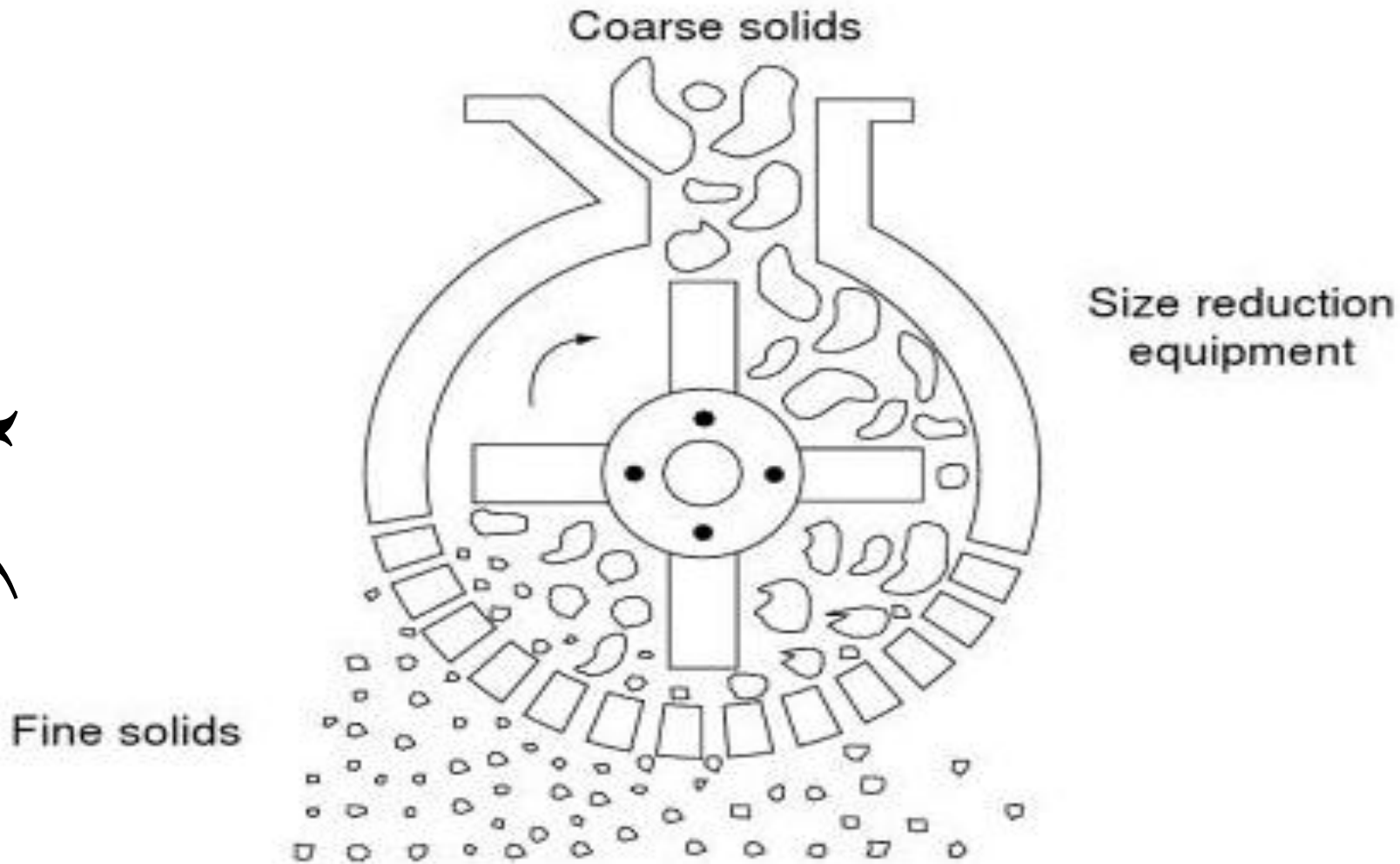


Chapter : Two

Size Reduction (communition)

Chapter : Two

Size Reduction (communion)



2.1.1 Introduction to Size Reduction

- **Size** → physical dimension or magnitude of an object.
- **Reduction** → the process of decreasing size.
- **Size reduction** = *the process of converting the object from one physical dimension of higher order to another of smaller order.*

or

- **Size reduction** *is the operation carried out for reducing the size of bigger particles into smaller ones of desired size and shape. This is accomplished with the help of external forces.*

2.1.2 objectives of size reduction

- It is almost carried out in every process industries for the following reasons:

I. To increase surface area

Eg : chemical rxn
: transfer rate } are directly proportional to the area.

II. To produce solid particles of desired shape , size and specific surface area

III. To separate unwanted particles effectively.

Eg: separation of minerals from ores

IV. To dispose solid wastes easily.

V. To mix solid particles more intimately.

VI. To improve the handling (storage and transportation) characteristics.

2.2 Mechanisms of Size reduction

- There are different size reduction equipments that employ different actions to solid particles for size reduction.
- There are four basic ways to reduce the size of material :
 - 1) **Impact** : instantaneous collision of one moving object against another. Both object may be moving.
 - 2) **Compression** : particle broken by two forces and reduction is done between two surfaces.
 - 3) **Attrition (Rubbing)** : method of size reduction by rubbing the materials between two hard surfaces.
 - 4) **Shear (cutting)** : knives are used to give a definite particle size and some times definite shape.

Types of size reduction	Feed Size
Coarse Crushers	50 - 250mm
Intermediate Crushers	25 - 75mm
Fine Crushers/grinders	5 - 15mm

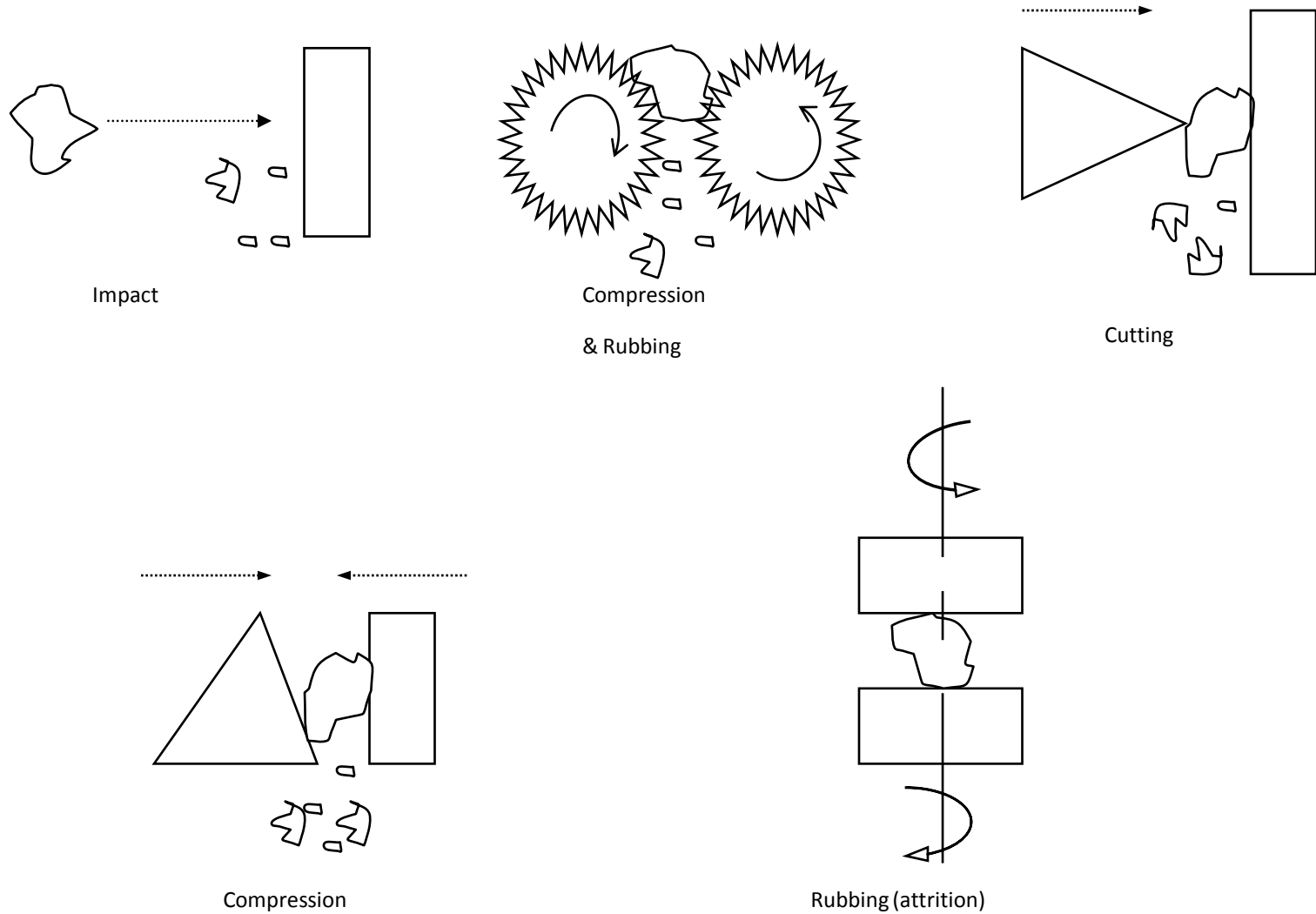


Figure 2.1:-The principal types of forces used in size reduction equipments

2.3 Principles of Size reduction

2.3.1 Factors Affecting Size Reduction

2.3.1.1 Properties of Solids

❖ **Hardness** : Resistance to scratching.

