The material is unsupported and the force of impact accelerates movement of the reduced particles towards the breaker plate and/or other hammers.
- Needed for cubical particles, materials are too hard and abrasive and the product must meet intermediate size specifications

Compression

- 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 the surfaces.
- **Jaw crushers using this method** of size reduction are suitable for reducing extremely hard and abrasive rock.

  - Both objects may be moving, Ex: Cricket bat connecting with a fast moving ball
  - One object may be motionless, Ex: Rock being struck by a hammer below

Chosen: The free falling material is momentarily stopped by the stationary object

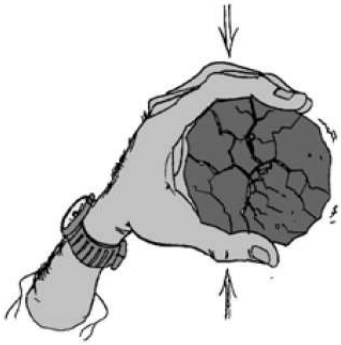
Ex: coal dropped onto a hard steel surface

- If the material is **hard** and **tough**
- If the material is **abrasive**
- If the material is **not sticky**
- If the finished product is to be relatively **coarse** in size
- When the material will **break cubically**

Attrition (file)

Attrition

- **Rubbing or scrubbing** the materials between two surfaces.
- Hammer mills operate with the close clearance between the hammers and screen bars, reduce the size of the materials by **attrition combined with shear and impact actions**.
- Though it consumes more power , it is **proffered** for crushing the **less abrasive** materials such as limestone and coal.
- It is most **useful** when the material is **friable** or **not too abrasive** and a closed circuit system is not desirable to control the oversize.

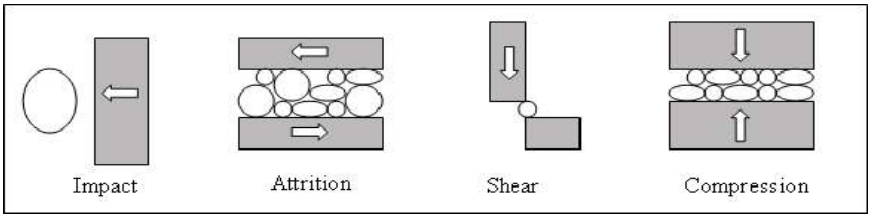


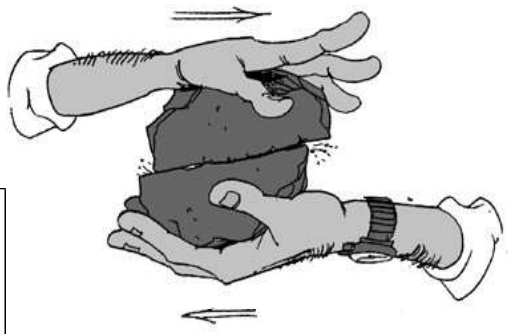
Compression (nutcracker)

Shear

- **Trimming or cleaving** action rather than rubbing action associated with attrition.
- It is usually combined with other size reduction actions.

  Ex: Single roll crushers employ shear together with impact and compression.
- It is needed for friable material , primary crushing with a reduction ratio of 6 to 1 and
- Production of relatively coarse product.



