CERAMIC MATERIALS I

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Preparation of Raw Materials in Traditional Ceramics Processing

- Most shaping processes for traditional ceramics require the starting material to be a plastic paste
  - This paste is comprised of fine ceramic powders mixed with water
- The starting raw ceramic material usually occurs in nature as rocky lumps
  - Purpose of the preparation step is to reduce the rocky lumps to powder

COMMINUTION

Comminution entails reducing the particle size of the raw material by ***crushing***, ***grinding***, and ***milling*** or fine grinding.

In mineral processing parlance, comminution in coarse range is known as **“crushing”** and in fine range it is called **“grinding”**.

Comminution : The act or process of reduction of particle size with attendant increase in surface area and population of particles, usually but not necessarily by grinding, milling, or pulverizing

The comminution process remains inherently inefficient. 85% of the energy used is dissipated as heat, 12% is attributed to mechanical losses and only 1% of the total energy input is used in size reduction of feed material.

During grinding (usually in water), the ore is ground from a maximum 20 mm diameter down to about 0.3 mm or less

Aims of Size Reduction

Some of the most common reasons for reducing a material are to

- ***create appropriate particle sizes***
- ***improve material blending and prevent segregation***
- ***increase the material's surface area***
- ***control a material's bulk density***
- ***liberate impurities***
- ***reduce porosity of the particles***
- ***modify shape of the particles***

Size Reduction

Desired Requirements for Size reduction

- ***Fast, efficient and reliable fine grinding***
- ***Versatility of the process***
- ***Low power consumption***
- ***Easy and safe operations***
- ***Low maintenance***
- ***Compact design, small plant area***

COMMINUTION

- Crushing
  - Primary
    - Jaw
    - Gyratory
  - Secondary
    - Cone
      - The standar type (for secondary crushing)
      - The short head type (for tertiary crushing)
    - Roll
      - Compression (Single roll and double roll
    - Impact
      - Hammer mill
      - Double rotor
      - Single rotor
  - Tertiary

COMMINUTION

The **purpose of comminution is** to liberate impurities, break up aggregates, modify particle morphology and size distribution, facilitate mixing and forming, and produce a more reactive material for firing.

Primary crushing generally reduces material up to 0.3 meter (m) (1 foot [ft]) in diameter down to 1 centimeter (cm) (0.40 inch [in.]) in diameter.

Secondary crushing reduces particle size down to approximately 1 millimeter (mm) (0.04 in.) in diameter.

Fine grinding or milling reduces the particle size down to as low as 1.0 micrometer (μm) (4 x 10-5 in.) in diameter.

Ball mills are the most commonly used piece of equipment for milling. However, vibratory mills, attrition mills, and fluid energy mills also are used. Crushing and grinding typically are dry processes; milling may be a wet or dry process. In wet milling, water or alcohol commonly is used as the milling liquid.

COMMINUTION

A primary crusher receive the raw material directly from a quarry after blasting, and produces the first reduction in size.

- The primary crusher in ore processing is usually a gyratory or jaw type, which in large operations is capable of accepting rocks up to 2 m in diameter.

- Reducing particle size in ceramics processing by using mechanical energy in various forms such as impact, compression, and attrition.

- Comminution techniques are most effective on brittle materials such as cement and metallic ores.

COMMINUTION

The reduction ratio is defined as the representative feed size by representative product size. The sizes are usually defined as the 80% passing size of the cumulative size distribution.

Crusher type	Reduction ratio
Jaw	
a) Double toggle	
1) Blake	4:1–9:1
2) Overhead pivot	4:1–9:1
b) Single toggle: Overhead eccentric	4:1–9:1
Gyratory	
a) True	
b) Cone	
1) Standard	4:1 – 6:1
2) Attrition	2:1 – 5:1

Crusher type	Reduction ratio
Roll	
a) Compression	
1) Single roll	Maximum 7:1
2) Double roll	Maximum 3:1
Impact	
a) Single rotor	to 15:1
b) Double rotor	to 15:1
c) Hammer mill	to 20:1
Speciality crushers	
a) Rod mill	
b) Ball mill	

CRUSHING

Crushing in general is an energy intensive process. Primary crushing in particular consumes large amounts of energy due to the significant amount of size reduction taking place. In addition to the amount of size reduction, the energy required for breakage in crushing applications is dependent upon the physical properties of the material and the quantity of material being crushed. The rate of energy input is dependent upon the type of crushing machine used since the application of the crushing force changes with machine type.

