PARTICLE SIZE REDUCTION

Theory and Practice

Particle Size Reduction

Terminology: crushing, comminution, grinding

Purposes:

- **To create particles of certain size and shape**
- **To increase surface area**
- **To extract valuable minerals held within the matrix of solid materials**
- **To improve mixing of solids**

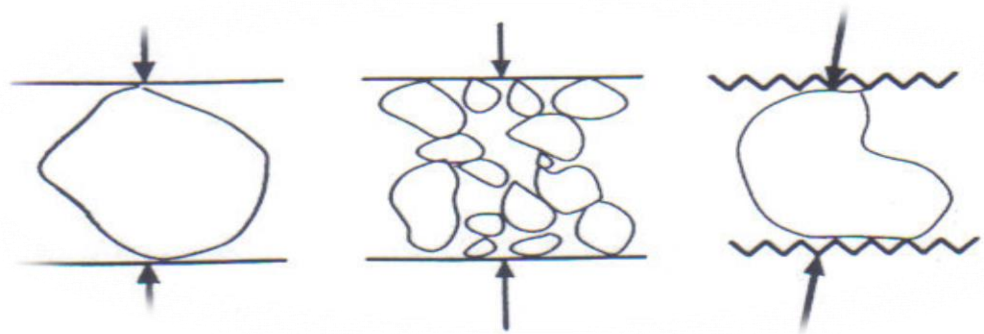
Solids can be broken by:

- Compression
- Impact or striking
- Attrition or rubbing and
- Cutting and tearing

Stressing Mechanisms

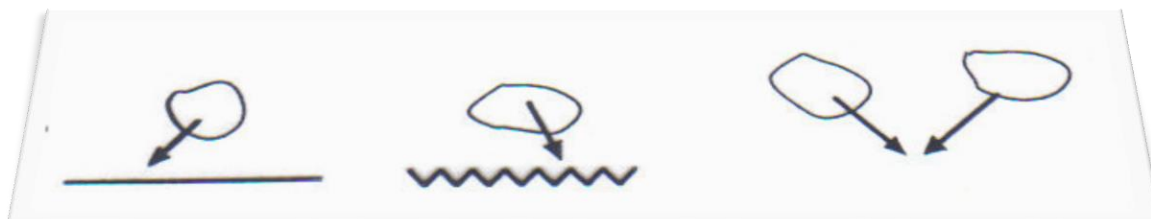
- Stress applied between two surfaces at low velocity

0.01-10 m/s
Crushing + attrition



- Stress applied at a single solid surface at high velocity

10-200 m/s
Impact fracture + attrition



Stressing Mechanisms

Stress applied by carrier medium*-usually in wet grinding to bring about dis-agglomeration

* gas ~ air, inert gases or liquid ~ water, oil

- Aid to transport material
- Transmit forces to particles.
- Influence the friction and abrasion.
- Affect crack formation.

How dose the crushing process take place?

- Cracks
- Opening cracks
- Applied force plays a significant role in cracking process
- Enough not enough force. Enough force yield crushing but no enough force will lead to material elastic deformation and then return to its original shape.
- Not enough force means energy losses.

Factors Affecting choice of Machine

- Stressing mechanism
- Size of feed and product
- Material properties
- Carrier medium

Factors influence choice of Machine

- **Mode of Operation**
- **Capacity**

Material Properties

- **Hardness**
- **Abrasiveness**
- **Cohesivity/adhesivity ~ 'stickiness'**
- **Moisture content**
- **Melting point**
- **Explosion limit ~ 'Explosive material'**
- **Special properties such as toxicity or radioactivity'**

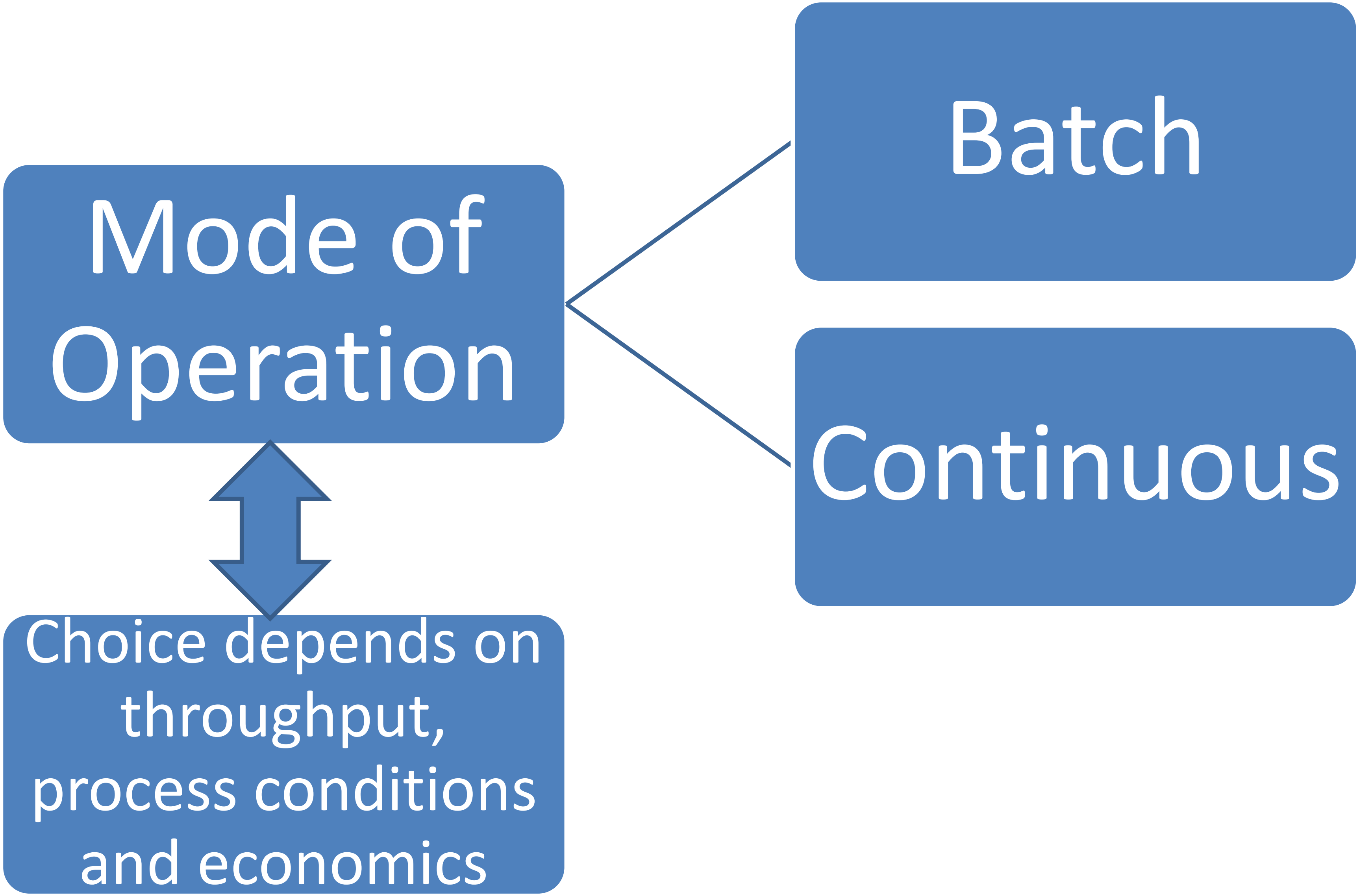
Low speed machine is recommended

The Mohs Scale of Hardness

1. Talc
2. Rock salt or gypsum
3. Calcite
4. Fluorspar
5. Apatite
6. Felspar
7. Quartz
8. Topaz (silicate mineral)
9. Carborundum (SiC)

   'Silicon Carbide'

10. Diamond.


Mode of Operation
Batch
Continuous
Choice depends on throughput, process conditions and economics

Conclusion

- Crushing Process is an ***inefficient operation.***
- about 10 per cent of the total power is usefully employed.
- Look to the energy utilization scheme in the next slide.

Energy utilization

(a) In producing elastic deformation of the particles before fracture occurs.

(b) In producing inelastic deformation which results in size reduction.

(c) In causing elastic distortion of the equipment.

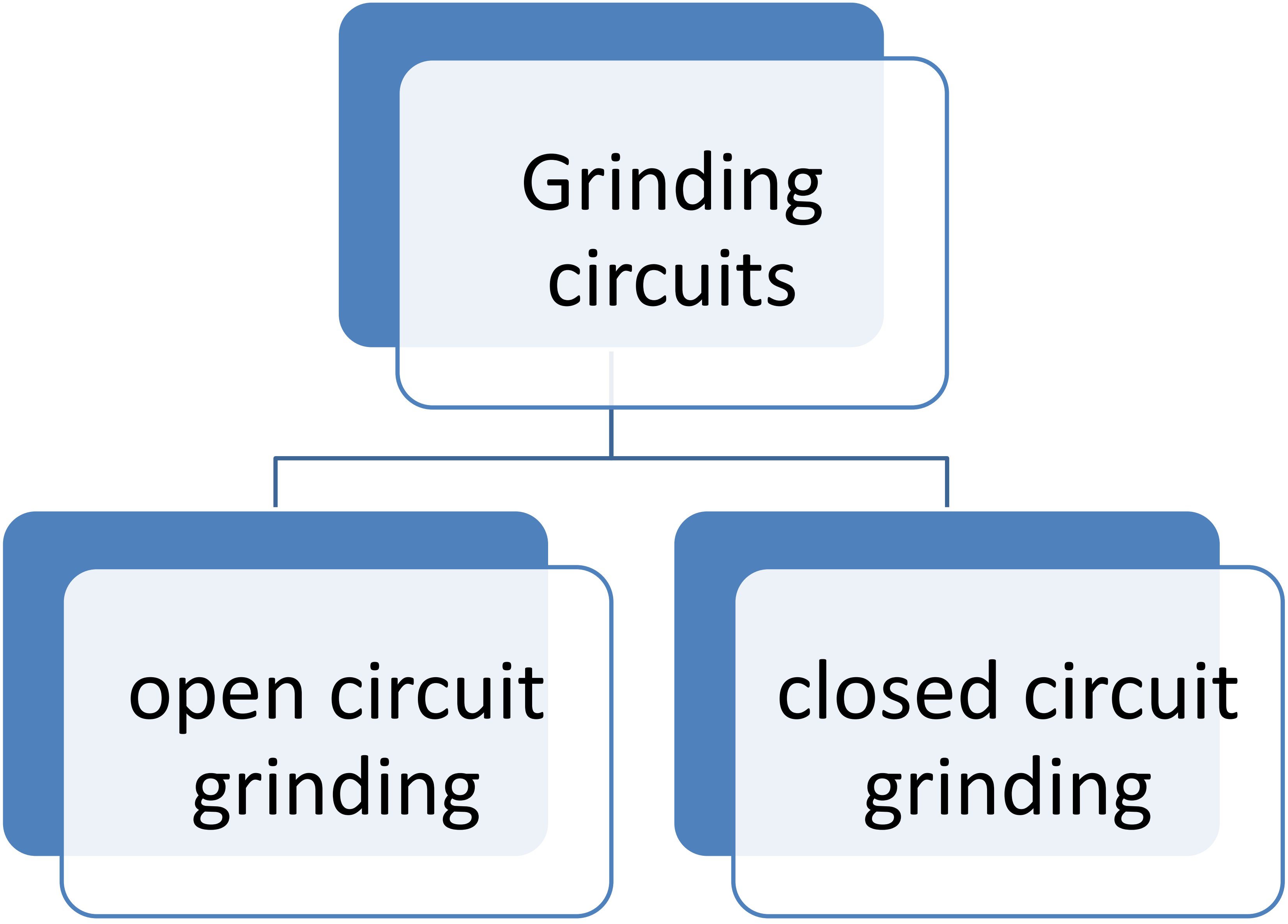
(d) In friction between particles, and between particles and the machine.