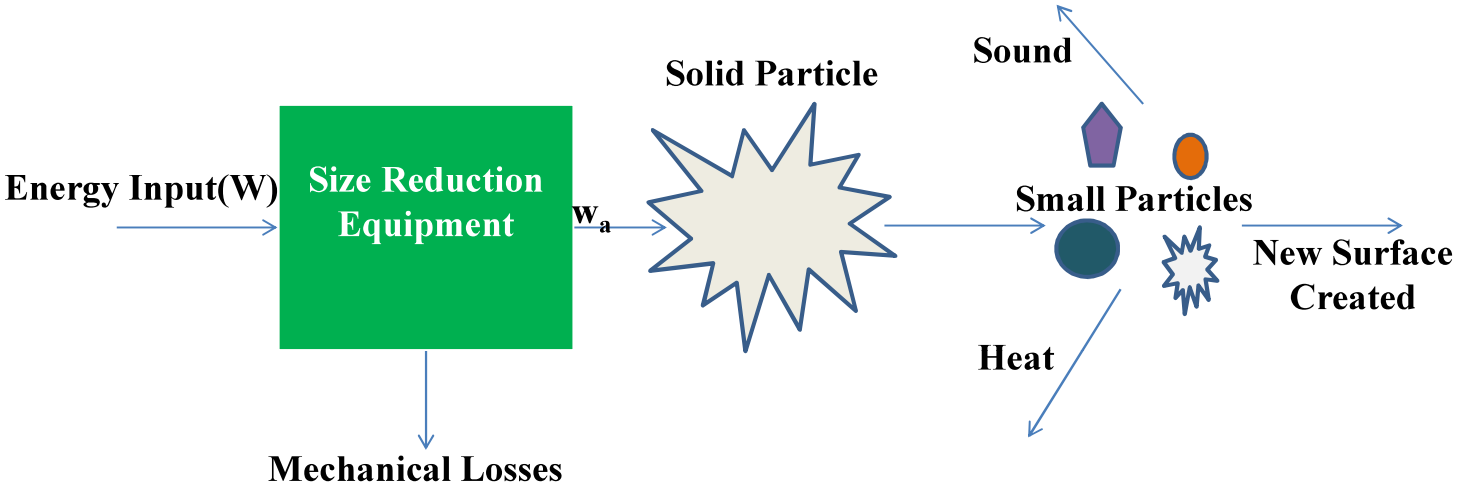


Shear

Factors affecting the size reduction process

a) Presence of moisture and sticky materials in equipment's feed
b) Presence of fines in the feed
c) Segregation of feed particles in the crushing chamber
d) Lack of feed control
e) Wrong motor size
f) Insufficient crusher discharge area
g) Insufficient capacity of the crusher's discharge conveyor
h) Materials being extremely hard to crush
i) Surface energy of solids
j) Power consumption
k) Selection of an appropriate crushing chamber

Energy and Power Consumption



Crushing Efficiency

- The ratio of surface energy created to the energy absorbed by the solid.
- The ratio of energy absorbed by the solid to form heat and energy input to the machine
- Range: 0.001 to 1 %.
- **Quantities needed:**
- **Total energy input** : Measured either by mechanical means or by electrical instruments
- **Energy lost during size reduction** : difficult to measure but may be measured in terms of energy consumption
- **Total new surface created**: determined by size distribution or by flow through a powder bed or by the adsorption of gas molecules on the powder surface , gas diffusion, and heats of adsorption
- **Specific surface energy** : indirect methods based on mathematical utilization of physicochemical quantities

Determination of Power Consumption

$$\eta_c = \frac{Surface\ energy\ created\ by\ crushing}{Total\ energy\ absorbed\ by\ the\ solid}$$

- W_a = Total energy absorbed by a unit mass of solid, J/Kg
- E_s= Surface energy per unit area, J/m^2
- A_{ssf}, A_{ssp} = Areas per unit mass of feed and product respectively(Specific Surfaces), m2/kg
- The surface energy created by crushing will be $E_s\ (A_{ssp} - A_{ssf})$

$$\eta_c = \frac{E_s\ (A_{ssp} - A_{ssf})}{W_a} \rightarrow \quad W_a = \frac{E_s\ (A_{ssp} - A_{ssf})}{\eta_c}$$