Primary crushers apply breakage forces by means of compression or impact.

Jaw and **gyratory crushers** are the most common types of primary compression crushers. Each applies a compressive force to rock particles as they come in contact with the crushing surfaces. The force is applied slowly (in comparison to impact machines) resulting in abrasion and cleavage fracture. Impact crushers apply a high-speed impact force to rock particles using hammers or blow bars. The rate of energy input is much higher causing particles to shatter. Impact crushers can achieve higher reduction ratios than jaws and gyratory’s but are limited by high rates of abrasive wear and thus are restricted to somewhat softer rocks.

CRUSHING

- The crushing forces have to be intense so that the elastic limit of the material being crushed is exceeded. Crushers tend to be massive and rugged (although sometimes portable), requiring large drive motors.

- They are energy intensive and expensive, both to construct and to operate. The rock is crushed to a maximum size of about 0.20 to 0.25 m in diameter at this stage. From this point, the ore passes on to a second or a third stage of crushing in either gyratory, cone, or roll crushers. Intermediate screening occurs at each stage to separate out the larger rock chunks for further crushing.

CRUSHING

- Final product of the ore crushing plant is usually all 10 to 20 mm in diameter (i.e., particles of this size will pass through a screen with these openings), with a high percentage of the product finer than this. This product then passes on to the ore grinding operation.

- The gyratory, jaw, cone, and roll crushers crush rock by applying high compressive forces to each rock. Another type of crusher accomplishes similar results using impact hammers or blow bars mounted on a rotor, thereby producing high kinetic energy impacts on each rock at velocities of around 30 m/s.

- These impact crushers are capable of producing a high ratio of size reduction in one stage of crushing. However, due to the high velocities of the hammer, the wear rate is very high. Impact hammers are, therefore, typically used to crush softer ores such as coal, limestone, and cement plant feed.

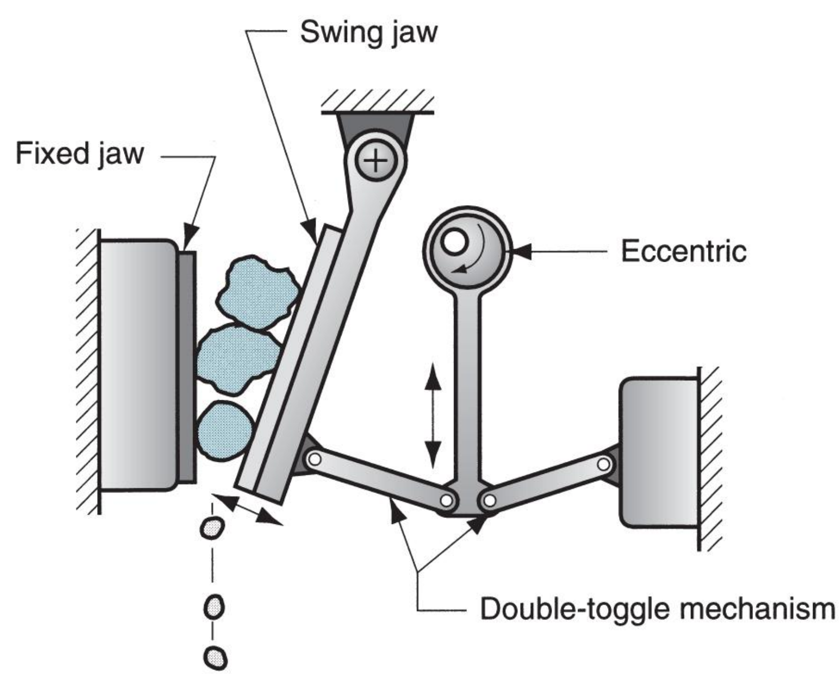
Crushing Equipment Selection

Some of the important parameters are given below:

- type of the raw material
- amount of the raw material
- maximum individual size of the feed materials
- target raw material size
- method of the feeding
- reguired capasity of the plant

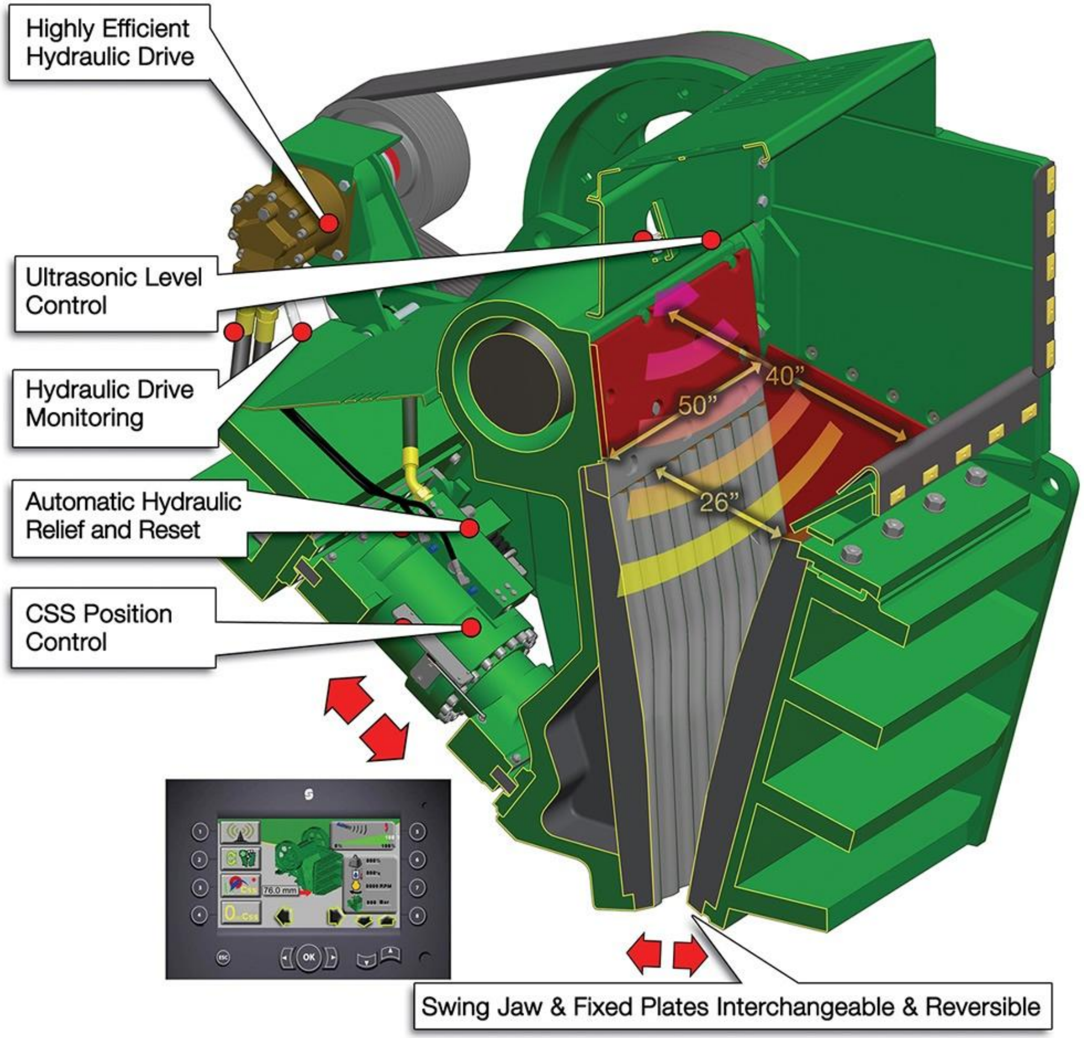
Jaw Crusher

Large jaw toggles back and forth to crush lumps against a hard, rigid surface



- Jaw crushers operate by allowing stone to flow into the space between two jaws, one of which is stationary while the other is movable .
- The distance between the jaws diminishes as the stone travels downward under the effect of gravity and the motion of the movable jaw, until the stone ultimately passes through the lower opening.