(e) In noise, heat and vibration in the plant, and

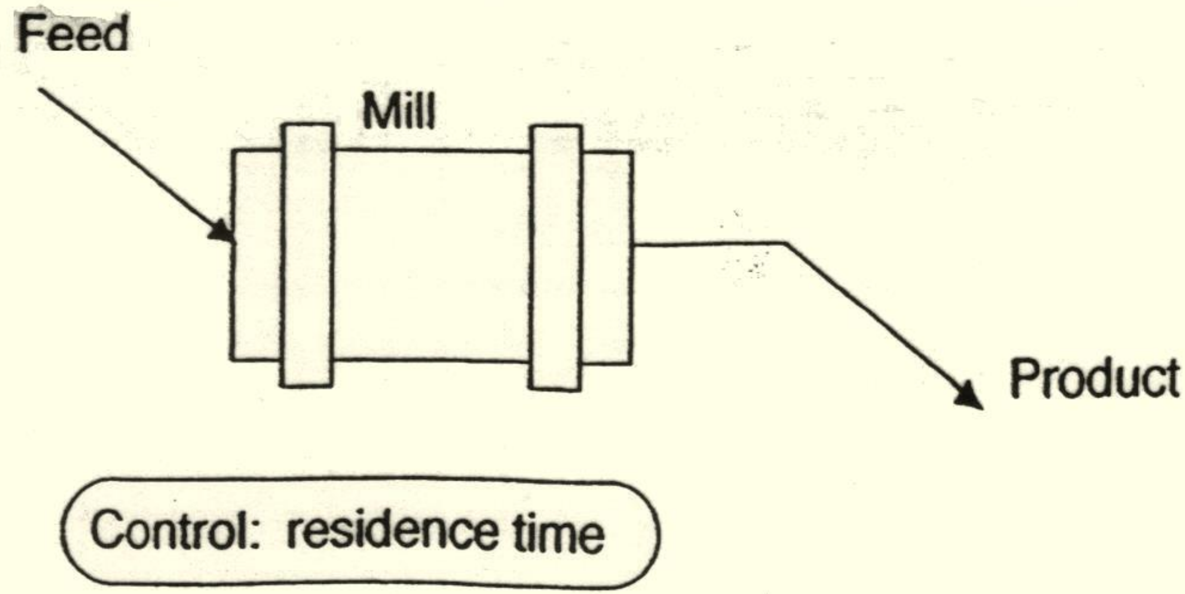
(f) In friction losses in the plant itself.

Methods of operating crushers

Free crushing	Choke feeding
✓ Continuous, low rate	✓ Batch
✓ Short residence time	✓ Long residence time
✓ Low degree of crushing	✓ Higher degree of crushing
✓ High capacity	✓ Low capacity
✓ Low energy consumption	✓ High energy consumption