Measured using **Mohs Scale**

affects - power consumption and

- also causes wear on grinding machine.

Moh's hardness scale	product body	Degree of size reduction
1	talcum	soft
2	gypsum or salt	soft
3	calcite	soft
4	florite	medium
5	apatite	medium
6	feldspar	medium
7	quartz	hard
8	topaz	hard
9	corundum	hard
10	diamond	hard

- ❖ **Friability** : tendency to fracture during normal handling.
- ❖ **Toughness** : 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).
 - **Formation of cake followed by clogging the machine. Directly reduces the crushing effectiveness.**
 - **Too dry operations can result in excessive dust.**

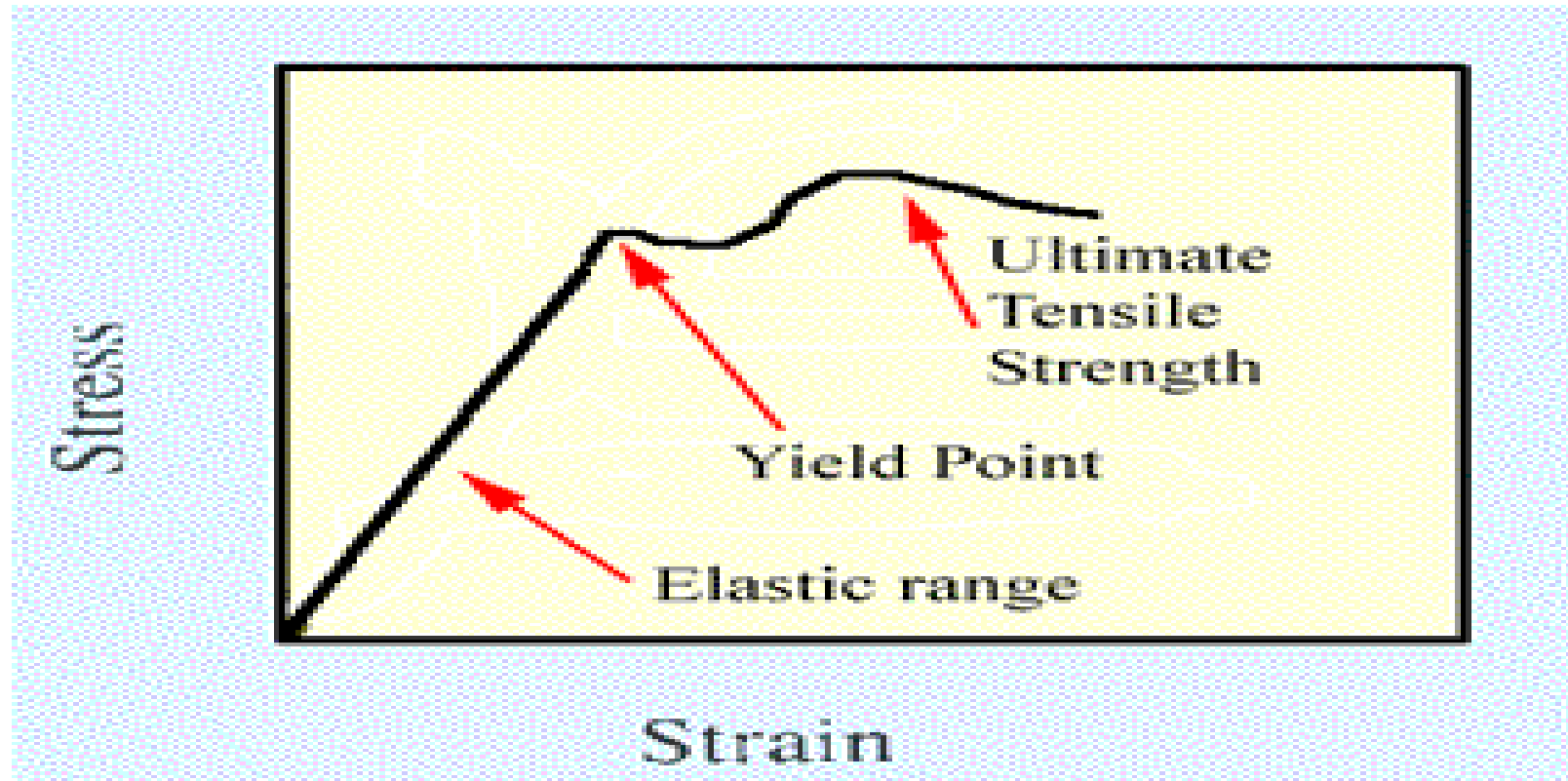
- ❖ **Explosive nature** : explosive materials should be ground under wet conditions or in the presence of an inert environment.
- ❖ **Soapiness** : is the measure of the coefficient () of friction of the surface material.
 - if the coefficient of friction is too low crushing will be more difficult.
- ❖ **Temperature sensitivity** : heat generated during size reduction can result in loss of heat-sensitive components from solids and
 - softening or melting may also cause clogging.

❖ **Crystallinity** : Every true solid material has specific **true crystalline structure**. That is the atoms in the crystals are arranged in a definite, repeating geometric pattern and there are certain planes in the crystal called **cleavage planes**, *along which breakage occurs when sufficient pressure is applied on the material.*

- When the material is broken into segments during Comminution, the shape of the segment **depends on its crystalline structure**.

- As a force is applied to a substance, it begins to deform. Unless the stress (force per unit area) exceeds the **elastic limit** or **yield point** the substance will return to its original shape when the force is removed, and the **stored energy is released as heat**.
- If stress is increased beyond the elastic limit, permanent deformation occurs until the breaking stress is exceeded - at this point the material fractures and **breaks along a line of weakness** (cleavage plane).

- As the size of a piece is reduced, there are fewer lines of weakness available, and the breaking stress which must be exceeded increases. There is therefore a substantial increase in energy requirement as the size of particles is reduced.



2.3.1.2. Energy and power Consumption in size reduction

- When external force is applied for size reduction:
 - 1st – the solid particles are twisted and strained.
(here the force is stored as mechanical force)
 - 2nd – if additional force is applied to the particle, beyond the particles ultimate strength, it will suddenly break down creating a new surface(which is smaller in size).

- Small amount out of the total energy supplied to the machine is utilized for the creation of new surface.

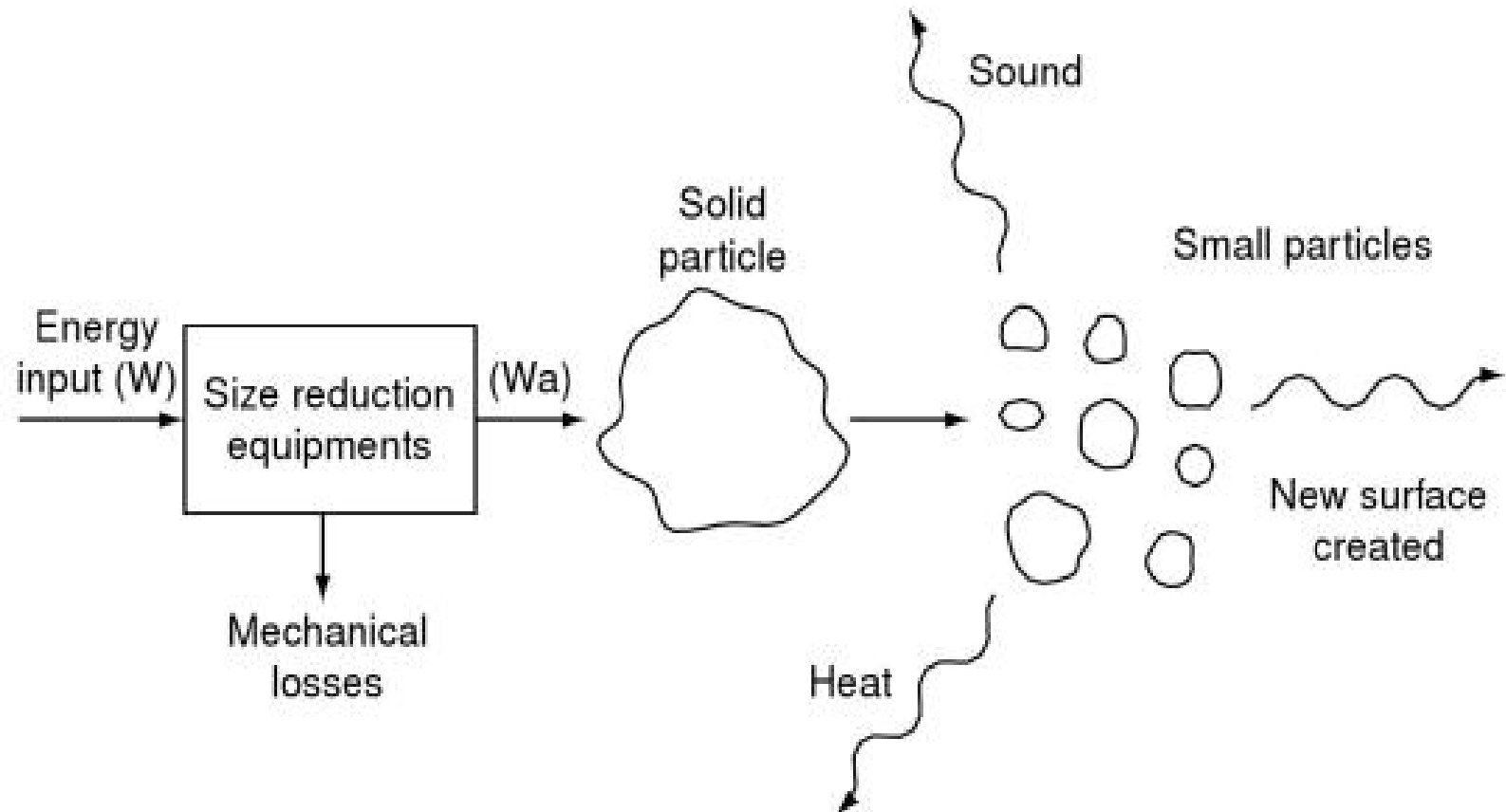


Fig. the creation of new surface

- **Mechanical losses** : E.g. losses to overcome friction (in the bearing and other moving parts of the machine).
- **Heat Loss and sound**: all energy of stress in excess of new surface energy are converted to heat.
- Thus the energy efficiency is less and when the energy is lost, the cost of power becomes a major constraint.
- This efficiency is one of the most important parameters in subject of size reduction because the cost is represented in terms of energy.