Jaw Crusher


Highly Efficient Hydraulic Drive
Ultrasonic Level Control
Hydraulic Drive Monitoring
Automatic Hydraulic Relief and Reset
CSS Position Control
50”
40”
26”
Swing Jaw & Fixed Plates Interchangeable & Reversible

GYRATORY CRUSHER

These machines operate on the principle of compressing the rocks in a cone. The rocks fall into the cavity from the top. The moving part is an eccentric cone. The rocks enter on the largest corner of the cavity but are compressed as the eccentric cone rotates. The outside cone is sometimes called the bowl, and the rotating cone is called the mantle. The bowl reduces in diameter toward the bottom, whereas the mantle increases in diameter with depth in the opposite direction.

Gyratory crushers are preferred for slabs or flat-shaped rocks as they snap the rock better. Gyratory crushers are manufactured to handle tonnage flows up to 3500 tph. Sandvik purchased the line of Nordberg mobile primary gyratory crushers that can be moved from one site to another as the mine expands.

GYRATORY CRUSHER

- Gyratory crushers are characterized by a gyrating mantle mounted within a deep bowl.
- Gyratory crushers provide continuous crushing action and are used for both primary and secondary crushing of hard, tough, abrasive rock.

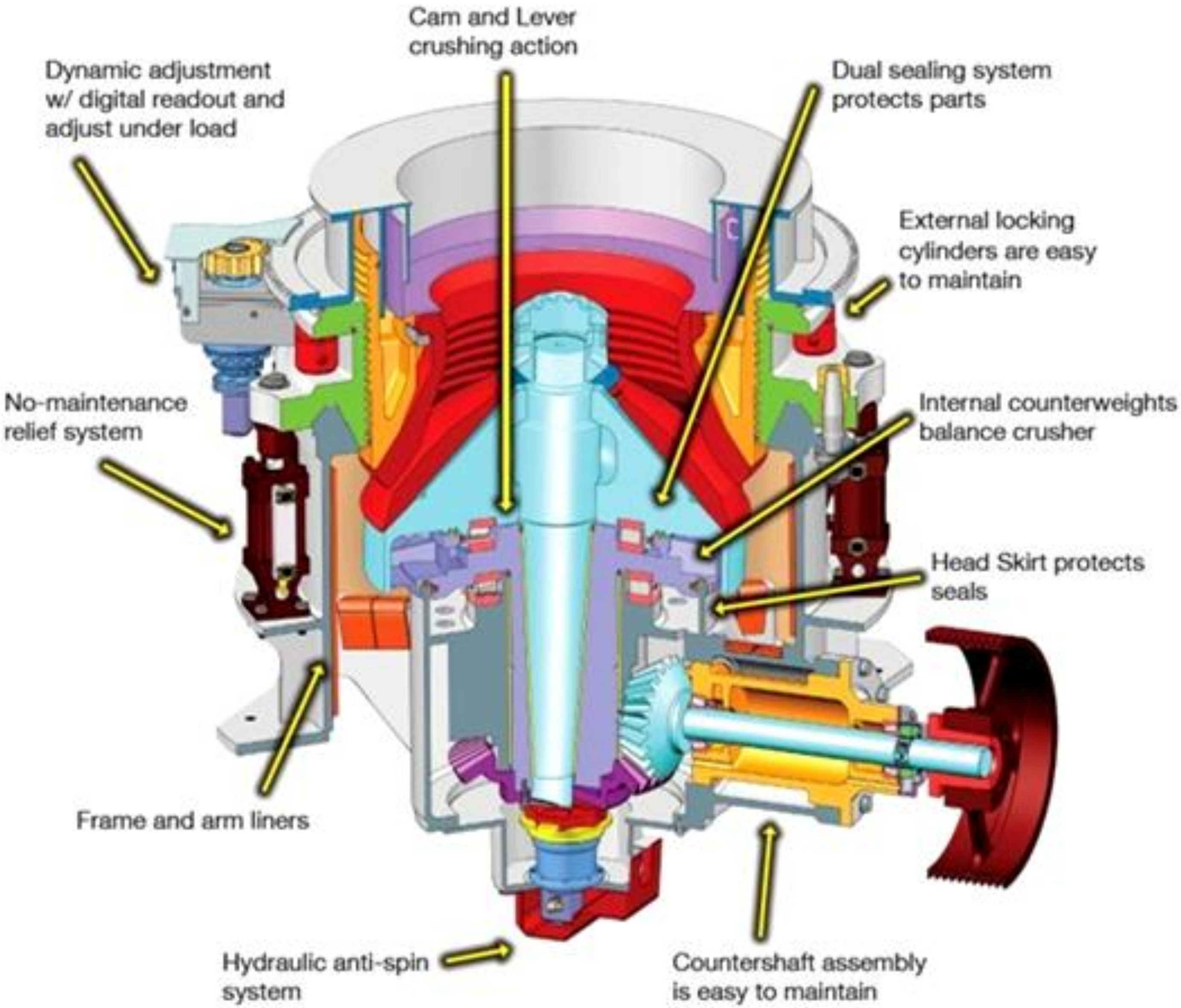
GYRATORY CRUSHER

CONE CRUSHER

- Cone crushers are used as secondary or tertiary crushers.