- Mechanical Efficiency : $\eta_m = \frac{Total\ energy\ absorbed\ by\ the\ solid}{Total\ energy\ fed\ to\ the\ machine} = \frac{W_a}{W} \quad \rightarrow W = \frac{W_a}{\eta_m}$

$$W = \frac{E_s\ (A_{ssp} - A_{ssf})}{\eta_m \eta_c}$$

$$P - W.m$$

$$A_s = \frac{6}{\Phi \rho_p D_{vs}}$$

$$P = \frac{E_s\ (A_{ssp} - A_{ssf})\ m}{\eta_m \eta_c}$$

$$P = \frac{6E_s m}{} \left[\frac{1}{} - \frac{1}{}\right]$$

Laws of Communition

Rittinger's Law : The work required for size reduction is proportional to the new surface area created.

$$W_R = \frac{P}{m} = KE_s\,(A_{ssp} - A_{ssf})$$

$$K = \frac{1}{\eta_c}$$

$$W_R = \frac{P}{m} = 6\,KE_s\left[\frac{1}{\Phi_p D_{vsp}\rho_{pp}} - \frac{1}{\Phi_f D_{vsf}\rho_{pf}}\right]$$

$$W_R = \frac{6\,KE_s}{\Phi_p \rho_p}\left[\frac{1}{D_{vsp}} - \frac{1}{D_{vsf}}\right] = K_R\left[\frac{1}{D_{vsp}} - \frac{1}{D_{vsf}}\right]$$

Rittinger's Num

Kick's Law : The work required for crushing a given mass of material is constant for a given reduction ratio irrespective of the initial size.

$$W_K = \frac{P}{m} = K_K \ln\left[\frac{D_{vsf}}{D_{vsp}}\right]$$

Laws of Communition

Bond's Law : The work required to form particles of size D_{pp} from a very large particle size is proportional to the square root of the surface to volume ratio of the product.

$$W_B = \frac{P}{m} = K\left[\sqrt{\frac{S_P}{V_P}}\right] = K\left[\sqrt{\frac{6}{\Phi_p D_{pp}}}\right] = K\sqrt{\frac{6}{\Phi}}\left[\sqrt{\frac{1}{D_{pp}}}\right] = K_B\sqrt{\frac{1}{D_{pp}}}$$

$$W_B = \frac{P}{m} = K_B\left[\sqrt{\frac{1}{D_{pp}}} - \sqrt{\frac{1}{D_{pf}}}\right]$$

Work Index: 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.

$$W_B = \frac{P}{m} = 0.3162\, W_i\left[\sqrt{\frac{1}{D_{pp}}} - \sqrt{\frac{1}{D_{pf}}}\right]$$

Generalized Law :

$$d(W) = d\left(\frac{P}{m}\right) = -K\,\frac{d\,(D_{vs})}{{D_{vs}}^n}$$

(n = 2, 1 and 1.5 for Rittinger's , Kik's and Bond's laws respectively)

Size Reduction Equipment

1. Mode of operation

a) Batch operated

b) Continuous operated

2. Method by which a force is applied

⟶ **Impact**

a) Impact at one surface

b) impact between particles

⟶ **Compression between two solid surfaces**

a) Crushing

b) Grinding

⟶ **Rubbing the materials between two solid surfaces**

3. Size of Feed and Product

4. Cutting machines - cutting

a) Knife cutters, dicers, slitters

Types of size reduction equipment

	Feed	Product
1. Crushers	large pieces into small lumps	
a) Primary crusher	very large lumps, run-of-mine material	150 to 250 mm
b) Secondary crusher	takes product from primary crusher	6 mm
2. Grinders	reduce crushed feed to powder	
a) Intermediate grinders		40 mesh screen
b) Fine grinders		200 mesh screen
3. Ultrafine grinders	Accepts feed < 6 mm	1 to 50 μm
4. Cutters		Definite size and shape (2 to 10 mm in length)