2.3.1.2.1 Crushing Efficiency

- The ratio of surface(potential) energy created to the energy absorbed by the solid (kinetic energy).

$$\text{K.E} = \text{P.E} + \text{HEAT} + \text{SOUND}$$

- The quantities needed to calculate the efficiency are:
 - **total energy input** : measured using mechanical means or electrical instruments.
 - **Energy lost during size reduction** : in terms of energy consumption.
 - **Total new surface created** : found from size distribution data after size reduction
 - **Specific surface energy** : measured with precision as it is numerically the same as surface tension

2.3.1.2.1 determination of power consumption

- From our definition of efficiency:

$$\eta_c = \frac{\text{Surface energy created by crushing}}{\text{Total energy absorbed by the solid}} \dots\dots\dots \text{Eqn (1)}$$

If, W_a = Total energy absorbed by a unit mass of solid, J/kg

E_s = Surface energy per unit area, J/m² and

A_{ssf}, A_{ssp} = Areas per unit mass of feed and product respectively,
(or, the specific surfaces), m²/kg,

then, the surface energy created by crushing will be

$$\text{Surface energy created} = E_s (A_{ssp} - A_{ssf}) \dots\dots\dots \text{Eqn(2)}$$

- The crushing efficiency(η_c)becomes :

$$\eta_c = \frac{E_s (A_{ssp} - A_{ssf})}{W_a} \dots\dots\dots \text{Eqn (3)}$$

We know that the energy absorbed by a unit mass of a solid (Wa) is less than the energy fed (W) for the purpose of the machine.

➤A portion of the total energy input is used to over come friction in bearings and other moving parts, and the rest is available for size reduction.

- Here we need to calculate the efficiency of the mechanical equipment

- Mechanical efficiency (η_m) is defined as the ratio of energy absorbed and the energy fed to the machine,

$$\eta_m = \frac{W_a}{W} \dots\dots\dots \text{Eqn(4)}$$

- The total energy input will be :

$$W = \frac{W_{st}}{\eta_m} \dots\dots\dots \text{Eqn(5)}$$

Substituting **Eqn(3)** in **Eqn(5)** ,

$$W = \frac{E_s (A_{ssp} - A_{ssf})}{\eta_m \eta_c} \dots\dots\dots \text{Eqn(6)}$$

- If $\dot{m}$ is the flow rate of solids to the machine then the power required, P, by the machine will be :

$$P = W \times \dot{m} \dots\dots\dots \text{Eqn(7)}$$

- Substituting Eqn (6) in Eqn (7) :

$$P = \frac{E_s (A_{ssp} - A_{ssf}) \dot{m}}{\eta_m \eta_c} \dots\dots\dots \text{Eqn(8)}$$

- Where Specific surface of feed and product materials are:

$$A_{ssf} = \frac{6}{\Phi_f \bar{D}_{vsf} \rho_{pf}} \quad \text{and} \quad A_{ssp} = \frac{6}{\Phi_p \bar{D}_{vsp} \rho_{pp}} \quad \dots\dots\dots \text{Eqn(9)}$$

where, Φ_f, Φ_p = Sphericity of the feed and the product materials,

$\bar{D}_{vsf}, \bar{D}_{vsp}$ = Sauter mean diameter for the feed and the product, m and

ρ_{pf}, ρ_{pp} = Density of the feed and the product materials, kg/m^3 .

- for homogeneous materials, $\rho_{pf} = \rho_{pp} = \rho_p$

$$P = \frac{6 E_s \dot{m}}{\eta_m \eta_c \rho_p} \left(\frac{1}{\Phi_p \bar{D}_{vsp}} - \frac{1}{\Phi_f \bar{D}_{vsf}} \right) \quad \dots\dots\dots \text{Eqn(10)}$$

- From the above relation we can see that power consumption increases for particles with higher surface energy and higher flow rate.
- All particles in a unit mass of solid particles have a definite amount of surface energy and when their surface energy is reduced, their surface area as well as the surface area per unit mass increases.
- And when this occurs, the power requirement becomes more and more for reducing fine particles to still finer ones than for breaking down large pieces of rocks

2.4 Laws of communiton

- It is difficult to determine the accurate energy requirement for size reduction. But a number of empirical relations has been proposed to relate size reduction with energy input to the machine. Such as:
 - Rittinger's law
 - Kick's law
 - Bond's law

2.4.1 Rittinger's law

- The work required for size reduction is proportional to the new surface area created.

$$W_R = \frac{P}{\dot{m}} = K E_S (A_{ssp} - A_{ssf}) \quad \text{.....Eqn(11)}$$

$$\text{Where } K = \text{constant} = \frac{1}{\sigma_c}$$

$$A_{ssf} = \frac{6}{\Phi_f \bar{D}_{vsf} \rho_{pf}} \quad \text{and} \quad A_{ssp} = \frac{6}{\Phi_p \bar{D}_{vsp} \rho_{pp}} \quad \text{.....Eqn(9)}$$

- For particles with constant sphericity and density :

$$W_R = \frac{6KE_S}{\Phi \rho_p} \left(\frac{1}{\bar{D}_{vsp}} - \frac{1}{\bar{D}_{vsf}} \right) = K_R \left(\frac{1}{\bar{D}_{vsp}} - \frac{1}{\bar{D}_{vsf}} \right) \quad \text{.....Eqn(12)}$$

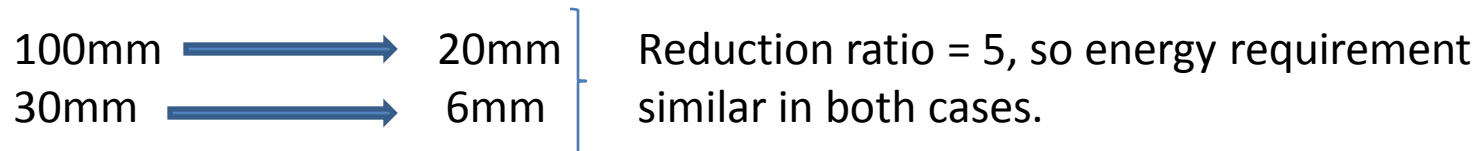
where, $K_R = \frac{6K E_s}{\Phi \rho_p}$, is known as *Rittinger's constant*. Eqn(13)

- **KEs** is some times taken as Rittinger's Constant
- This law is applicable for feed size less than *0.05mm and most accurate for fine grinding.*
- The inverse of Rittinger's constant is ***Rittinger's number***.

2.4.2 Kick's Law

- States that **the work required for crushing a given material is constant for a given reduction ratio irrespective of the Initial size.**
- Where : **reduction ratio** is the ratio of the initial particle size to final particle size.

$$W_K = \frac{P}{\dot{m}} = K_K \ln \left(\frac{\bar{D}_{vsf}}{\bar{D}_{vsp}} \right) \dots\dots\dots \text{Eqn(14)}$$



- 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 greater than 50mm.

2.4.3 Bond's Law

- States that : **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(S_p/V_p) of the product.**

$$W_B = \frac{P}{\dot{m}} = K \left[\left(\sqrt{\frac{S_p}{V_p}} \right) \right] \dots\dots\dots \text{Eqn(15)}$$

$$= K \sqrt{\frac{6}{\Phi D_{pp}}} = K \sqrt{\frac{6}{\Phi}} \times \frac{1}{\sqrt{D_{pp}}} = K_b \frac{1}{\sqrt{D_{pp}}} \dots\dots \text{Eqn(16)}$$

$$W_B = \frac{P}{\dot{m}} = K_b \left(\frac{1}{\sqrt{D_{pp}}} - \frac{1}{\sqrt{D_{pf}}} \right) \dots\dots\dots \text{Eqn(17)}$$

If feed particle size is very large

Where : K is some constant and

$$K_b = K \sqrt{\frac{6}{\Phi}} = \text{Bond's constant.} \dots\dots\dots \text{Eqn(18)}$$

- ***This law is applicable for feed size between 0.05 and 50mm.***
- Bond's constant is dependent on type of:
 - machine
 - Material to be crushed
- And it is expressed using **work index(W_i)**, which is defined as ***the gross energy requirement in kilowatt hour per 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 micro m or 0.1mm screen.***

$$W_i = K_b \frac{1}{\sqrt{D_{PP}}} \quad \Rightarrow \quad K_b = W_i \sqrt{D_{PP}} \quad \text{.....Eqn(19)}$$

Now, if P is in kW, $\dot{m}$ is in tons per hour, and

- (i) D_{pp} is in μm then $K_b = 10 W_i$, and
- (ii) D_{pp} is in mm then $K_b = \sqrt{0.1} W_i = 0.3162 W_i$

Thus, if 80% of feed particles pass through a D_{pf} mm screen and 80% of product particles pass through a D_{pp} mm screen then

$$W_B = \frac{P}{\dot{m}} = 0.3162 W_i \left(\frac{1}{\sqrt{D_{pp}}} - \frac{1}{\sqrt{D_{pf}}} \right) \dots\dots\dots \text{Eqn(20)}$$

A typical work index for some common minerals

Material	Specific gravity	Work index W_i
bauxites	2.20	8.78
cement clinker	3.15	13.45
cement raw material	2.67	10.51
clay	2.51	6.30
coal	1.4	13.00
coke	1.31	15.13
granite	2.66	15.13
gravel	2.66	16.06
gypsum rock	2.69	6.73
iron ore (hematite)	3.53	12.84
lime stone	2.66	12.74
phosphate rock	2.74	9.92
quartz	2.65	13.57
shale	2.63	15.87
slate	2.57	14.30
trap rock	2.87	19.32

2.5 Size Reduction Equipment

Types of size reduction	Feed Size
Coarse Crushers	50 - 250mm
Intermediate Crushers	25 - 75mm
Fine Crushers/grinders	5 - 15mm

Criteria for size reduction

An ideal crusher would

- (1) have a large capacity;
- (2) require a small power input per unit of product; and
- (3) yield a product of the single size distribution desired.

