SIZE REDUCTION

Content

- introduction of Size reduction
- Types of grinding
- Theory of crushing and grinding,
- Laws of comminution
- size reduction equipment and their selection.

Introduction

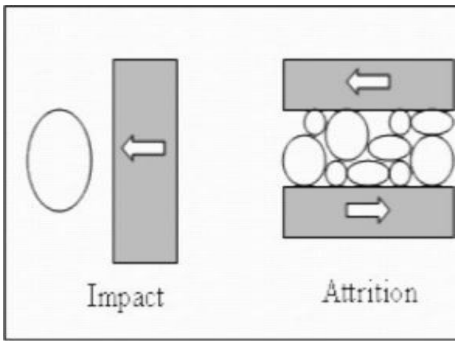
- **Size reduction:** All the ways in which particles of solids are broken or cut to smaller pieces.
- Throughout chemical industries solids are reduced in size by different methods for different purposes e.g.
    - Chunks of crud ores are crushed to workable size
    - Synthetic chemicals are ground into powder.
- Commercial products must sometimes meet very specific requirements as to the size and sometimes the shape of the product.
- Particles are ground to increase the reactivity of solids in some industrial reactions.
- It eases the separation of unwanted large impurities by mechanical methods
- It reduces the bulk of fibrous materials for easier handling.

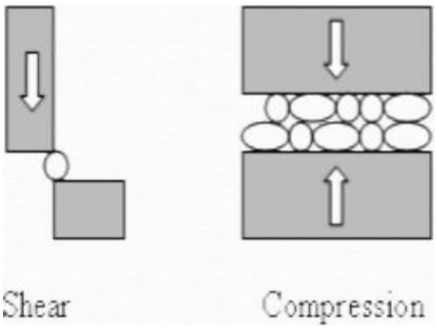
Different ways of size reduction

- Solids are broken in four different ways:
    - Compression
    - Impact
    - Attrition
    - Cutting

- Compression is the main mode for coarse reduction, giving off only few fines.
- Impact can yield coarse or fine particles
- Attrition gives extremely fine particles.

Cutting is only used whenever the product is to be of some definite shape with little or no fines.





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
  - 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

Advantages of Size Reduction

- Content uniformity
- Uniform flow
- Effective extraction of drug
- Effective drying

- Improves physical stability. The rate of sedimentation decreases by reducing particle size
- Improves dissolution rate
- Improves rate of absorption. Smaller the particle, greater is the absorption.
- Increases surface area and viscosity
- Facilitates bioavailability, uniform mixing and drying

Factors related to nature of raw materials affecting size reduction

- **Hardness -** It is easier to break soft material than hard materials
- **Fibrous** - These are tough in nature. A soft, tough material has more difficulty than a hard, brittle substance. Ex: Ginger. Here cutters can be used.
- **Friable-** These tend to fracture along well defined planes.
- **Brittle** substances can be easily converted into fine particles
- **Elastic / Sticky** - Become soft during milling. Ex: synthetic gums, waxes, resins.
- **Low melting** substances should be chilled before milling.
- **Melting point -** Waxy substances, fats and oils are softened during size reduction due to heat generated. This is avoided by cooling the mill and the substance.
- **Hygroscopic -** Certain substances absorb moisture content rapidly. This wet mass hampers the milling process
- **Solvated-** Hydrates liberate water during milling, causes clogging of mill. Ex: sodium sulphate.
- **Thermolability-** Certain Substances are degraded by hydrolysis and oxidation, due to moisture and atmospheric oxygen. Heat produced on milling enhances these reactions.

THEORIES OF SIZE REDUCTION / MILLING

A number of theories have been proposed to establish a relationship between energy input and the degree of size reduction produced.