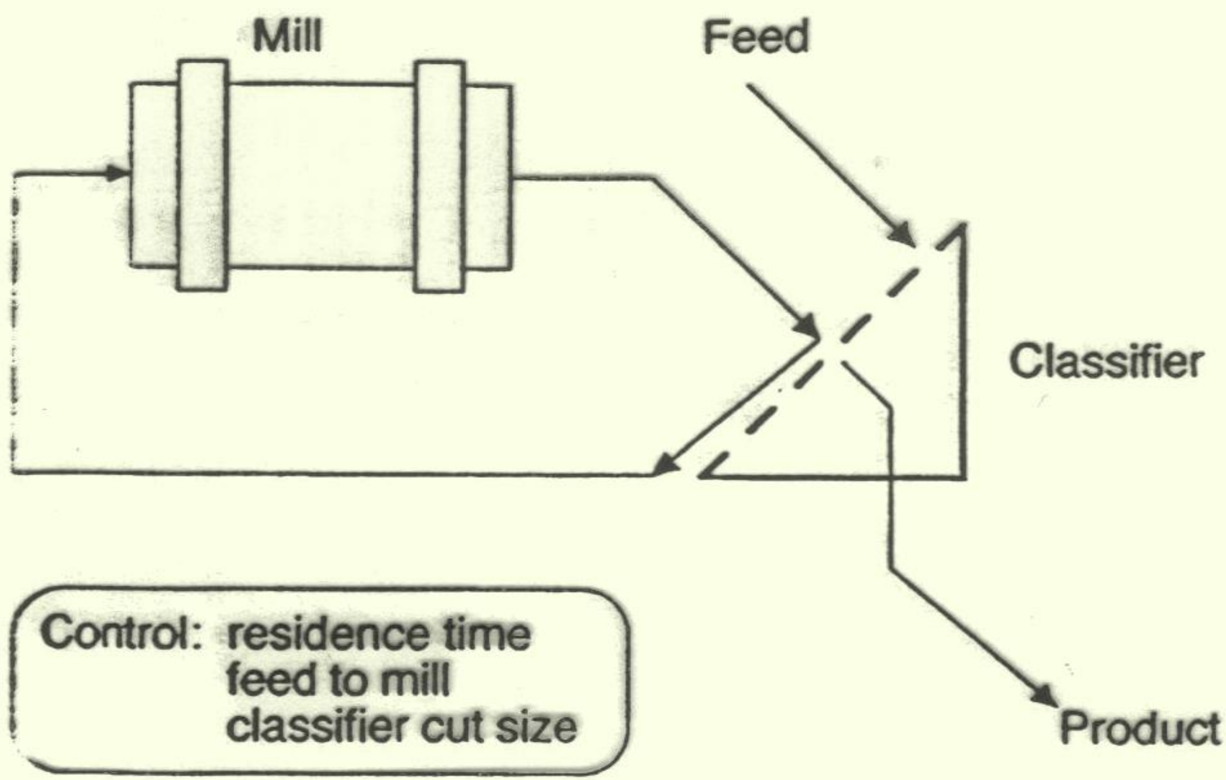

Grinding circuits
open circuit grinding
closed circuit grinding

Open circuit mill



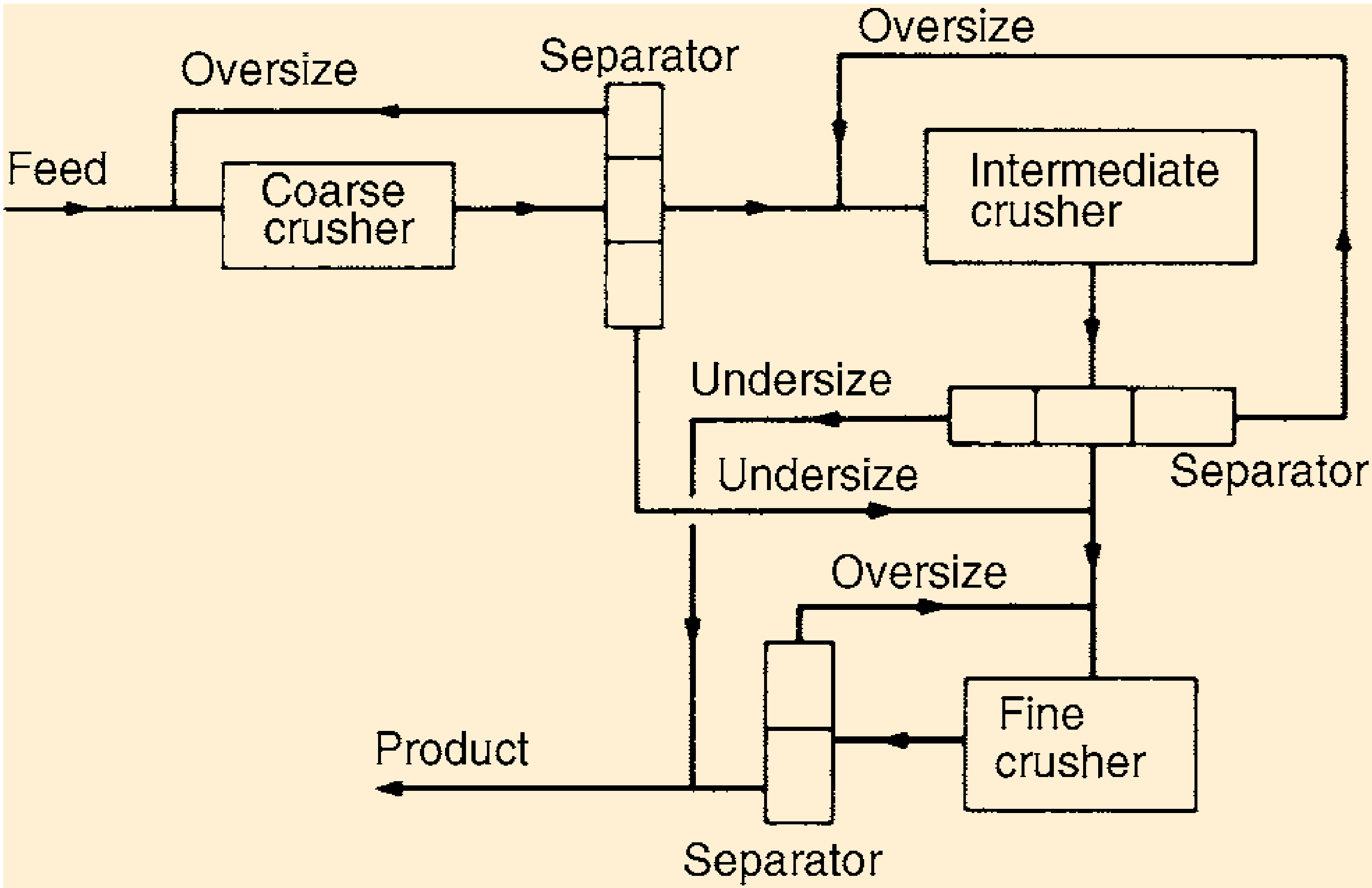
Open circuit milling

Closed circuit mill



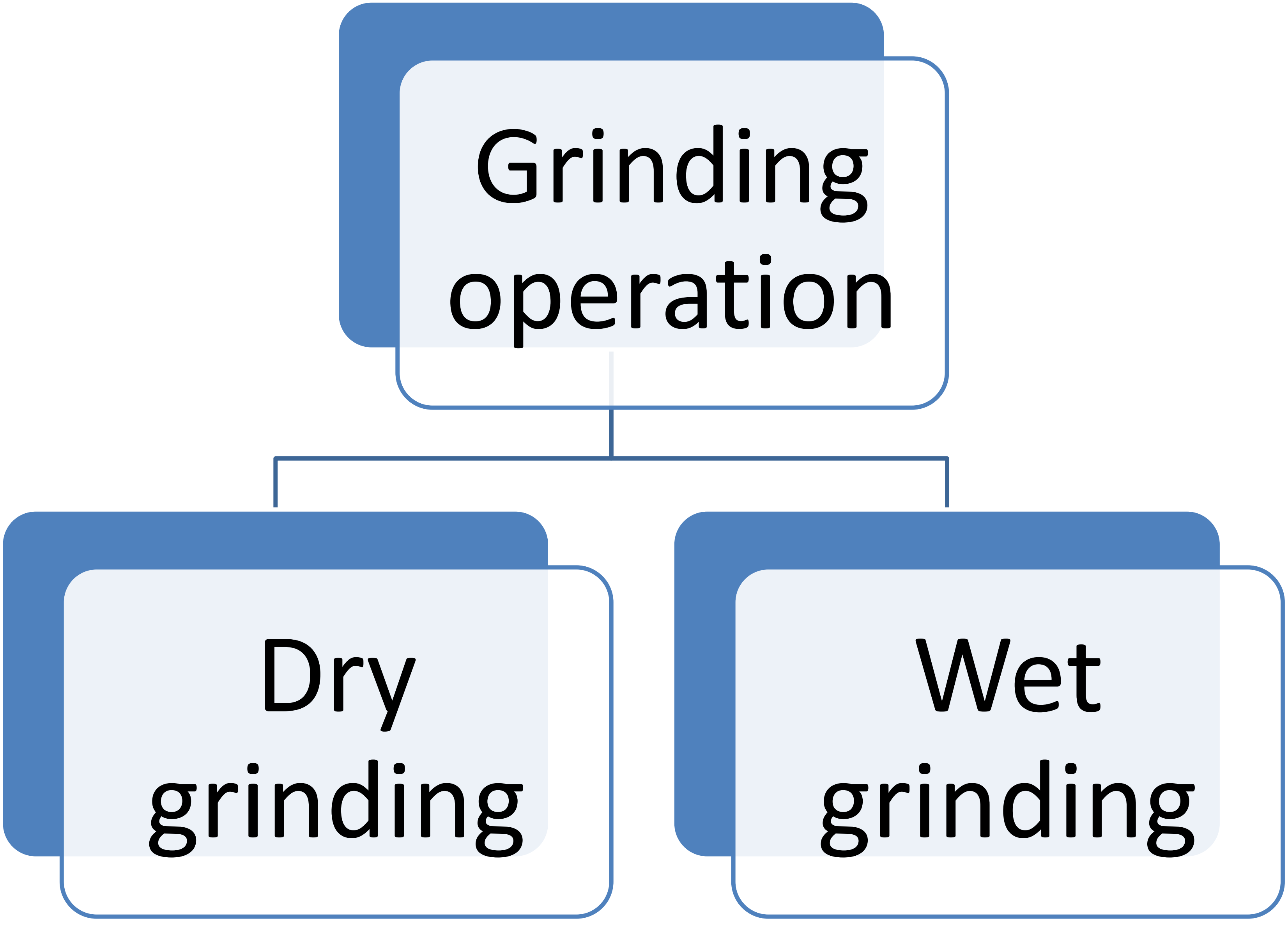
Closed circuit milling

Flow diagram for closed circuit grinding system

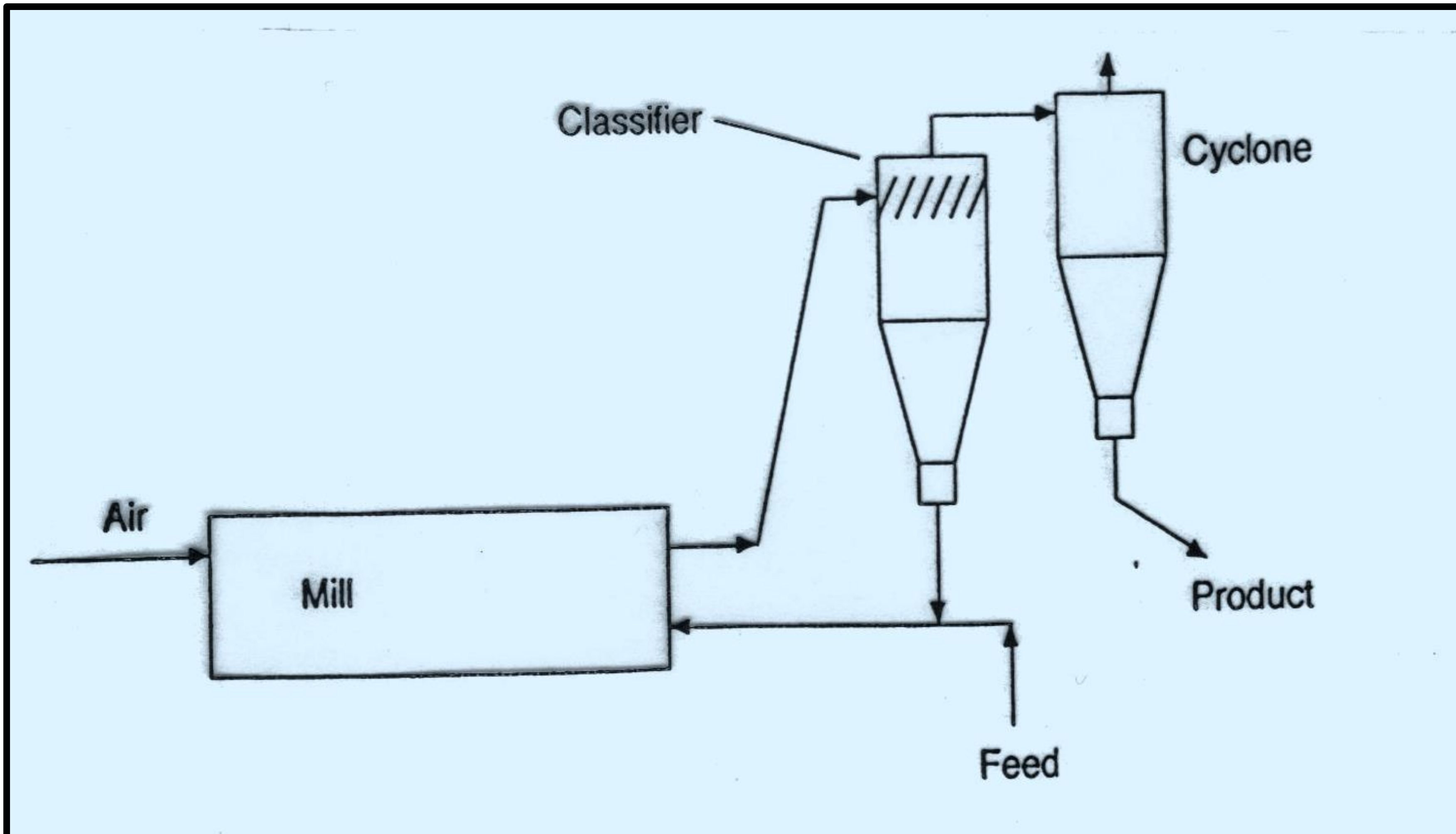


Classification of size reduction equipment

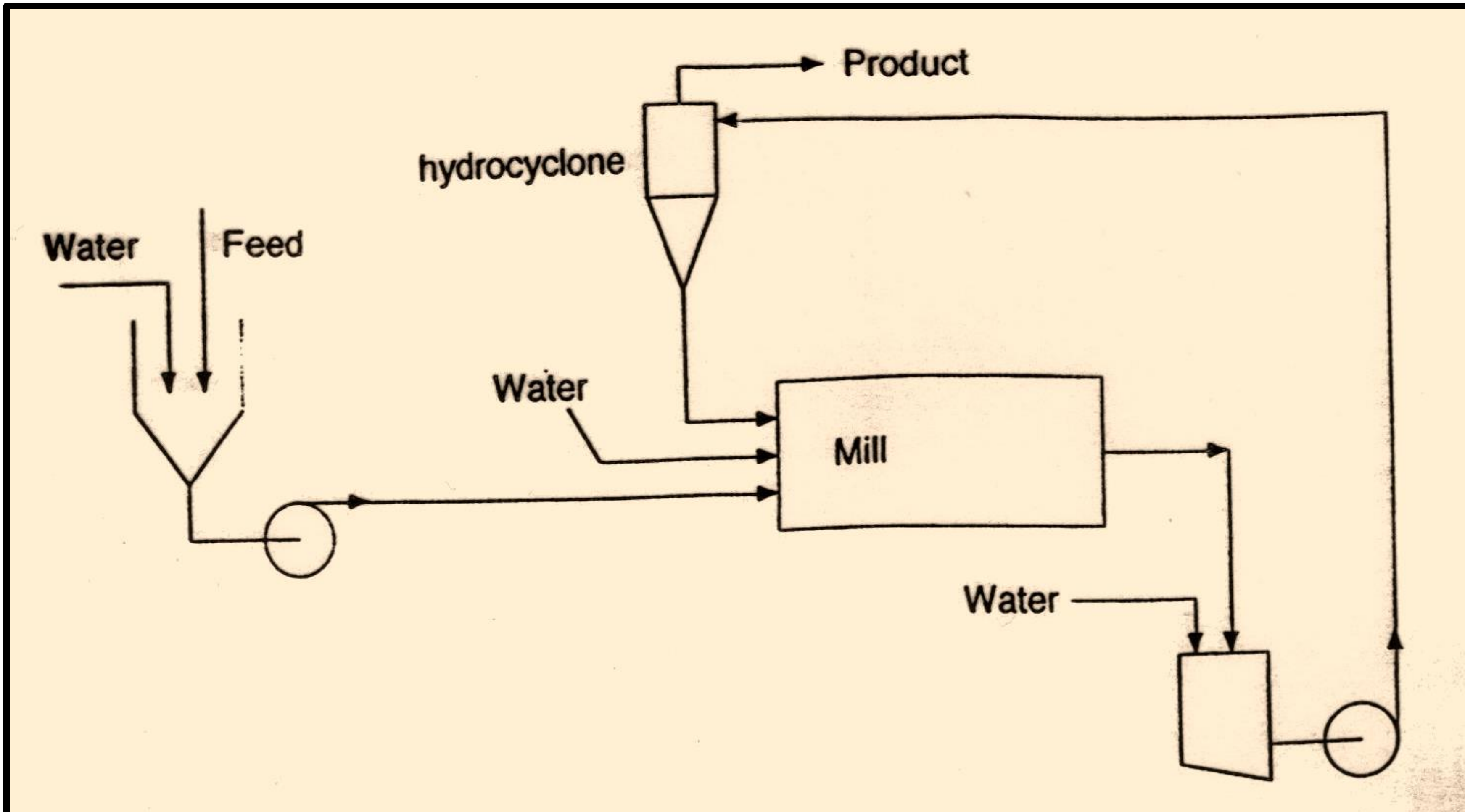
	Feed size	Product size
Coarse crushers	1500–40 mm	50–5 mm
Intermediate crushers	50–5 mm	5-0.1 mm
Fine crushers	5–2 mm	2-0.1 mm
Colloid mills	0.2 mm	down to 0.01 µm


Grinding operation
Dry grinding
Wet grinding

Dry milling; closed circuit operation



Wet milling; closed circuit operation



Advantages of wet grinding

(a) The power consumption is reduced by about 20–30 per cent.