- ✓ **Coarse crusher** (to produce coarse and fine)

The main existing coarse crushers are:

Jaw crusher, Gyratory crusher, Roll crusher

- ✓ **Grinders** (to produce intermediate and fine particles)

The main existing equipment are:

- Hammer mills, disk mills.

- Rolling compression mills such as bowl mills and roller mills.

- Attrition mills.

- Tumbling mills such as: rod mills, ball mills, pebble mills, tube mills & compartment mills

- ✓ **Ultra-fine grinders:**

Hammer mills with internal classifications, Fluid energy mills, Agitated mills.

- ✓ **Cutting machines:**

Knife cutter, dicers, slicers.

2.5.1 Coarse Crushers

- Mainly employ compression to large rocks.
- Are slow speed machines.
- The size reduction results from stresses that are applied to the solid particles to be crushed by some moving part in the machine against stationary part or some other moving parts.
- Always done on dry materials.
- The main existing coarse crushers are:
Jaw crusher, Gyratory crusher, Roll crusher

2.5.1.2 Jaw crusher

- Feed admitted b/n two jaws.
- One jaw is fixed(anvil) which is nearly vertical and the other swinging jaw reciprocates(frwr and bckwr) in a horizontal manner.
- The anvil and swinging jaws make an angle of 20-30 degree.
- The jaws open 250-400 times/ minute.

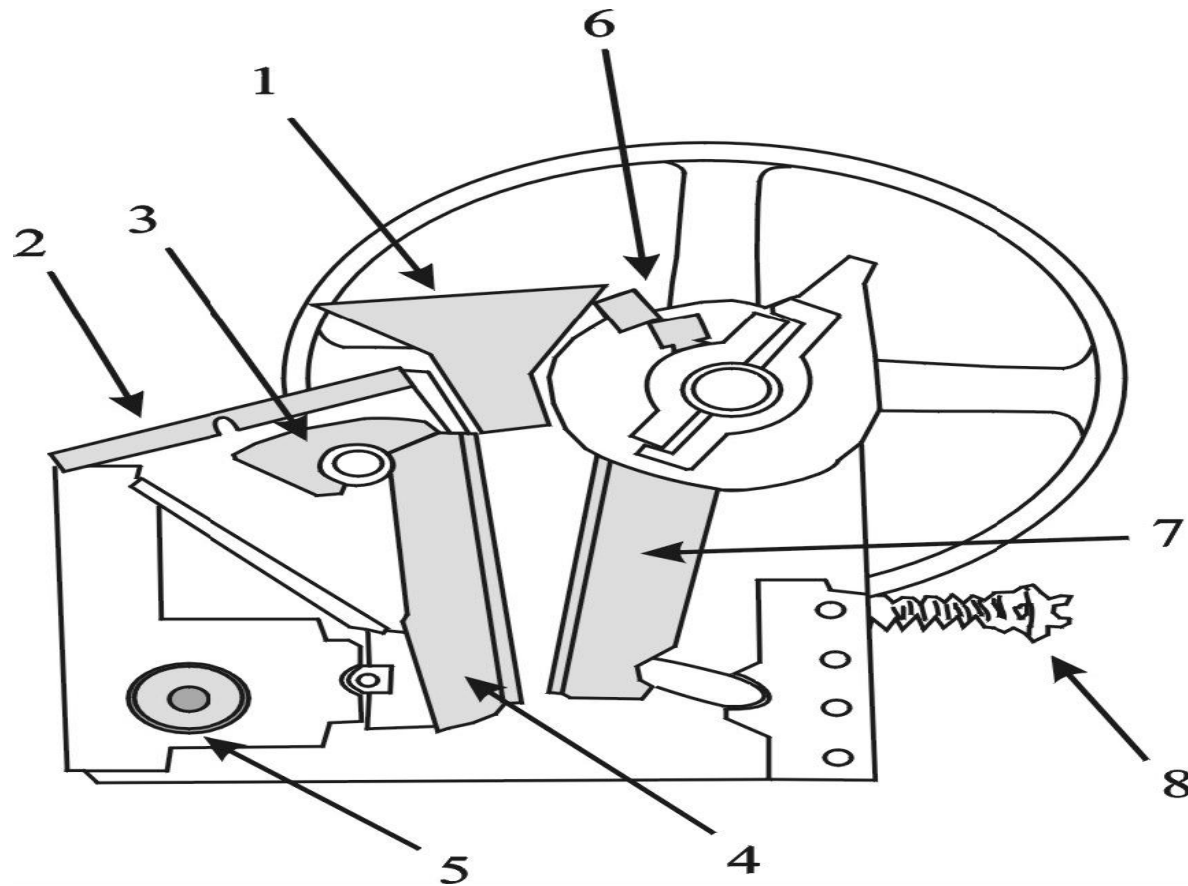
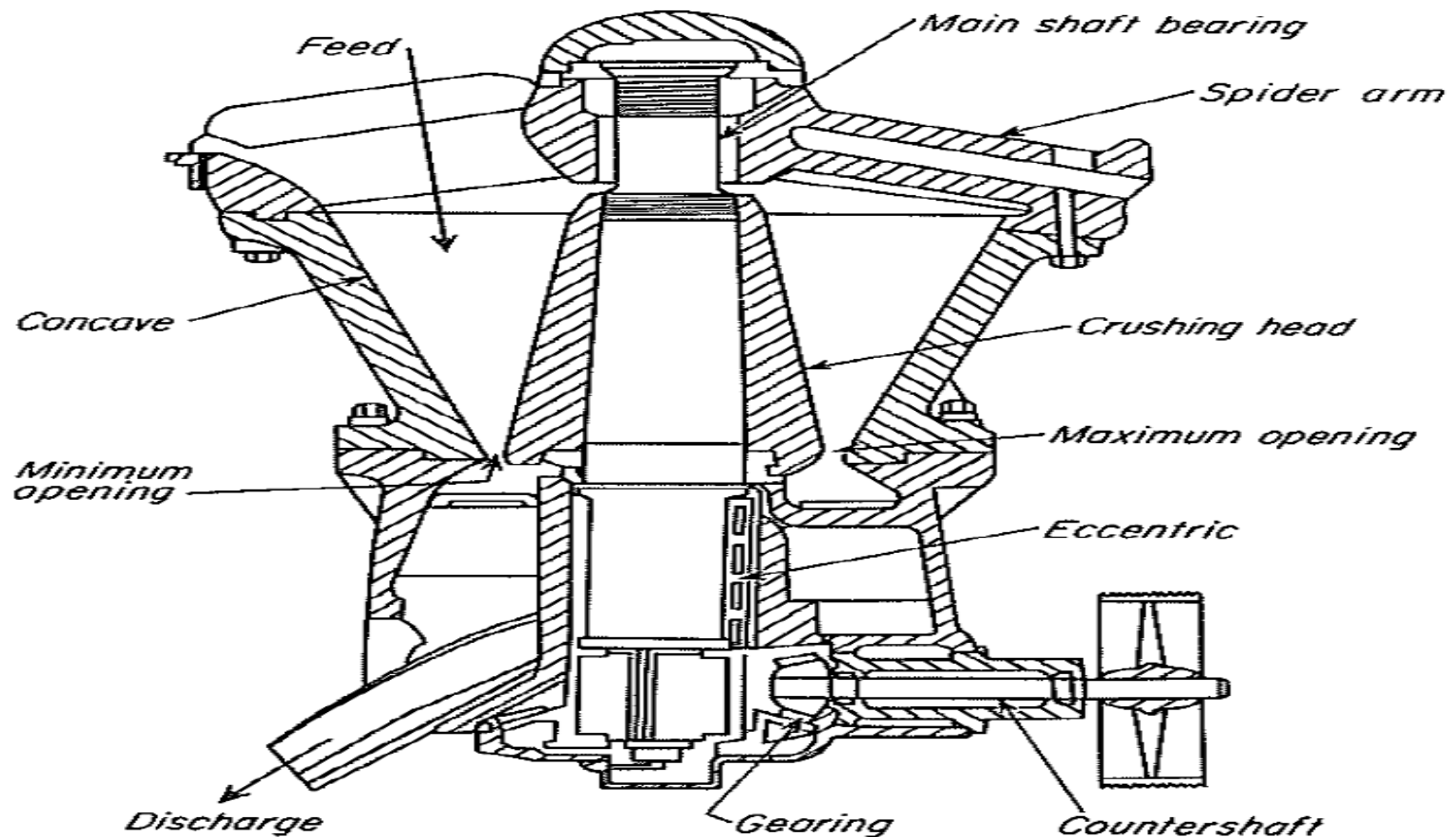