- **Rittinger's theory**
- **Bond's theory**
- **Kick's theory**

Rittinger's Law

- The oldest theory, Von Rittinger (1867), stated that.
- *The energy consumed in size reduction is proportional to the area of new surface produced*
- $E = K_R\{(1/d_2) - (1/d_1)\}$
- E(J.kg-1) = the energy required per mass of feed (W/(kg/s))
- K_R = Rittinger's constant, d_1 (m) = the average initial size of pieces, d_2 (m) = the average size of ground particles.

Kick's law

the energy required to reduce the size of particles is proportional to the ratio of the initial size of a typical dimension to the final size of that dimension

$$E = K_K \ln\left(\frac{d_1}{d_2}\right)$$

E(J.kg-1) = the energy required per mass of feed (W/(kg/s))
K_K = Kick's constant,
d_1 (m) = the average initial size of pieces,
d_2 (m) = the average size of ground particles.
d_1/d_2 = the *size reduction ratio (RR)* and is used to evaluate the relative performance of different types of equipment.

Both *Kick's law* ***and*** *Rittinger's law* ***have been shown to apply over limited ranges of particle size, provided K_R and K_K are determined experimentally by test in machine of type to be used and material to be crushed. Thus they have limited utility.***

Bond's law

Energy used for size reduction is proportional to the new cracks length

$$E/W = (100/d_2)^{0.5} - (100/d_1)^{0.5}$$

E(J.kg^{-1}) = the energy required per mass of feed (W/(kg/s))
W (J kg^{-1}) = the Bond Work Index work required to reduce a unit weight .
d_1 (m) = diameter of sieve aperture that allows 80% of the mass of the feed to pass d_2 (m) = diameter of sieve aperture that allows 80% of the mass of the ground material to pass.

- *Kick's law gives reasonably good results for coarse grinding in which there is a relatively small increase in surface area per unit mass.*
- *Rittinger's law gives better results with fine grinding where there*

is a much larger increase in surface area

Bond's law is intermediate between these two. However, equations Rittinger's law and Bond's law were developedfrom studies of hard materials (coal and limestone).

Problem: A material is crushed in jaw crusher such that average size of particle reduces from 60mm to 10mm and 13kW energy is consumed. How much energy consumed to crush same material of average size from 85mm to 15mm when

a) Rittinger's Law applied
b) Kick's Law applied

The principal types of size-reduction machines are as follows:

A. ***Crushers (coarse and fine)***
  1. ***Jaw crushers***
  2. ***Gyratory crushers***
  3. ***Crushing rolls***

B. ***Grinders (intermediate and fine)***
  1. ***Hammer mills; impactors***
  2. ***Rolling-compression mills***
    a. ***Bowl mills***
    b. ***Roller mills***
  3. ***Attrition mills***
  4. ***Tumbling mills***
    a. ***Rod mills***
    b. ***Ball mills; pebble mills***
    c. ***Tube mills; compartment mills***

C. ***Ultrafine grinders***
  1. ***Hammer mills with internal classification***
  2. ***Fluid-energy mills***
  3. ***Agitated mills***

D. ***Cutting machines***
  1. Knife cutters; dicers; slitters

The Grinding:

In the grinding process, materials are reduced in size by fracturing them. In the process, the material is stressed by the action of mechanical moving parts in the grinding machine and initially the stress is absorbed internally by the material as strain energy.

Grinding is achieved by mechanical stress followed by rupture and the energy required depends upon:

1. the hardness of the material
2. the tendency of the material to crack (friability).

The force applied may be compression, impact, or shear, and both the magnitude of the force and the time of application affect the extent of grinding achieved.

$$V_p = pD_p^3 \qquad\qquad A_p = 6qD_p^2$$

Where
V_p is the volume of the particle.
A_p is the area of the particle surface
D_p is the typical dimension of the particle
q is factor of the particle geometries.
And , The ratio of surface area to volume is:
$A_p/V_p = (6q/p)/D_p = 6\lambda/D_p$
$A_p = 6\lambda V_p/D_p$

$\lambda = q/p$ *is a shape factor.*

It has been found experimentally for example.