Classification of Size Reduction Equipment

1. Crushers (coarse & fine) - compression

- **a) Jaw crusher**
- **b) Gyratory crusher**
- **c) Crushing rolls**

2. Grinders (Intermediate & fine) - impact & attrition

- **a) Hammer mills and impactors**
- **b) Rolling-compression mills**
  - **(i) Bowl mills**
  - **(ii) Rolling mills**
- **c) Attrition mills**
- **d) Revolving/Tumbling mills**
  - **(i) Rod mills (ii) Ball mills; pebble mills, and (iii) tube mills**

3. Ultrafine grinders - attrition

- **a) Hammer mills with internal classification**
- **b) Fluid-energy mills**
- **c) Agitated mills**

4. Cutting machines - cutting

- **a) Knife cutters, dicers, slitters**

Crushers

- Slow speed machines for coarse reduction of large quantities of solids
- They operate by compression
- Can break large lumps of hard materials
- Find application in rockery and mining industries
- Types:
  - a) **Jaw crusher**
  - (i) **Blake jaw crusher**
  - (ii) **Dodge jaw crusher**
  - b) **Gyratory crusher**
  - **c) Smooth-roll crusher**

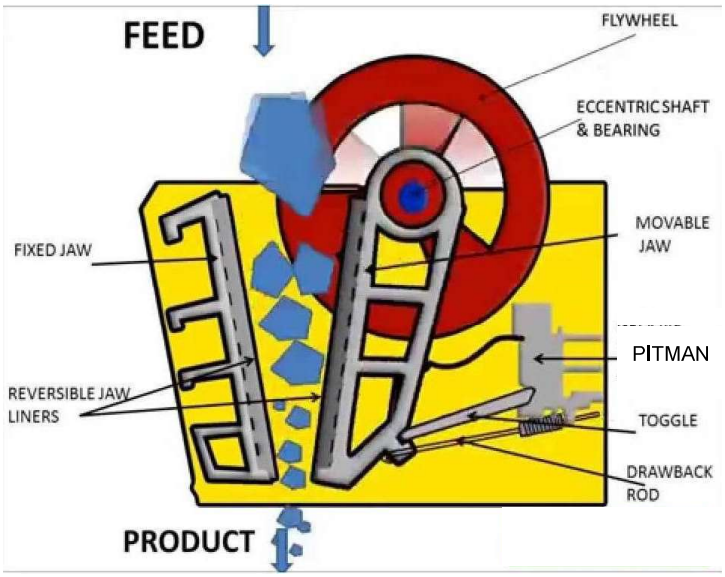
Jaw Crushers

- Compress the feed between a stationary jaw and a movable jaw

(i) **Blake jaw crusher** : movable jaw is pivoted at the top, maximum movement at the bottom

Blake Jaw Crusher - Construction

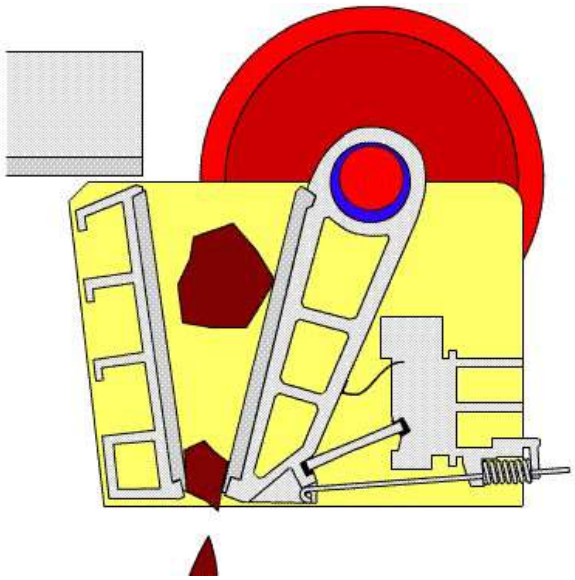
Working principle: **Compression**



- Fixed jaw and movable jaw (pivoted at top) form V-open
- Swinging jaw reciprocates in horizontal plane, makes an angle of 20-30° with the nearly vertical fixed jaw
- Jaws made of manganese steel to withstand abrasion
- Faces usually corrugated
- Eccentric- causes vertical oscillation of pitman, communicated horizontally (reciprocating motion) to the movable jaw by toggles
- Speed of operation - should not be high since fines cannot escape