Fig . Jaw crusher. 1. feed hopper, 2. wedge block 3. Jaw cam block 4. Movable jaw, 5. Adjustment knob, 6. Grease caps, 7. Stationary jaw, 8. Spring rod assembly

2.5.1.2 Gyrator crusher

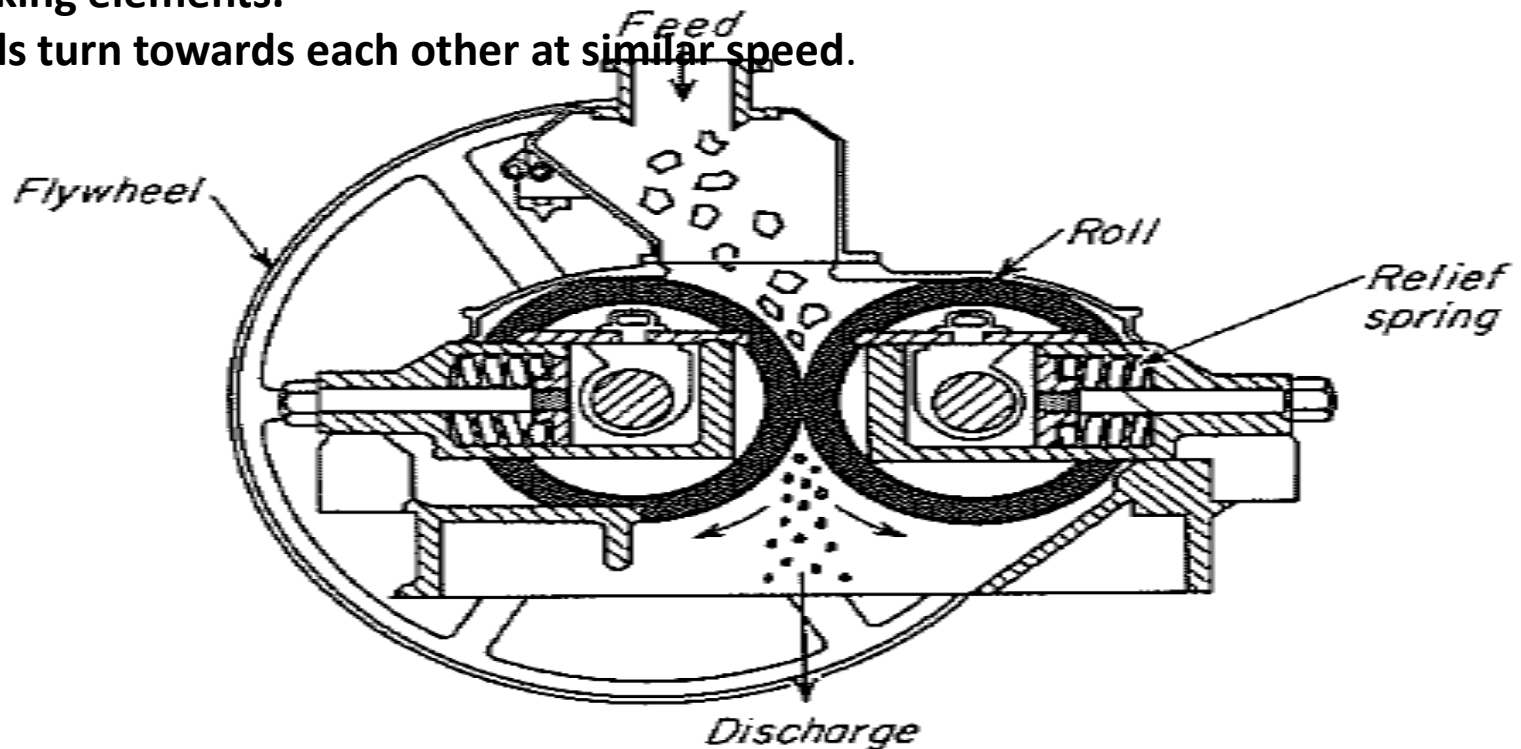
- Jaw crusher with circular jaw.



2.5.1.3 Roll crusher

1.smooth roll crusher

- Two heavy, smooth faced metal rolls turning on parallel horizontal axes are the working elements.
- Rolls turn towards each other at similar speed.



- The limiting maximum particle size ($D_{p,max}$) : maximum particle size that can be nipped between the rolls.
- Depends on: coefficient of friction b/n the material and the rolls.

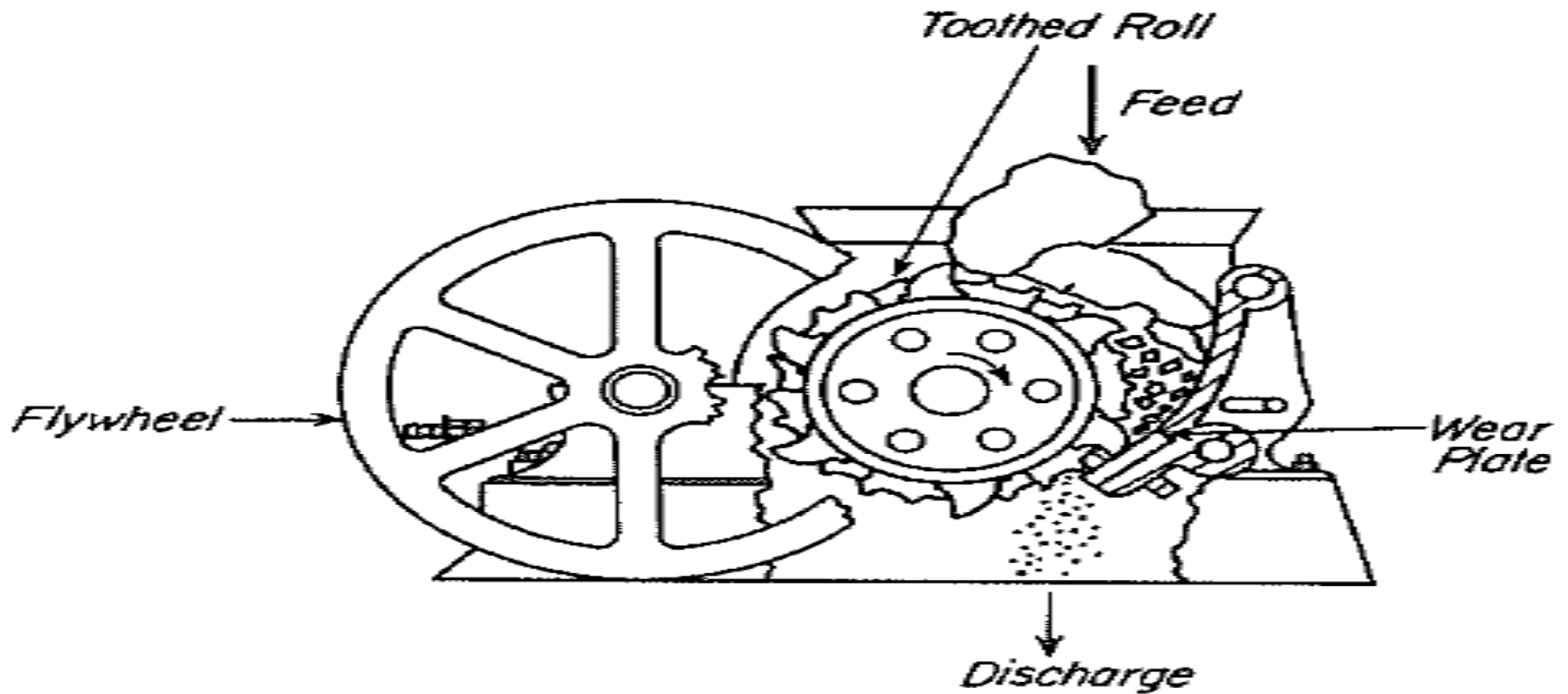
$$D_{p,max} = 0.04R + d$$

where : R = roll radius

: d = spacing between rolls

2. Toothed roll crusher

- Operate by compression, impact and shear.
- May have two toothed rolls or single toothed roll.