	Vp	***Ap***	***Specific surface Vp / Ap***	***λ***
Cube	***Dp3***	***6Dp2***	***6/Dp***	***1***
Sphere	***πDp3/6***	***πDp2***	***6/Dp***	***1***

A number of particles (N) is:

$$N = \frac{m}{m_p} = \frac{m}{V_p\,\rho_p}$$

Where :

m is a total mass of particles
m_p is a mass of particle
ρ_p is the density of particles
So total area of the mass of particles (A_t) is:

$$A_t = NA_p = \left[\frac{m}{\rho_p V_p}\right]\left[\frac{6\lambda V_p}{D_p}\right]$$

$$A_t = \frac{6\lambda m}{\rho D_p}$$

Example :

In an analysis of ground salt using Tyler sieves, it was found that 38% of the total salt passed through a 7-mesh sieve and was caught on a 9-mesh sieve. For one of the finer fractions, 5% passed an 80-mesh sieve but was retained on a 115-mesh sieve. Estimate the surface areas of these two fractions in a 5 kg sample of the salt, if the density of salt is 1050 kg/m^3 and the shape factor is 1.75.

Aperture of Tyler sieves ,
7 mesh = 2.83 mm
9 mesh = 2.00 mm
80 mesh = 0.177 mm

115 mesh = 0.125 mm .

Solution:

Mean aperture 7 and 9 mesh = 2.41 mm = 2.4 x 10^{-3}m
Mean aperture 80 and 115 mesh = 0.151 mm = 0.151 x 10^{-3}m
At = (6 x 1.75 x0.38 x 5)/(1050x 2.41x10^{-3})
At = 7.88 m2
At = (6 x 1.75x 0.05 x 5)/(1050 x 0.151x10^{-3})
At = 16.6 m^2.

Emulsification

Emulsions are stable suspensions of one liquid in another, the liquids being immiscible. Stability of the emulsion is obtained by dispersion of very fine droplets of one liquid, called the **disperse phase**, through the other liquid, which is called the **continuous phase**. The emulsion is stable when it can persist without change, for long periods of time, without the droplets of the disperse phase coalescing with each other, or rising or settling. The **stability of an emulsion** is controlled by interfacial surface forces, size of the disperse phase droplets, viscous properties of the continuous phase and density difference between the two phases.

The dispersed particles in the emulsion have a very large surface area, which is created in the process of emulsification. Surface effects depend upon the properties of the materials of the two phases, but very often a third component is added which is absorbed at the interface and which helps to prevent the droplets from coalescing. These added materials are called **emulsifying agents** and examples are phosphates and glycerol monostearate.

Stokes' Law gives a qualitative indication of the physical factors that influence the stability of an emulsion. This is because the relative flow of the particles under gravitational forces may break the emulsion, so stability is enhanced by small settling velocities. From eqn.

$v = D^2 g(\rho_c - \rho_d)/18\mu_c$

where:
v: settling velocity
D:drops diameter
g : specific gravity
ρ_c , ρ_d :densities for continuous and dispersed face
μ_c: viscosity of continuous face.

Work indexes for dry crushfngf or wot grinding^

Material	Specific gravity	Work index, fF,-
Bauxite	2.20	8.7S
Cement clinker	3.15	13.-45
Cement raw material	2.67	10.51
Clay	2.51	6.30
Coal	1-4	13.00
Coke	1.3 1	15.13
Granite	2.66	1 5.13
Gravel	2.66	16.06
Gypsum rock	2.69	6.73
Iron ore (hematite)	3-53	12.8-4
Limestone	2.66	12.74
Phosphate rock	2.7-4	*9,92*
Quartz	2.65	13.57
Shale	2.63	15.87
Slate	2.57	14.30
Trap rock	2,87	*19.32*

"f For dry grinding, multiply by f.

i From Allis-Chalmcrs, Solids Processing Equipment: Div., Appleton, Wisconsin, by