(b) The capacity of the plant is increased.

(c) The removal of the product is facilitated and the amount of fines is reduced.

(d) Dust formation is eliminated.

(e) The solids are more easily handled.

Energy Input and Particle size

There are three postulates to predict the required energy for particle size reduction.

Most of these postulates depend on the following power formula:

$$dE = -C\left(\frac{dL}{L^{p}}\right) \qquad (1)$$

or

$$\frac{dE}{dL} = -C\,L^{-p} \qquad (2)$$

where

L : object's diameter

E : Energy Input

p , C : constants depend on the type and size of material and type of machine

If $p = 2$

equation (1) becomes

$$dE = -C\frac{dL}{L^2} \qquad (3)$$

or

$$E = C\left(\frac{1}{L_2} - \frac{1}{L_1}\right) \qquad (4)$$

equation 4 is called Rittinger's Law

Where

$$C = K_R f_c \quad ;$$

K_R: **Rittengir's constant** m^4/kg

f_c: **crushing strength of the material.**

If p=1 ; equation (1) after integration becomes;

$$E = C \ln\left(\frac{L_1}{L_2}\right) \qquad (5)$$

Where

$C = K_K f_c$; K_K : Kick's constant ~ m^3/kg

L_1/L_2 = reduction ratio

Equation (5) is called Kick's Law, where the energy required is directly proportional to the reduction ratio.

However, the relation can be applied successfully to coarse crushing or sometimes to very fine grinding!

If we assume a value for the exponent, p, midway between the $p=2$ and $p=1$, say $p=3/2$. Upon Integration, we obtain the following relationship:

$$E = 2C\left(\frac{1}{L_2^{1/2}} - \frac{1}{L_1^{1/2}}\right) \qquad (6)$$

$$= 2C\sqrt{\frac{1}{L_2}}\left\{1 - \frac{1}{q^{1/2}}\right\} \qquad (7)$$

It is called Bond's Law

Where $q = L_1/L_2$ **reduction ratio** , $C = 5\ E_i$

Equation (7) can be rewritten as:

$$E = E_i \sqrt{\frac{100}{L_2}} \left\{ 1 - \frac{1}{q^{1/2}} \right\} \qquad (8)$$

Where

E_i :work index "the amount of energy required to reduce the unit mass of the material from infinite large particle size to 80% passing a 100μm screen i.e with 80% of the particles passing".

Equation 8 is better to be written like this

$$W = W_i \sqrt{\frac{100}{L_2}} \left\{ 1 - \frac{1}{q^{1/2}} \right\} = 10 W_i \left\{ \frac{1}{L_2^{1/2}} - \frac{1}{L_1^{1/2}} \right\}$$

Where W_i : work index, kw.h/ton

W : required work for crushing, kw.h/ton

L_1, L_2: size in μm

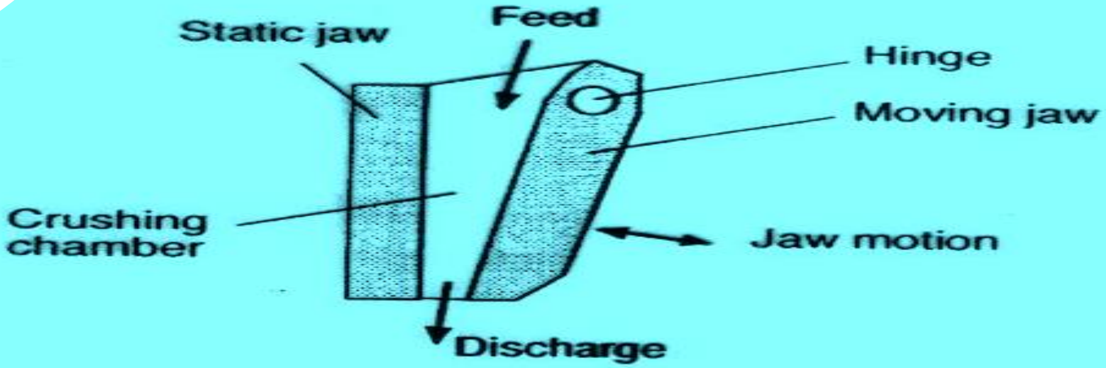
Average indexes

Material	Sp. Gr.	Work index, W_i
Copper ore	3.2	12.7
Glass	2.53	12.3
Phosphate rock	2.74	9.9
Oil shale	1.84	15.8

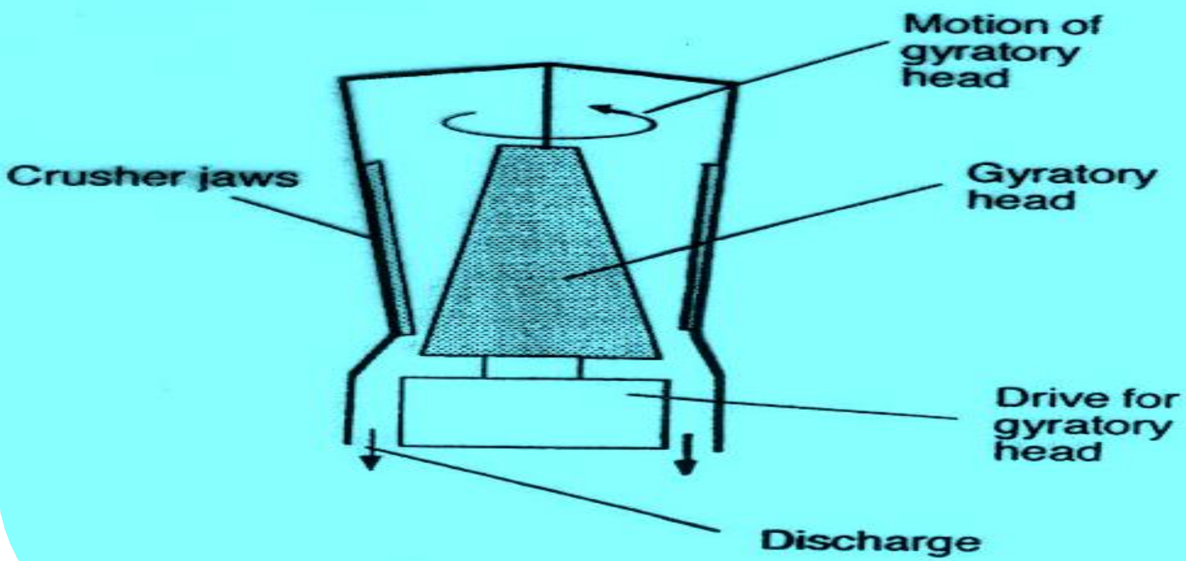
Crushing equipment

Coarse crushers	Intermediate crushers	Fine crushers
Jaw crusher	Crushing rolls	Roller mill
Gyratory crusher	Hammer mill	Ball mill
	Pin mill	Pendulum mill