- Cone crushers are capable of producing large quantities of uniformly fine crushed stone.

- A cone crusher differs from a true gyratory crusher in the following respects:
  1. It has a shorter cone.
  2. It has a smaller receiving opening.
  3. It rotates at a higher speed, about twice that of a true gyratory
  4. It produces a more uniformly sized stone.

CONE CRUSHER



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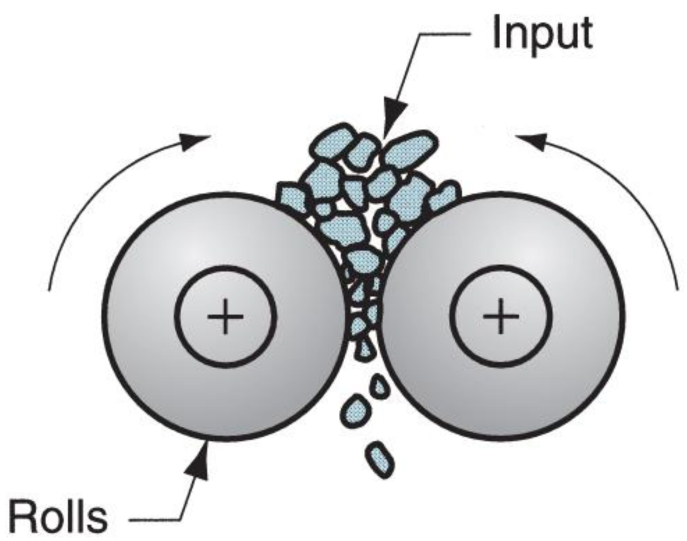
CONE CRUSHER

Cone crushers operate on the same principle as gyratory crushers. This allows a gradual reduction of the area between the two cones. The rotating cone or mantle is inclined, thus providing a combination of impact loads and compression loads. By comparison with the gyratory crusher, the outer bowl is inverted, and the mantle rotates at much higher speeds. There are two types of cone crushers:

- The standard type (for secondary crushing)
- The short head type (for tertiary crushing)

Roll Crusher

Ceramic lumps are squeezed between rotating rolls.



Roll crushers consist of two counterrotating cylinders. The gap between the cylinders is adjusted by threaded bolts. Roll crushers can use springs to hold the cylinders in place. Each cylinder is then driven by its own belt drive. Roll crushers are used for less abrasive stones than cone crushers. They are most effective on soft and friable stones, or when a close-sized product is required.