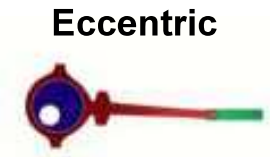
Protection: 2 toggles held by bolts that shear first, failure at easily repairable point

Blake Jaw Crusher - Working



- Material caught between upper part of jaws is crushed into smaller size during forward motion by compression
- Crushed material falls into narrow space during backward motion and is recrushed
- Crushed material drops out from bottom
- Jaws open and close at 250-400 times/min

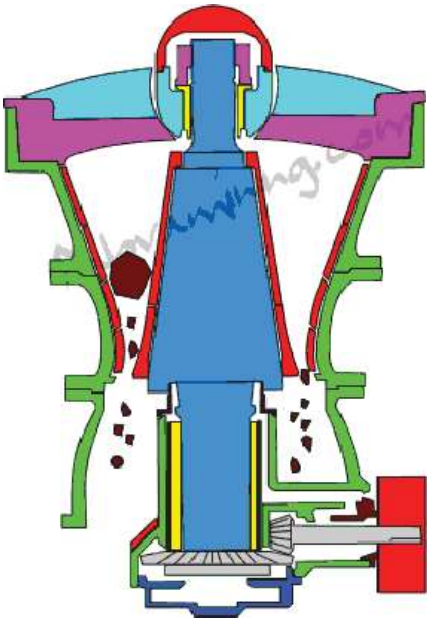
- Maximum movement of the jaw at the discharge end, less choking
- Loading is uneven, so heavy flywheel



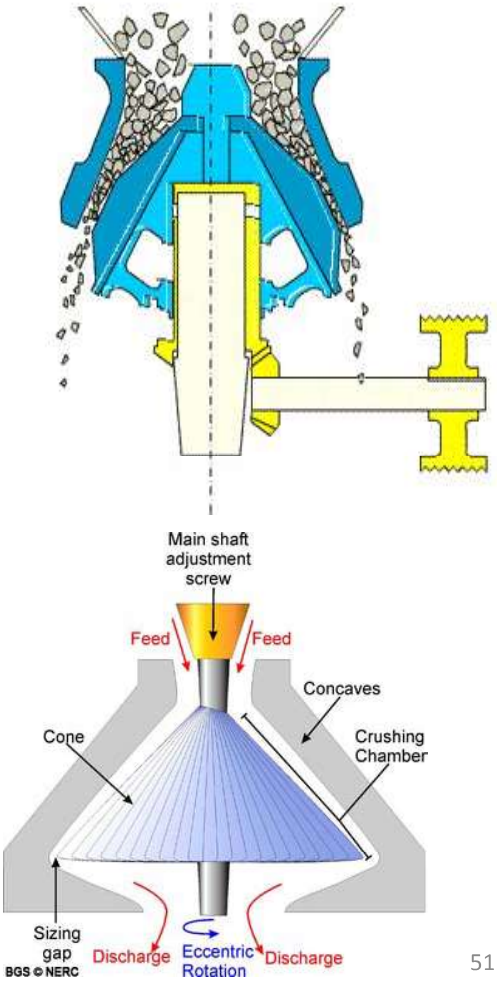
Blake Jaw Crusher

- Movable jaw is pivoted at top
- Maximum movement at bottom
- No tendency to choke/clog
- Suitable for higher production rates
- Large reduction ratio is not possible
- Low maintenance
- Made in larger sizes
- Does not give uniform product
- Widely used