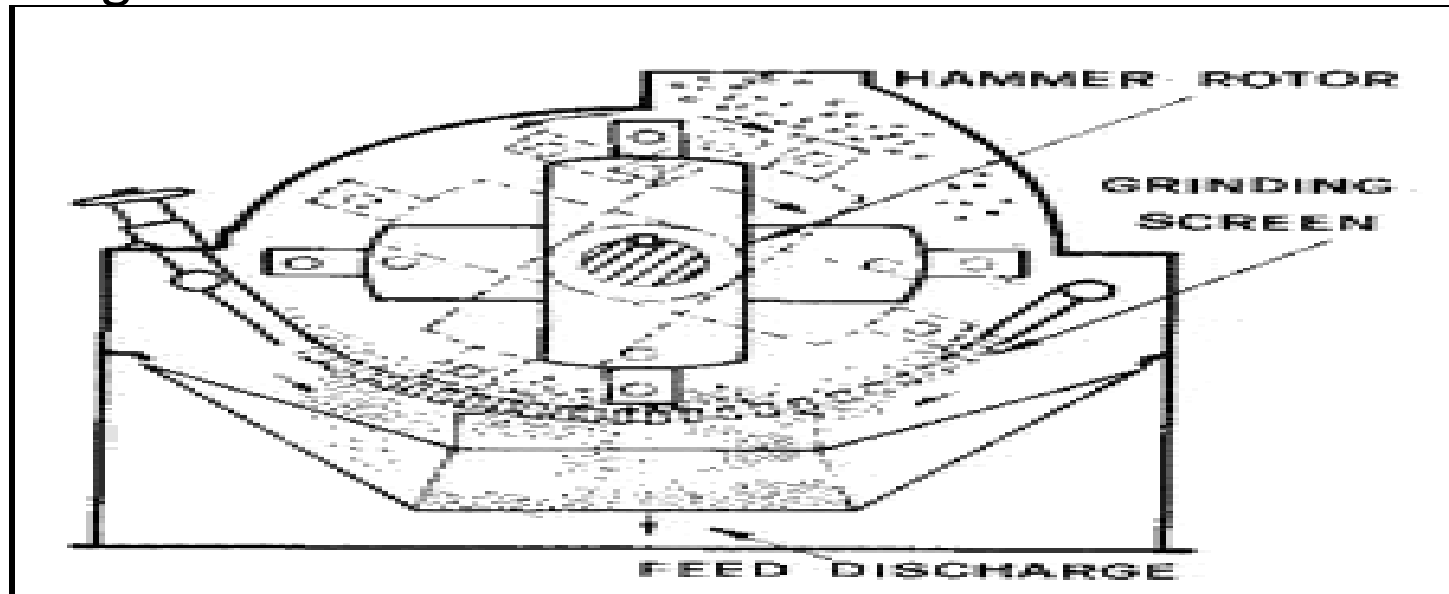


2.5.2 grinders

- Term given to size reduction machines with intermediate duty.
- Product from crusher is mostly fed to grinder for further reduction.
- Types of grinders :
 - **Hammer mills and Impactors**
 - **Rolling compression machines**
 - **Attrition mills**
 - **Tumbling mills**

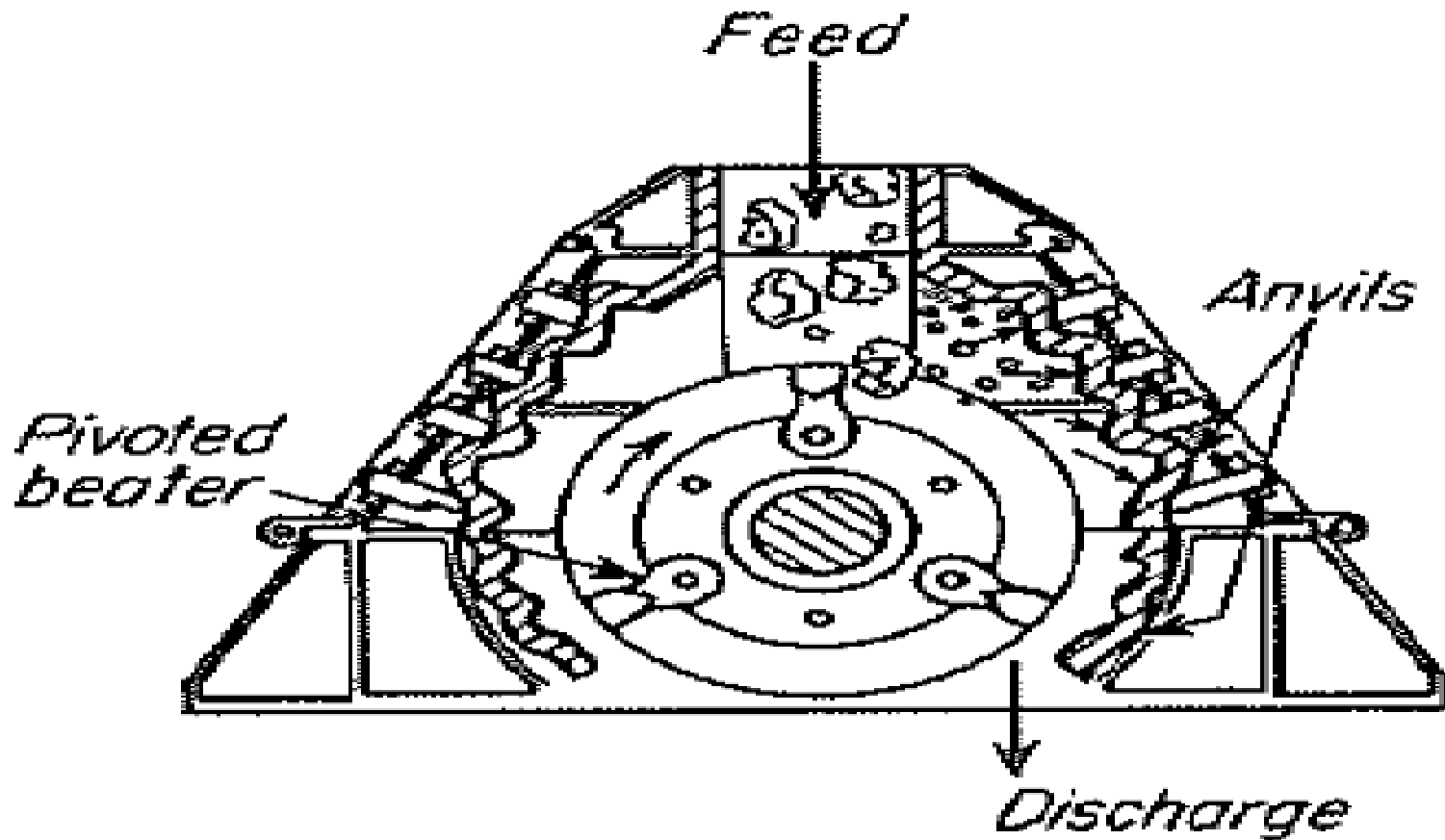
2.5.2.1 Hammer mills and Impactors

- Materials fed to the machine are **struck by the hammers into the walls.**
- **Hammers could be** : *straight bars of metals* with enlarged ends or with ends sharpened to a cutting edge.
- hammer mills **contain graits or screen** which reduce particle size by rubbing.



Hammer mill

Impactors



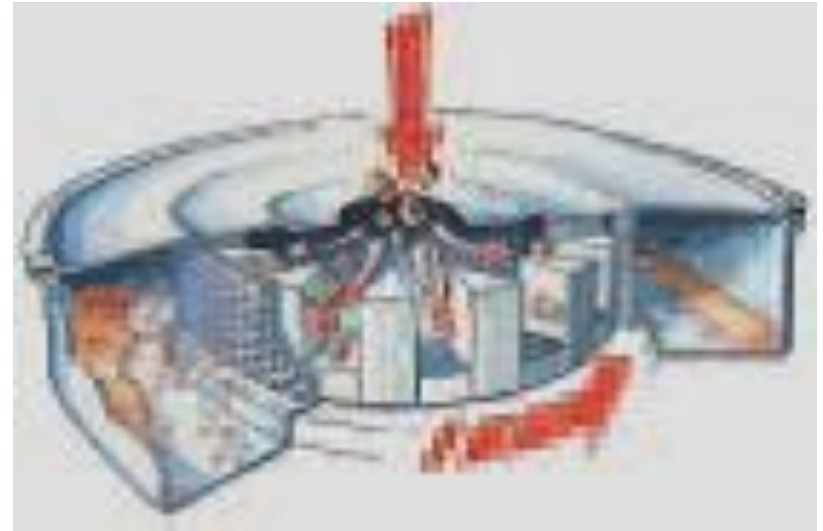
What is the difference between hammer and impactors?

2.5.2.2 Attrition mills



- Particles of solid are rubbed between the grooved flat faces of rotating circular disks.
- In certain types of mills, one of the circular disks could be stationary.