Coarse crushers

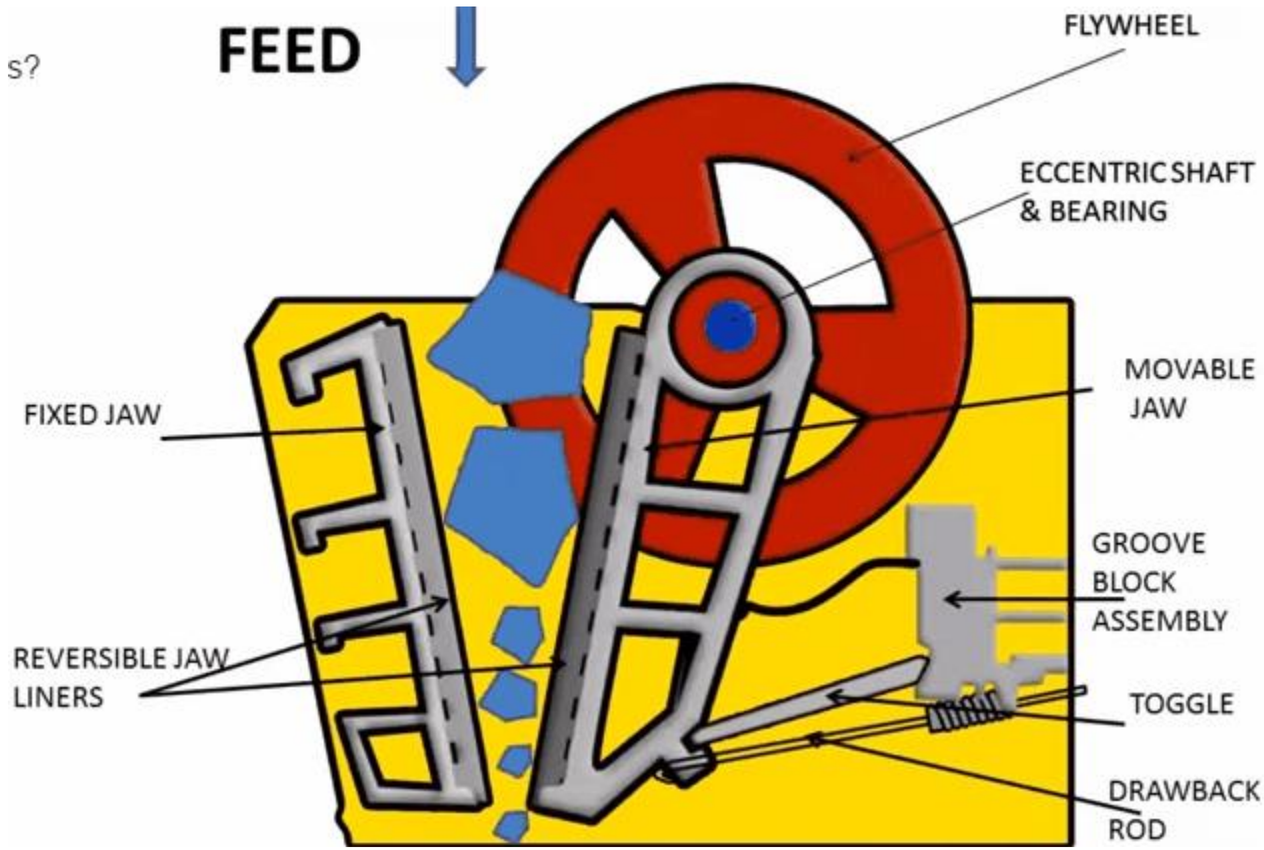


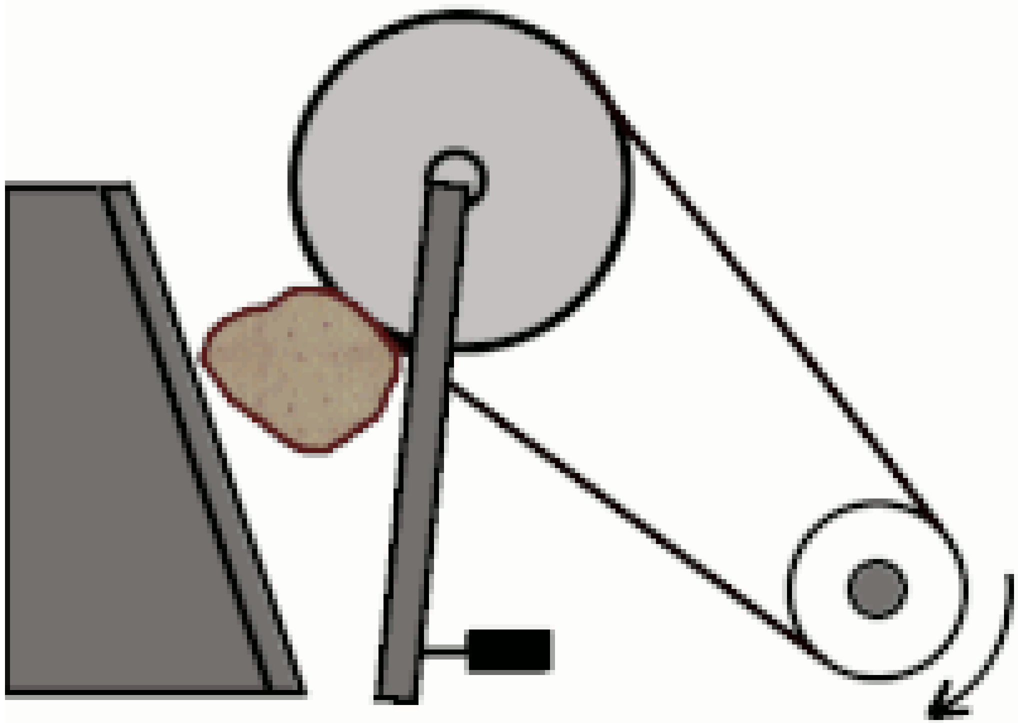
Schematic diagram of a jaw crusher

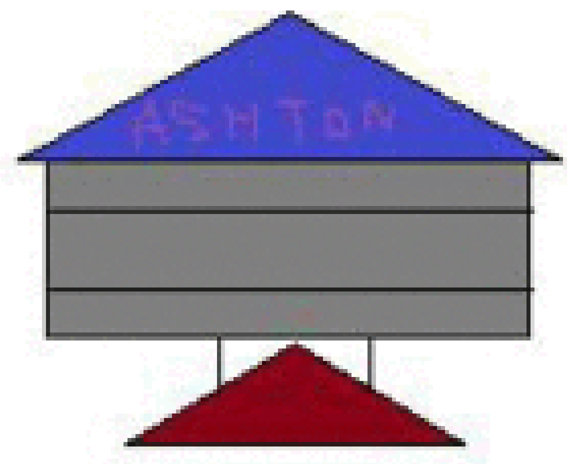


Schematic diagram of gyratory crusher

Jaw crusher


s?
FEED
FLYWHEEL
ECCENTRIC SHAFT
& BEARING
MOVABLE
JAW
FIXED JAW
GROOVE
BLOCK
ASSEMBLY
REVERSIBLE JAW
LINERS
TOGGLE
DRAWBACK
ROD

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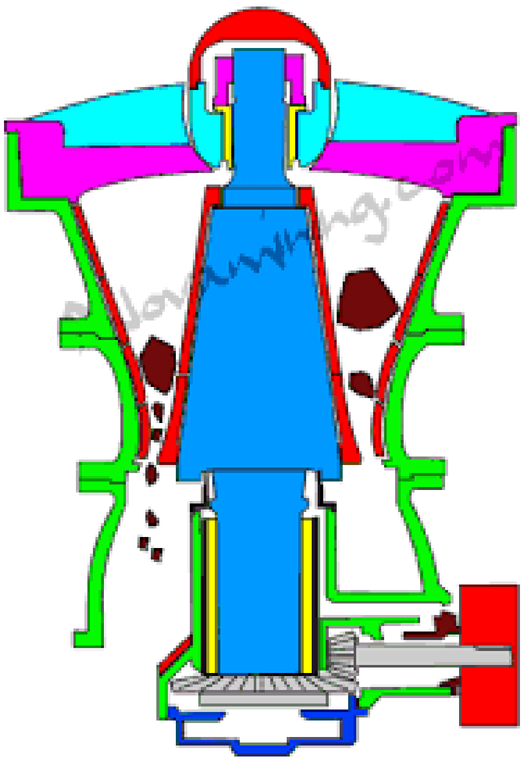
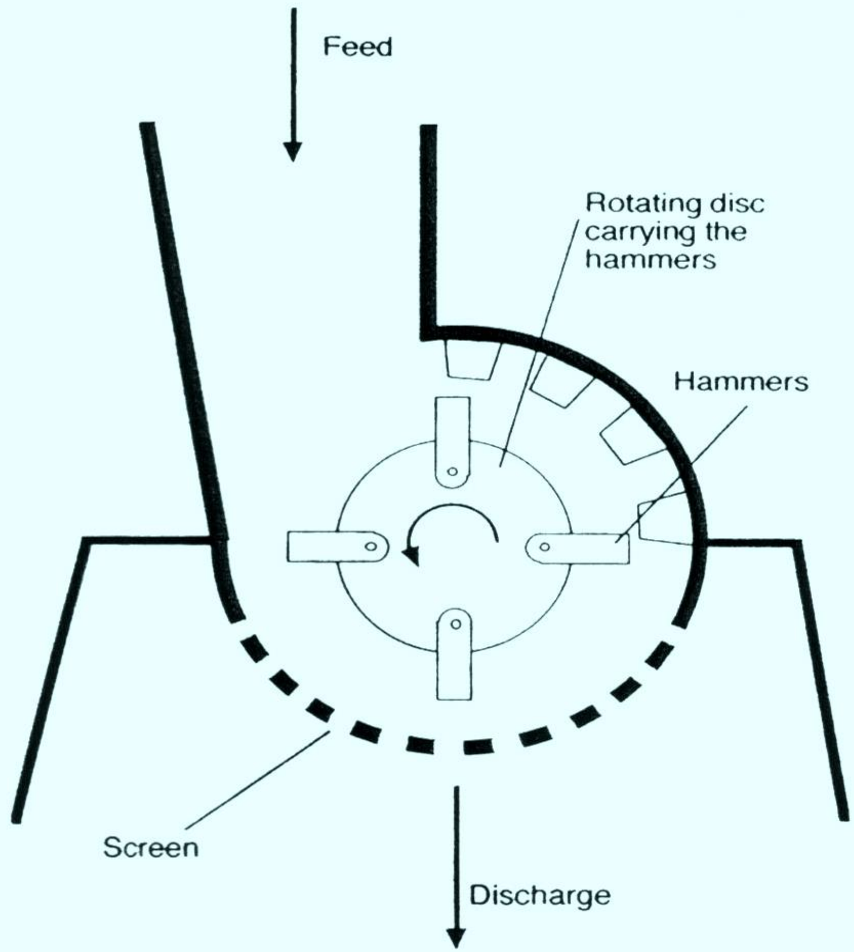