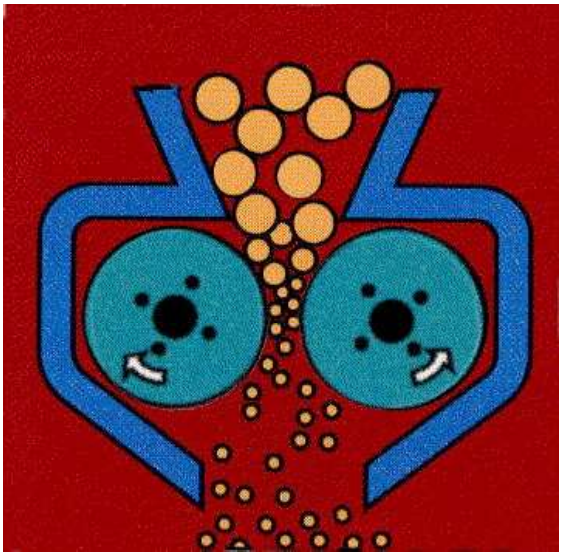
Gyratory Crusher



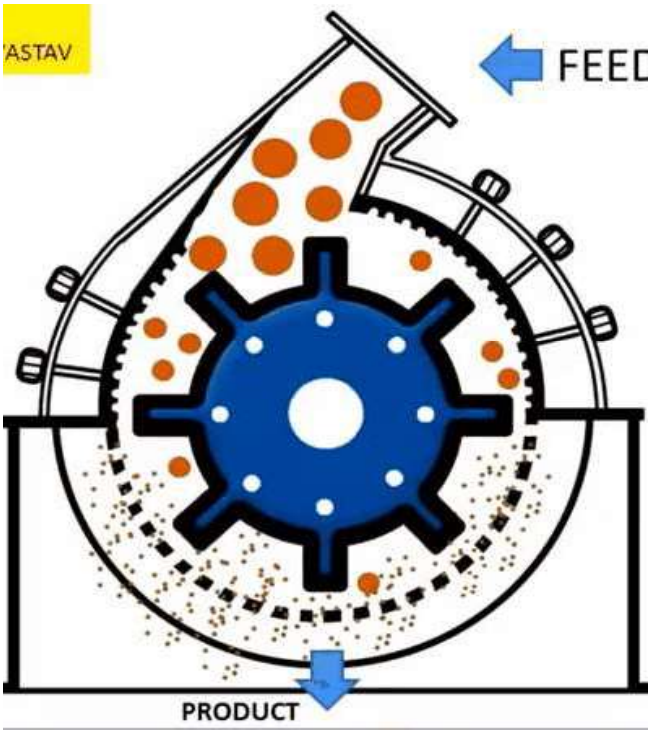
Cone Crusher



Roll Crusher



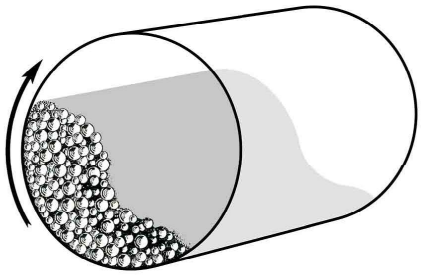
Grinders - Edge Runner Mill and Hammer Mill