- **The Centrifugal Mill**

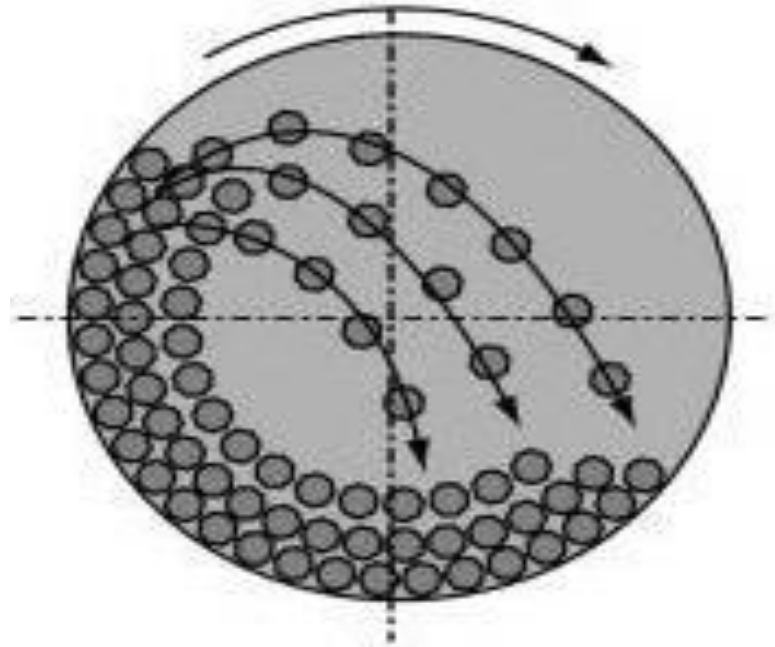


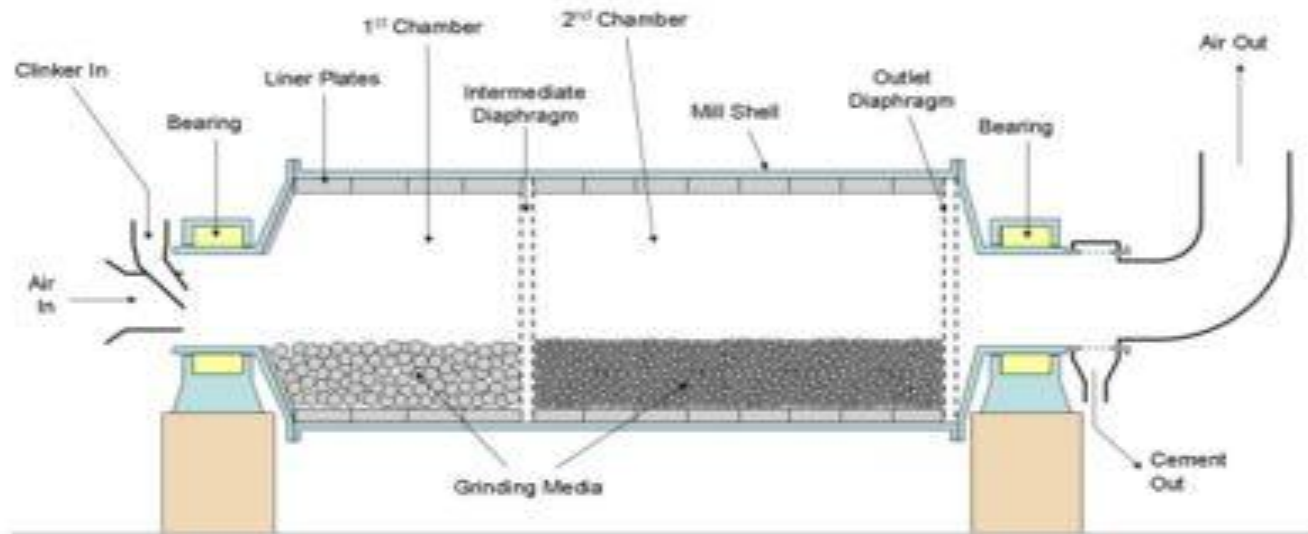
2.5.2.3 Tumbling mills

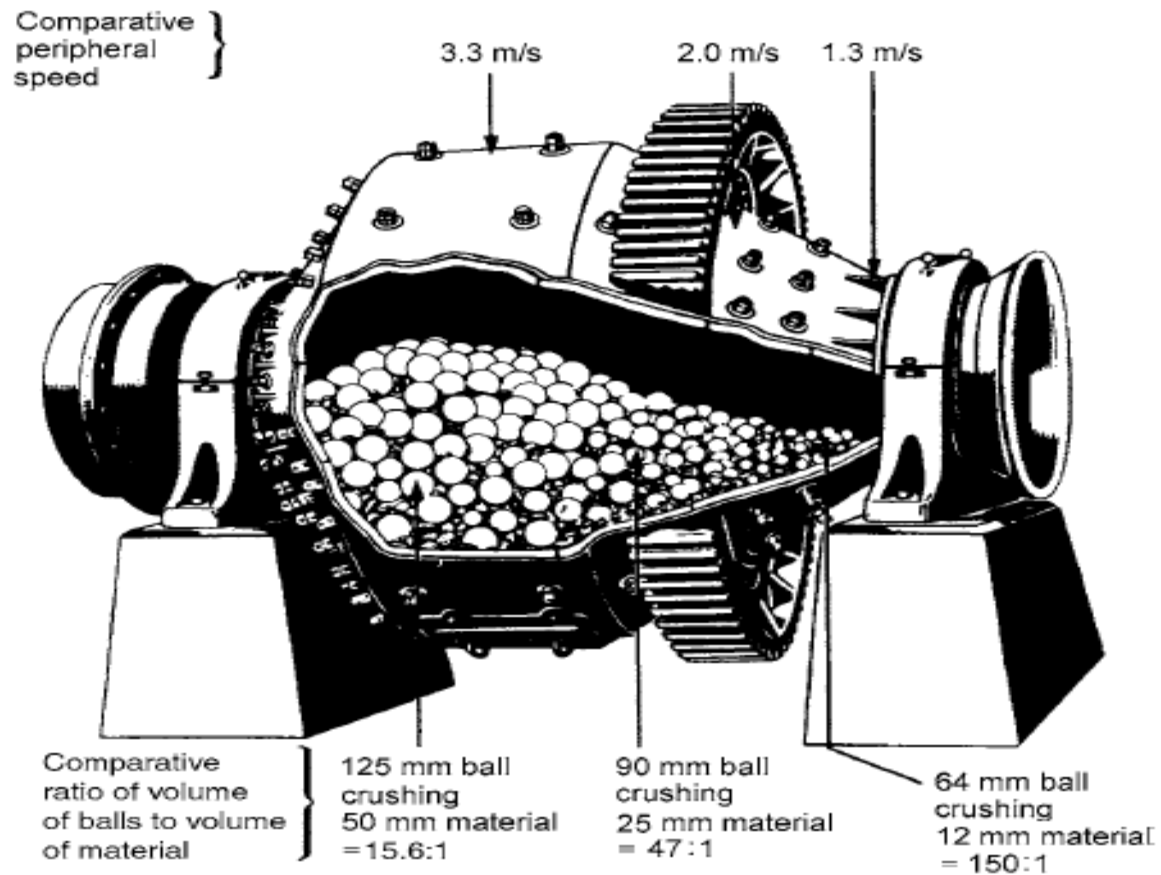
- Consists:
- **A cylindrical shell turning about horizontal axis.**
- **Filled with a solid grinding medium**
 - Rod mill : metal rods
 - Ball mills : metal balls
 - Pebble mills : flint pebbles(rocks with spherical shape, made by wear created by water)
- They operate  continuously or batch

- **Grinding elements** carried up the side of the shell nearly to the top, from there they fall on the particle underneath.
- **Mechanisms utilized**
 - Compression :
 - Attrition : as rods slide down and roll over one another.

- **Ball Mills and Rod Mills**





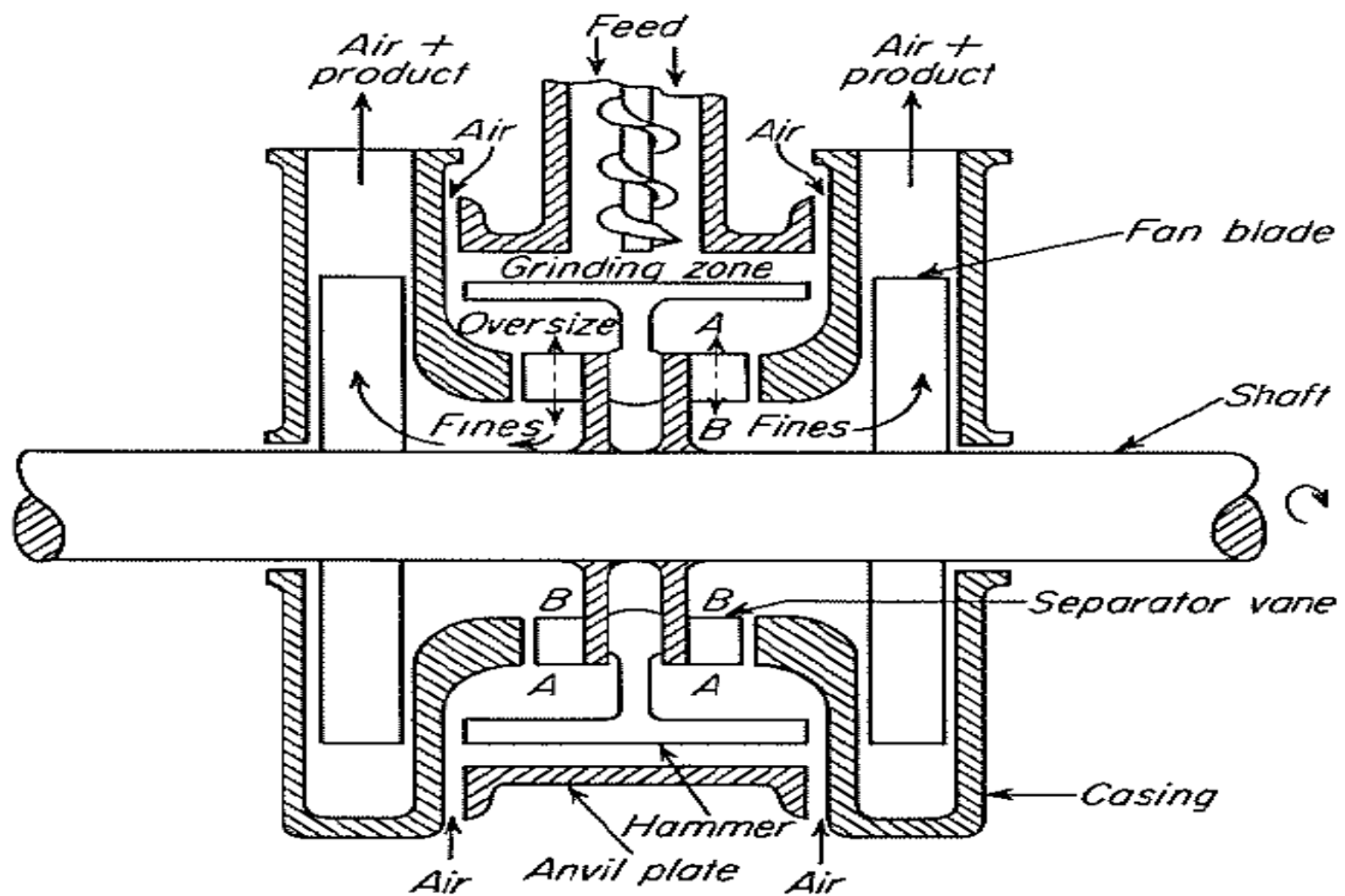


Cut-away view of the Hardinge conical ball mill showing how energy is proportioned to the work required

✓ **Ultra-fine grinders:**

Hammer mills with internal classifications,
Fluid energy mills, Agitated mills.