Hammer Mill

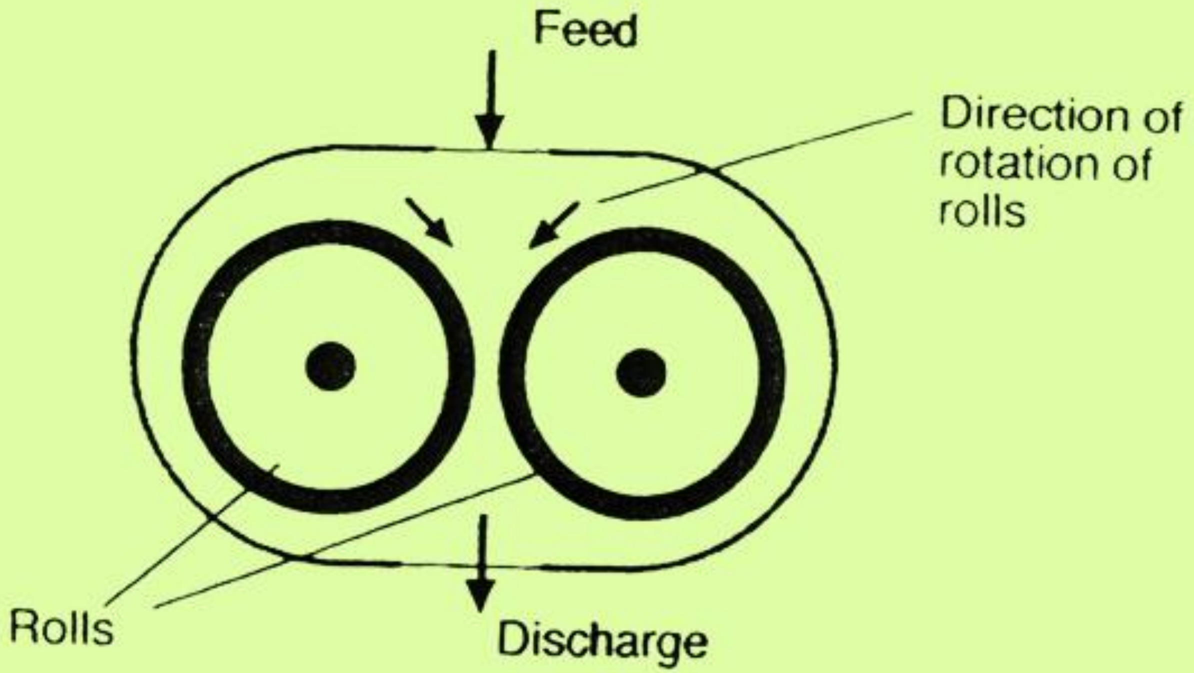


Schematic diagram of a hammer mill

Hammer mill

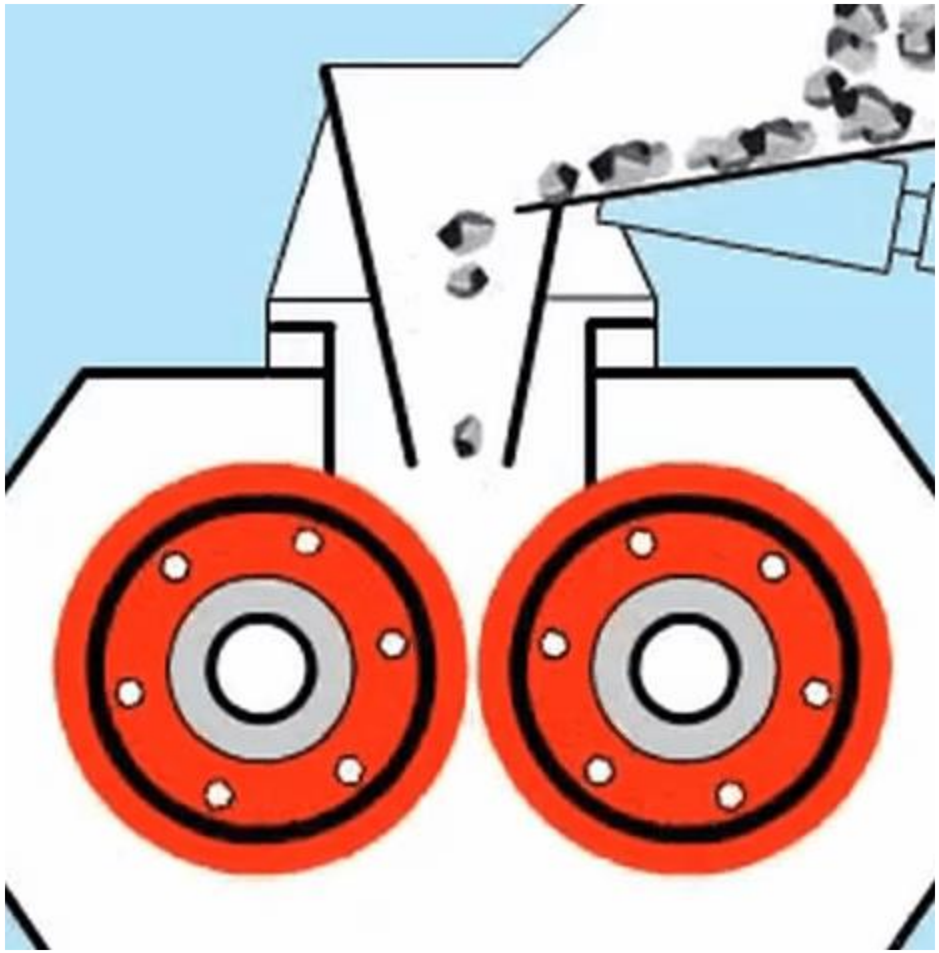
Hammer mill ‘High throughput’

Crushing rolls



Schematic diagram of crushing rolls

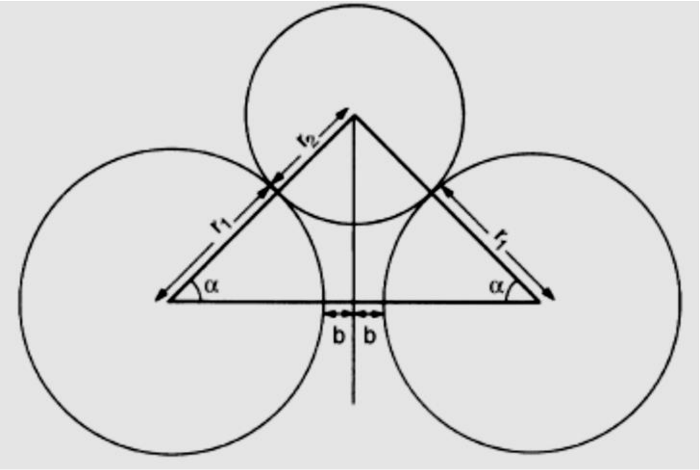
Crushing Rolls



Crushing Rolls

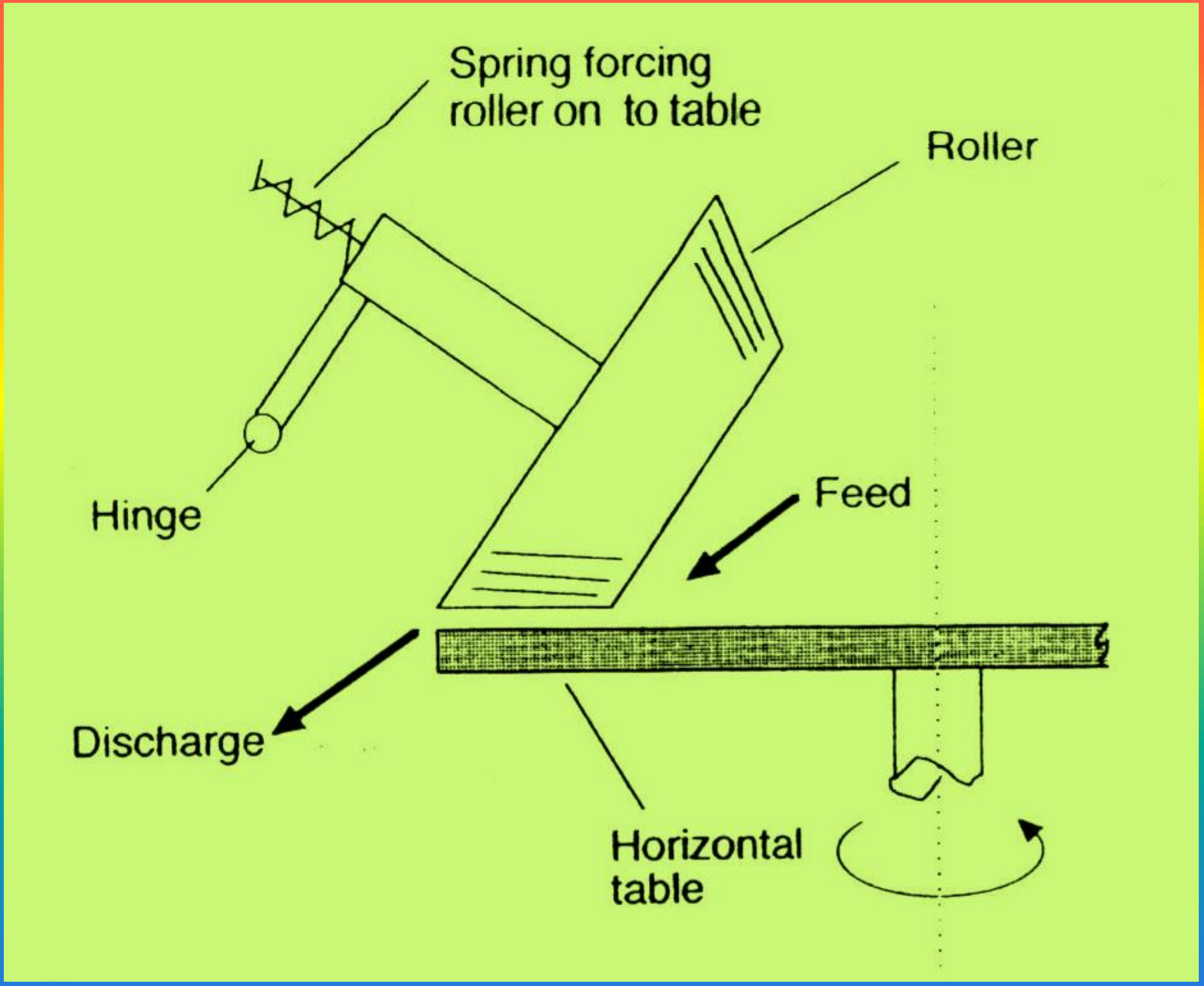
An idealized system where a spherical or cylindrical particle of radius r_2 is being fed to crushing rolls of radius r_1 is shown in Figure 2.16. 2α is the angle of nip, the angle between the two common tangents to the particle and each of the rolls, and 2b is the distance between the rolls. It may be seen from the geometry of the system that the angle of nip is given by:

$$\cos\alpha = \frac{(r_1 + b)}{(r_2 + r_1)}$$

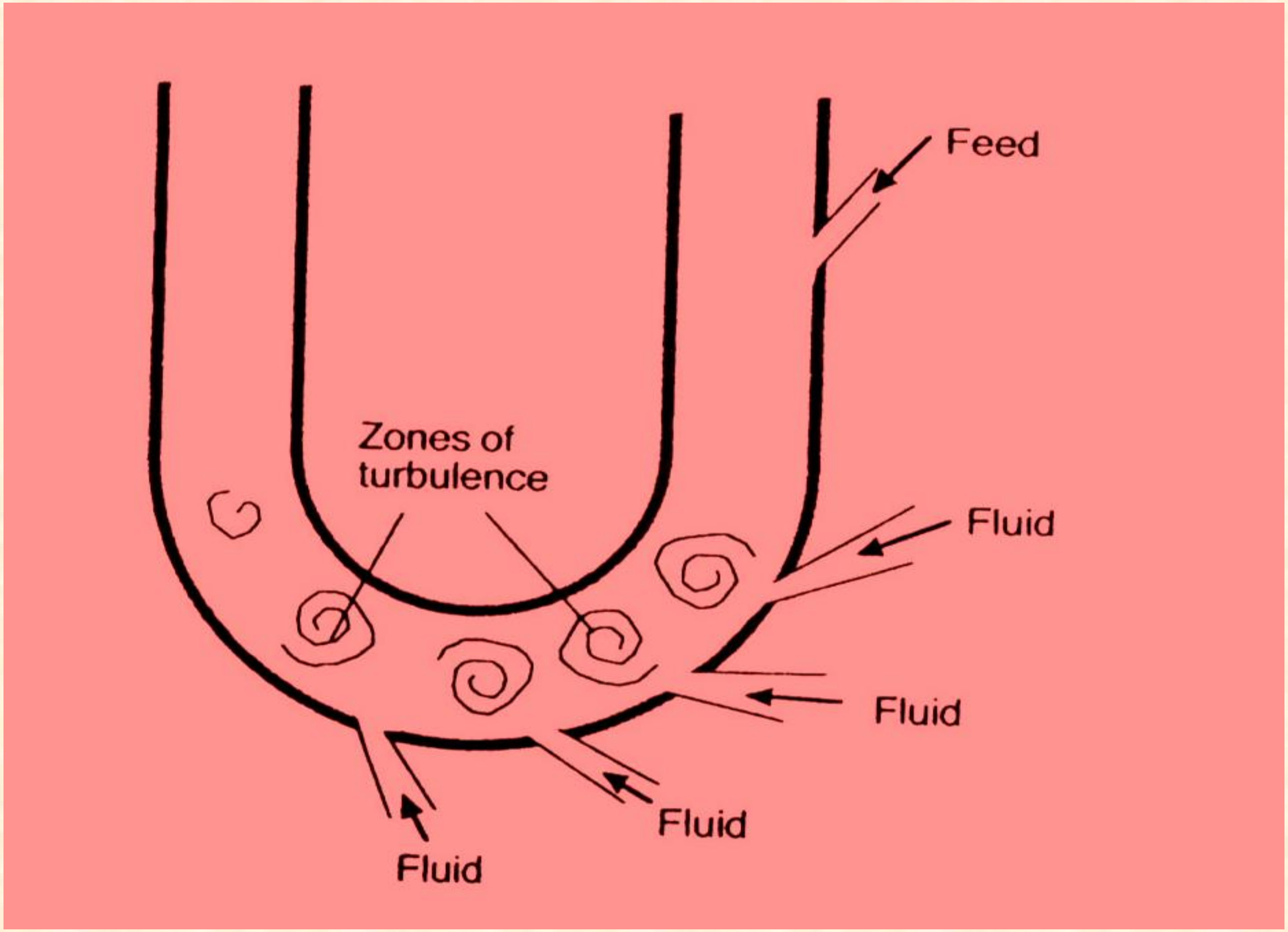


For steel rolls, the angle of nip is not greater than about 32◦.
Crushing rolls are extensively used for crushing oil seeds and in the gunpowder industry and they are also suitable for abrasive materials. They are simple in construction and do not give a large percentage of fines.