Revolving / Tumbling Mills

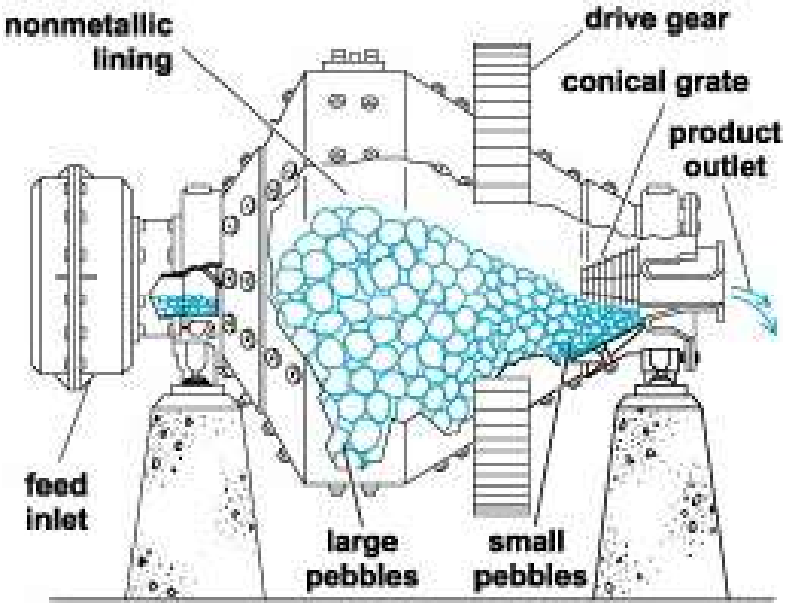
- Cylindrical shell slowly rotating on horizontal axis and charged with grinding medium to about half its volume
- Shell - steel; Lined with abrasion resistant materials (manganese steel, ceramic, or rubber)
- Operation - (a) Batch, (b) Continuous

Type	Reduced by	Grinding Medium
Ball mill (L=D)	Impact	Steel balls/ rubber/wood
Tube mill (L ≥ 2D)	Impact	Smaller balls (finer product)
Rod mill	Rolling, compression, attrition	Steel rods
Pebble mill	Impact	Flint/ceramic pebbles



Ball Mill - Construction

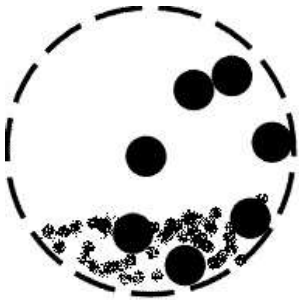
Principle: **Impact**
(when balls drop from near the top of shell)

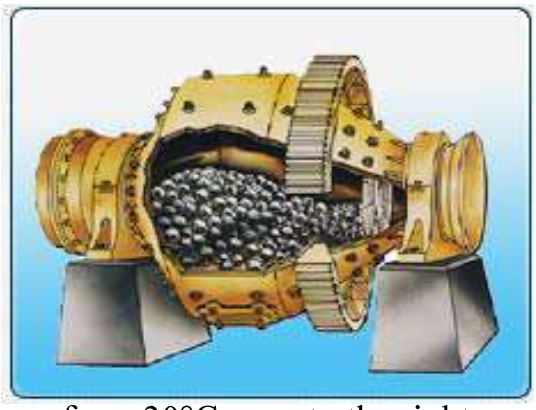


- Batch or continuous, wet or dry operation
- Large ball mill (3 m diameter, 4.25 m length)

- Hollow cylindrical shell (horizontal or slightly inclined) rotating about its axis at low speed using a drive gear (60 to 100 rpm)
- Length = diameter of mill
- Inner lining - abrasion resistant manganese steel or rubber
- Partially filled with balls made of steel, stainless steel or rubber
- Coarse screen at outlet - to prevent escape of balls
- **Balls**
- - occupy 30 to 50 % of mill volume
- - Diameter 12 to 125 mm
- - Optimum ball diameter
- $= \sqrt{Feed\ size}$

Ball Mill - Working





Continuous Operation

- Feed - from left through 60°C cone; Product discharge - from 30°C cone to the right
- Balls rise and then drop on feed; Solids are ground and reduced in size by impact
- When shell rotates, large balls segregate at feed end, small balls near product end
- Initial breaking – by large balls dropping from largest distance
- Small particles – by small balls from short distance
- If rate of feed ↑ coarse product obtained ↑
- If speed of rotation ↑ fineness for given capacity

Batch Operation

- After feeding, close opening
- Mill is rotated for a fixed time
- Stop mill and discharge product