- **Agitated mills** : Ultrafine grinding for wet solids
- For Particles passing through **40 micrometer screen or 325- mesh.**



- **The Cutting Mills**

- ✓ where specially designed for processing **thermoplastic syrup**, but they are also applicable for reduction of **cork, cellulose, fabric, leather**, etc. the mill consisting of housing in which a cutting rotor with knives, is rotating. The grinded products **fall through a screen** which, partially encloses, the rotor? The mesh size of this screen essentially influences the particle size of product.

Mode of operation of comminution:

Open circuit operation:

✓ **Free crushing:** The product material is continuously discharged as soon as it is produced.

✓ **Choke feeding:** It does not freely discharge the crushed product.

By injecting compressed air, water or by centrifugal means. Large capacity prevent formation of fines.

Closed circuit operation: size reduction With a classifying or separation unit.

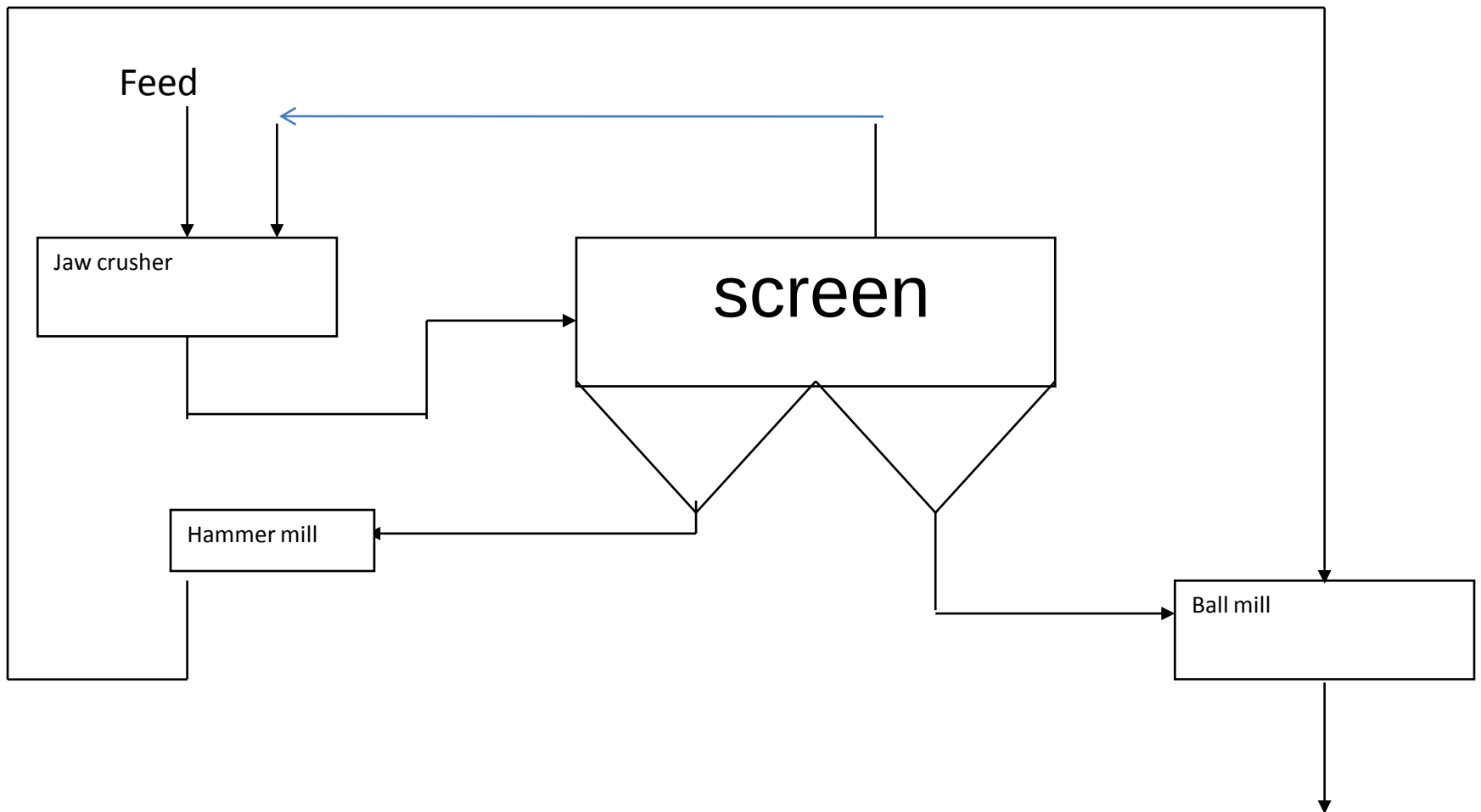
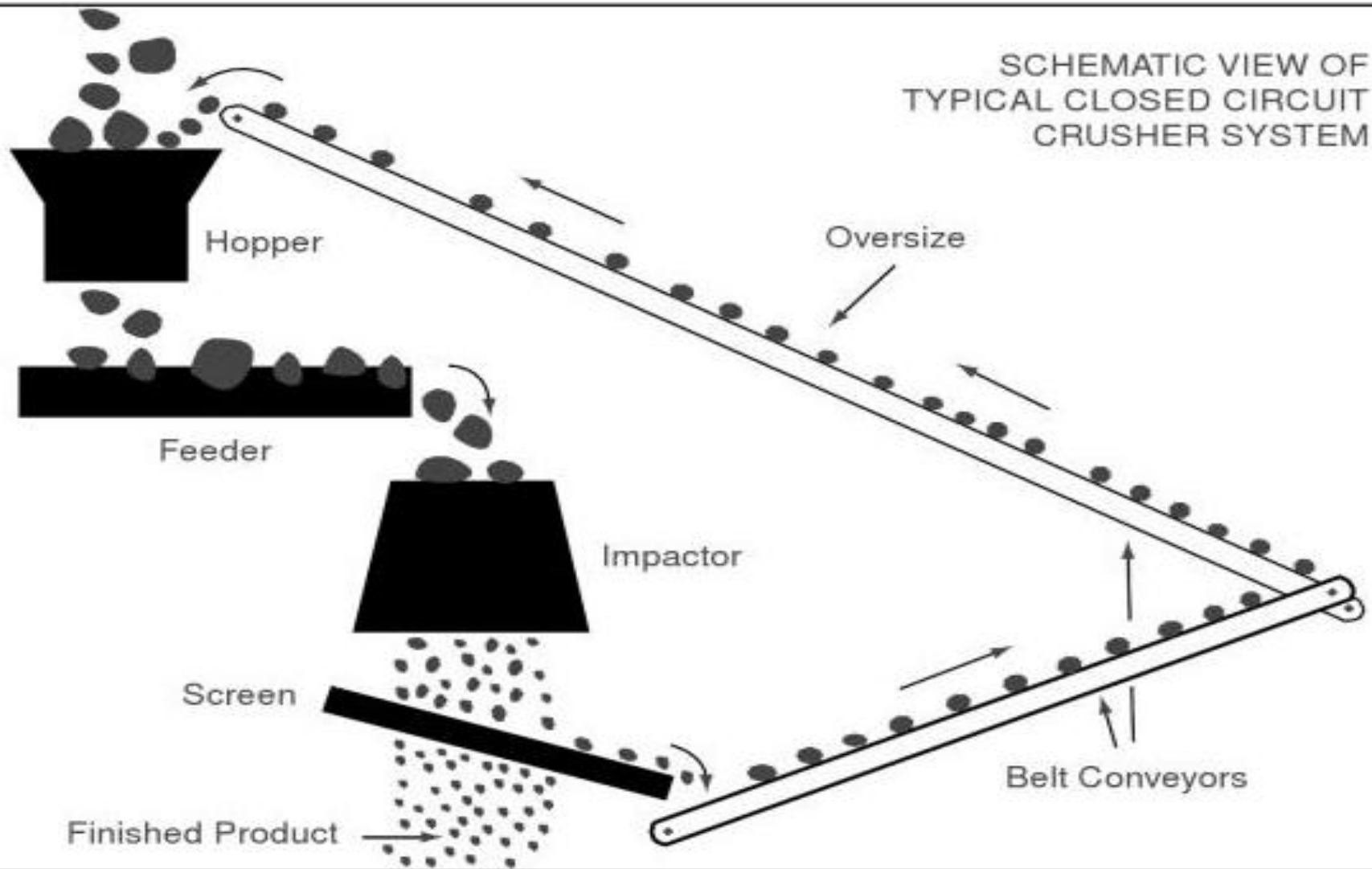


Figure: Closed circuit operation

fine

SCHEMATIC VIEW OF
TYPICAL CLOSED CIRCUIT
CRUSHER SYSTEM



- End of chapter 2