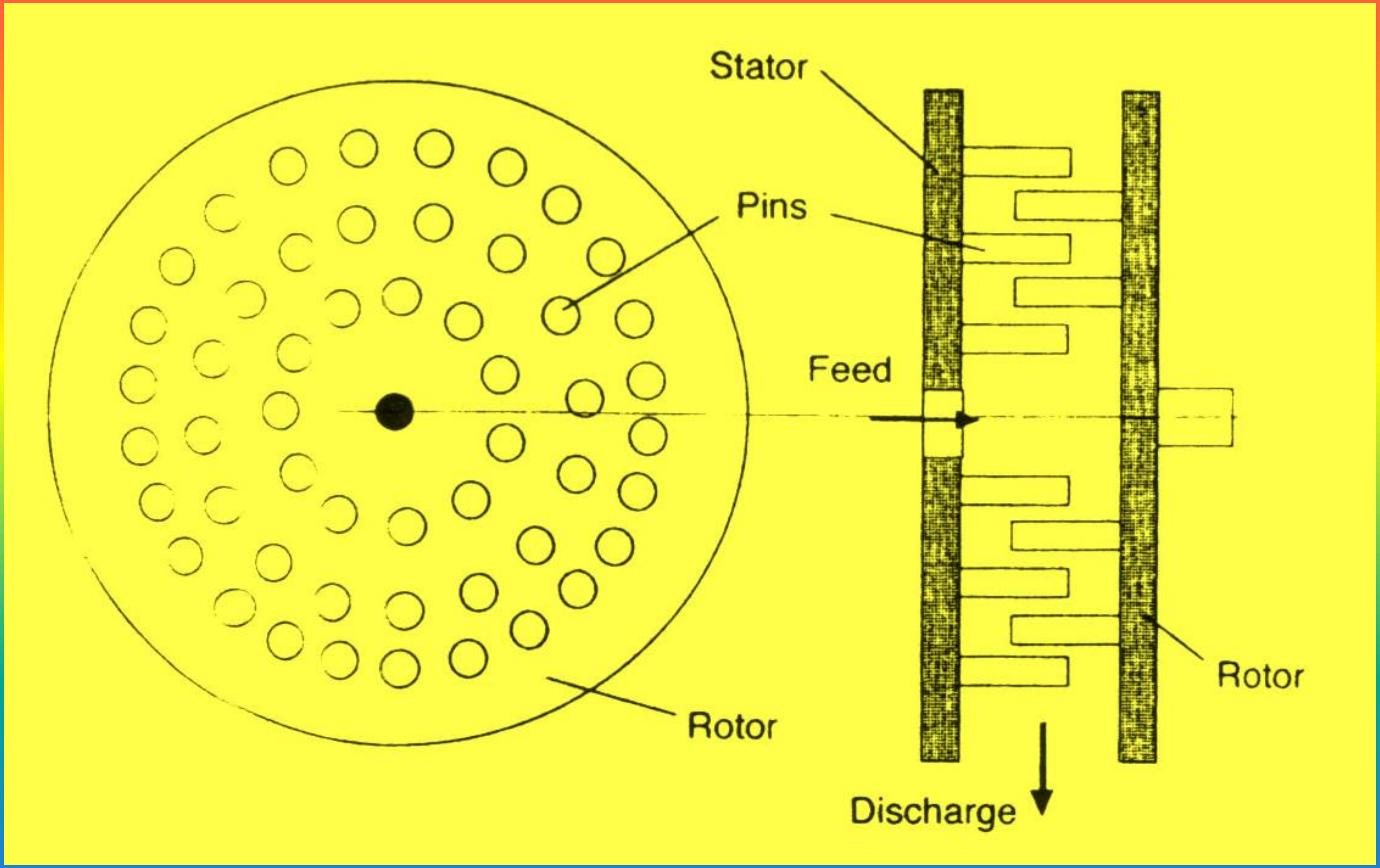
Horizontal table



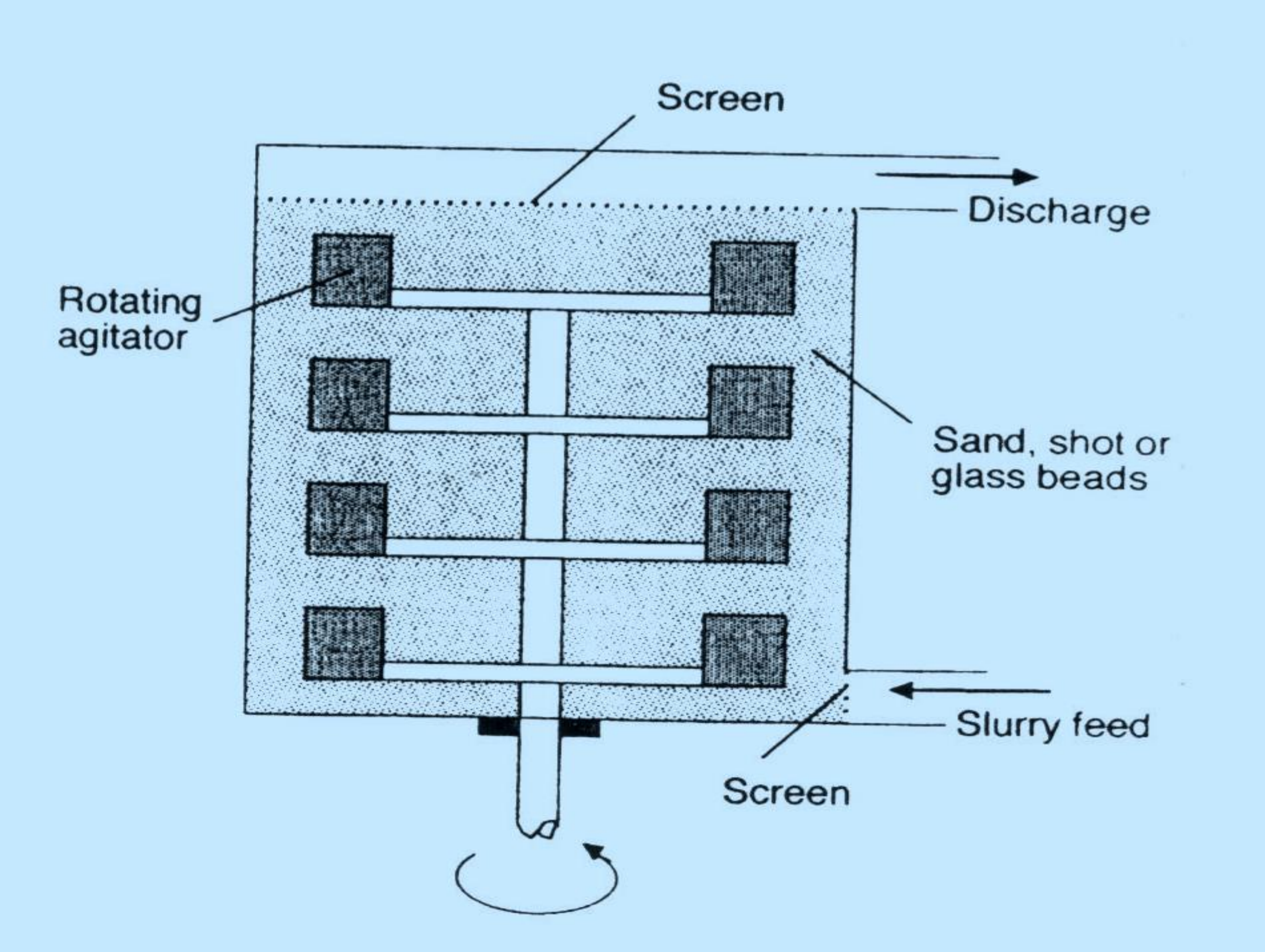
Fluid energy mill



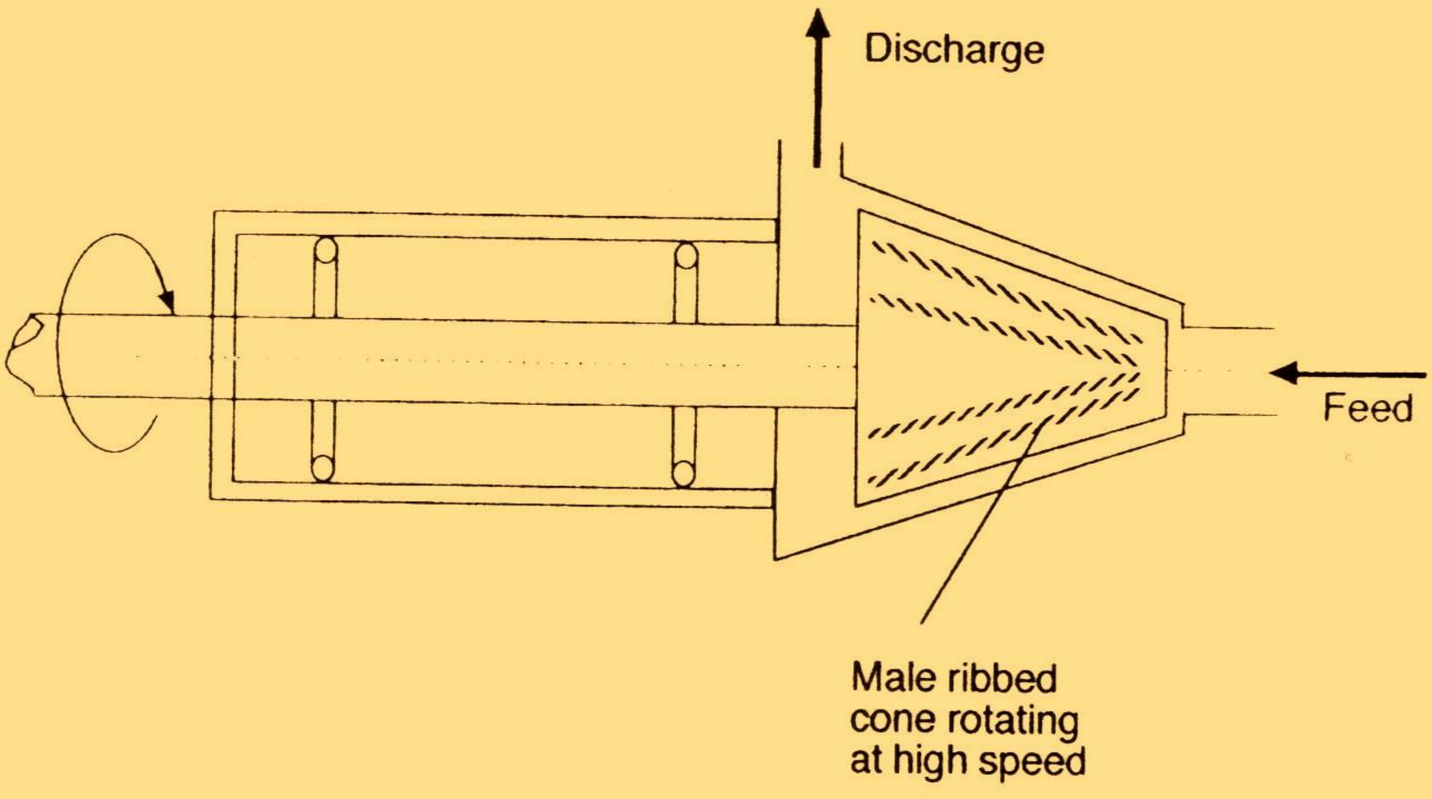
Pin Mill



Sand mill

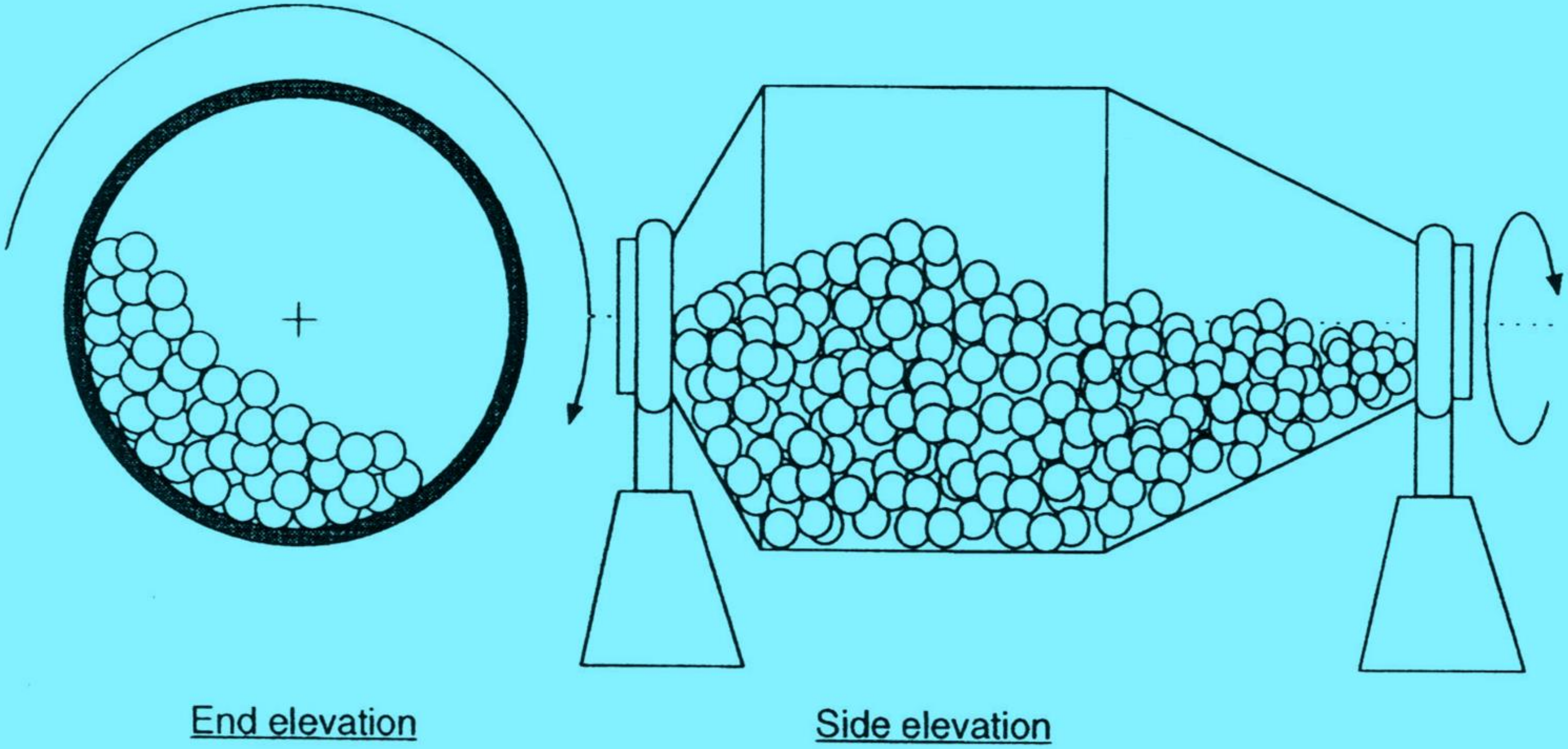

Screen
Discharge
Rotating agitator
Sand, shot or glass beads
Slurry feed
Screen

Colloid mill



Schematic diagram of a colloid mill

Ball mill



Schematiac diagram of a ball mill

The speed of rotation of the mill

- ✓ At low speeds of rotation, the balls simply roll over one another and little crushing action is obtained.
- ✓ At slightly higher speeds, the balls are projected short distances across the mill, and at still higher speeds they are thrown greater distances and considerable wear of the lining of the mill takes place.
- ✓ At very high speeds, the balls are carried right round in contact with the sides of the mill and little relative movement or grinding takes place again.
- ✓ The minimum speed at which the balls are carried round in this manner is called the critical speed of the mill and, under these conditions, there will be no resultant force acting on the ball when it is situated in contact with the lining of the mill in the uppermost position, that is the **centrifugal force** will be exactly equal to **the weight of the ball**.
- ✓ If the mill is rotating at the critical angular velocity ω_c, then:

$$r\omega_c^2 = g$$

Or

$$\omega_c = \sqrt{\frac{g}{r}}$$

The corresponding critical rotational speed, N_c in revolutions per unit time, is given by:

$$N_c = \frac{\omega_c}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{g}{r}}$$

In this equation, r is the radius of the mill less that of the particle. It is found that the optimum speed is between one-half and three-quarters of the critical speed.

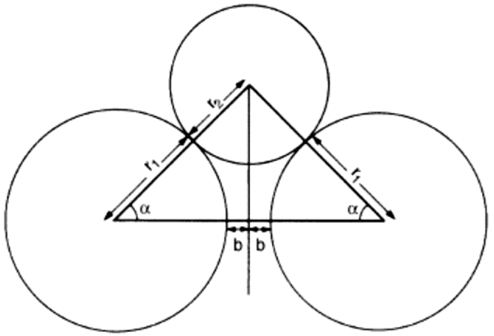
Note ω_c in units rad/time

$\omega_c = 2\pi N_c$, where Nc in rev/time

Example 1

If crushing rolls, 1 m in diameter, are set so that the crushing surfaces are 12.5 mm apart and the angle of nip is 31°, what is the maximum size of particle which should be fed to the rolls?
If the actual capacity of the machine is 12 per cent of the theoretical, calculate the throughput in kg/s when running at 2.0 m/s if the working face of the rolls is 0.4 m long and the bulk density of the feed is 2500 kg/m^3.

Solution



The particle size may be obtained from:

$$\cos\alpha = (r_1 + b)/(r_1 + r_2)$$

In this case: $2\alpha = 31°$ and $\cos\alpha = 0.964$, $b = (12.5/2) = 6.25$ mm or 0.00625 m and:

$$r_1 = (1.0/2) = 0.5 \text{ m}$$

Thus: $$0.964 = (0.5 + 0.00625)/(0.5 + r_2)$$

and: $$r_2 = 0.025 \text{ m or } \underline{\underline{25 \text{ mm}}}$$

The cross sectional area for flow $= (0.0125 \times 0.4) = 0.005 \text{ m}^2$

and the volumetric flowrate $= (2.0 \times 0.005) = 0.010 \text{ m}^3/\text{s}$.

Thus, the actual throughput $= (0.010 \times 12)/100 = 0.0012 \text{ m}^3/\text{s}$

or: $$(0.0012 \times 2500) = \underline{\underline{3.0 \text{ kg/s}}}$$

Example 2

A ball mill, 1.2 m in diameter, is run at 0.80 Hz and it is found that the mill is not working properly. Should any modification in the conditions of operation be suggested?

Solution

The angular velocity is given by:

$$\omega_c = \sqrt{(g/r)}$$

In this equation, r = (radius of the mill − radius of the particle). For small particles, $r = 0.6$ m and hence:

$$\omega_c = \sqrt{(9.81/0.6)} = 4.04 \text{ rad/s}$$

The actual speed $= (2\pi \times 0.80) = 5.02$ rad/s and hence it may be concluded that the speed of rotation is too high and that the balls are being carried round in contact with the sides of the mill with little relative movement or grinding taking place.

The optimum speed of rotation lies in the range $(0.5–0.75)\omega_c$, say $0.6\omega_c$ or:

$$(0.6 \times 4.04) = 2.42 \text{ rad/s}$$

This is equivalent to: $(2.42/2\pi) = 0.39$ Hz, or, in simple terms:

the speed of rotation should be halved.