Ball Mill

Applications:
To grind coal, pigments, and feldspar for pottery

WET GRINDING - at low speeds

- Low power consumption (20 to 30 % less than dry grinding)
- High capacity
- Dust reduction
- Necessary to dry the product
- High wear on grinding medium (20 % higher than dry grinding)

Factors influencing product size:

a) Feed rate
b) Properties of feed material
c) Weight of balls
d) Speed of rotation of mill
e) Level of material in the mill

BALL MILL - ADVANTAGES

- Low installation cost
- Low power requirement
- Suited for all degrees of hardness
- Batch, continuous mode
- Open, closed circuit grinding
- Explosive materials ground in inert atmosphere
- Grinding medium - cheap

Action in Tumbling Mills

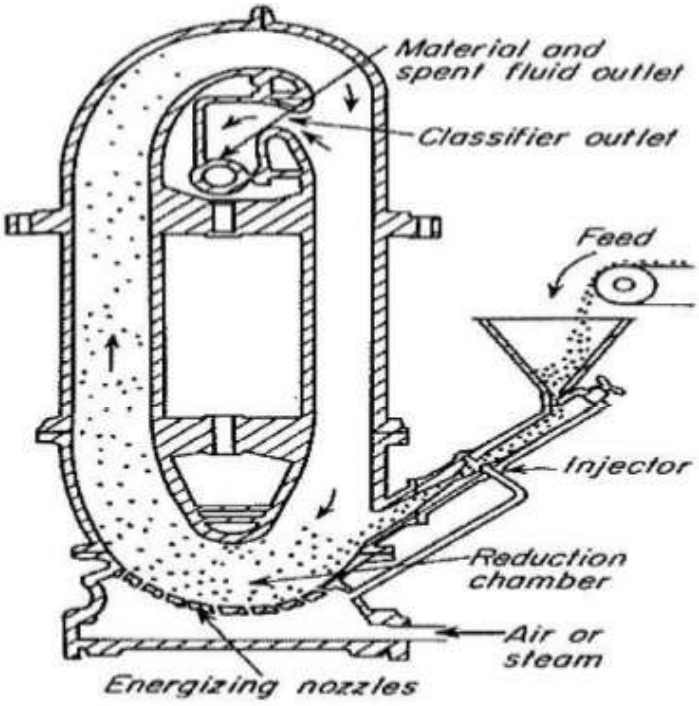
- During upward movement of balls - balls + wall in contact due to centrifugal force (some grinding due to slipping and rolling)
- Maximum grinding - when free falling ball strikes bottom by impact
- Balls are projected across mill depending on speed of rotation
  - Low speed – balls simply roll over - little crushing
  - High speed- balls carried up in mill & greater power consumption (greater impact, larger capacity)
  - Very high speed – balls carried round in contact with sides & mill is ***centrifuging***
  - Minimum speed at which centrifuging occurs - **critical speed of mill** (centrifugal force will be exactly balanced by weight of ball)
  - Little or no grinding when mill is centrifuging
  - Operating speed = 50 to 75 % of critical speed
  - **Critical speed,**

    R- radius of mill $N_c = \frac{1}{2\Pi}\sqrt{\frac{g}{R-r}}$

    r- radius of ball

    g - acceleration due to gravity

Ultrafine Grinders - Fluid Energy Mills



Effective Methods for Operating

- **Open Circuit Grinding:** 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.
- Conditions that favor open circuit grinding are small reduction ratios, coarse reduction of particles.
- **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.
- Conditions that favor closed circuit grinding are larger reduction ratios and finer reduction of particles.
- **Advantages:** higher capacity, lower power consumption, fine to ultrafine, avoids coarse material in final product, eliminates overgrinding of fines.

Size Reduction Equipment in Industry

1) Jaw crusher - cement industry
2) Ball mill - paint industry
3) Ultrafine grinders - Cosmetic, pharmaceutical
4) Cutters - Leather tanning
5) Hammer mill - Food industry