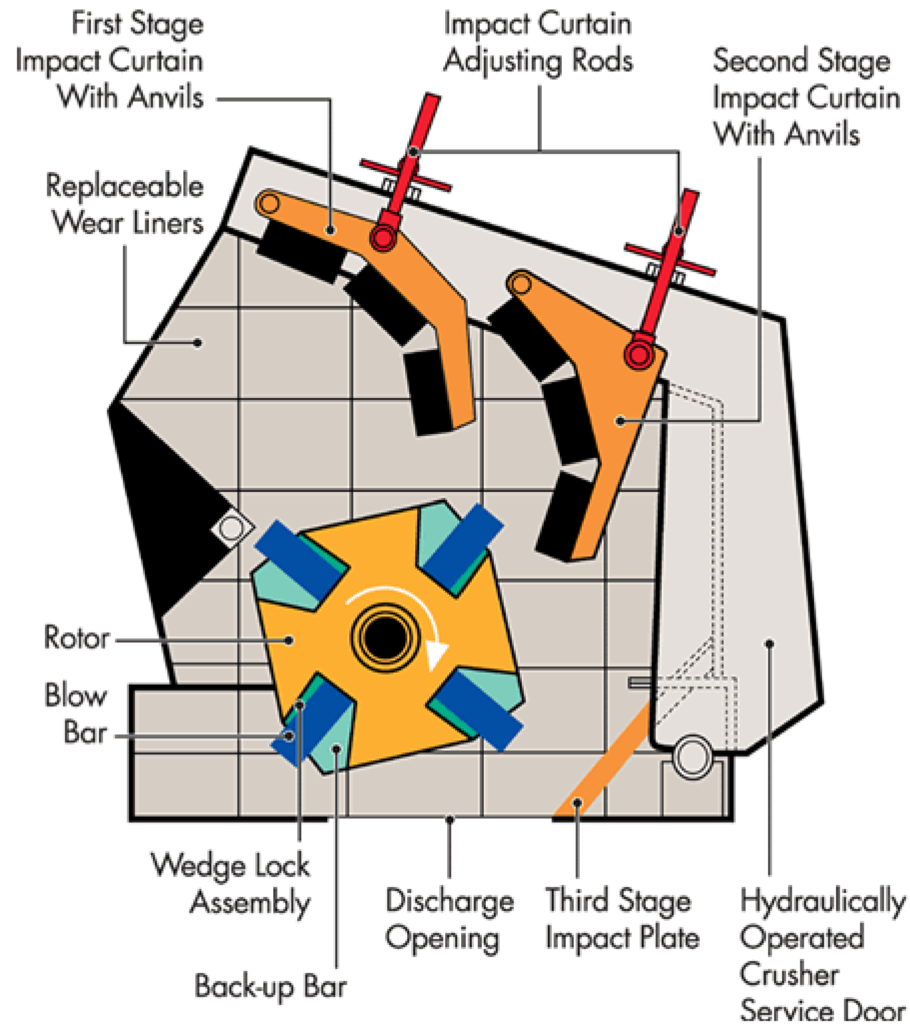
Roll Crusher

- The capacity of a roll crusher will vary with:
  - ✓The kind of stone
  - ✓The size of feed
  - ✓The size of the finished product
  - ✓The width of rolls
  - ✓The speed at which the rolls rotate
  - ✓The extent to which the stone is fed uniformly into the crusher.

IMPACT CRUSHERS

- In impact crusher stones are broken by the application of <u>high-speed impact forces.</u>
  - ✓**Single rotor.** The single rotor-type impact crusher breaks the stone both by the impact action of the impellers striking the feed material and by the impact which results when the impeller-driven material strikes against the aprons within the crusher unit.

✓**Double rotor.** These units are similar to the single rotor models and accomplish aggregate-size reduction by the same mechanical mechanisms. They will produce a somewhat higher proportion of fines. With both single and double rotor crushers, the impacted material flows freely to the bottom of the units without any further size reduction.



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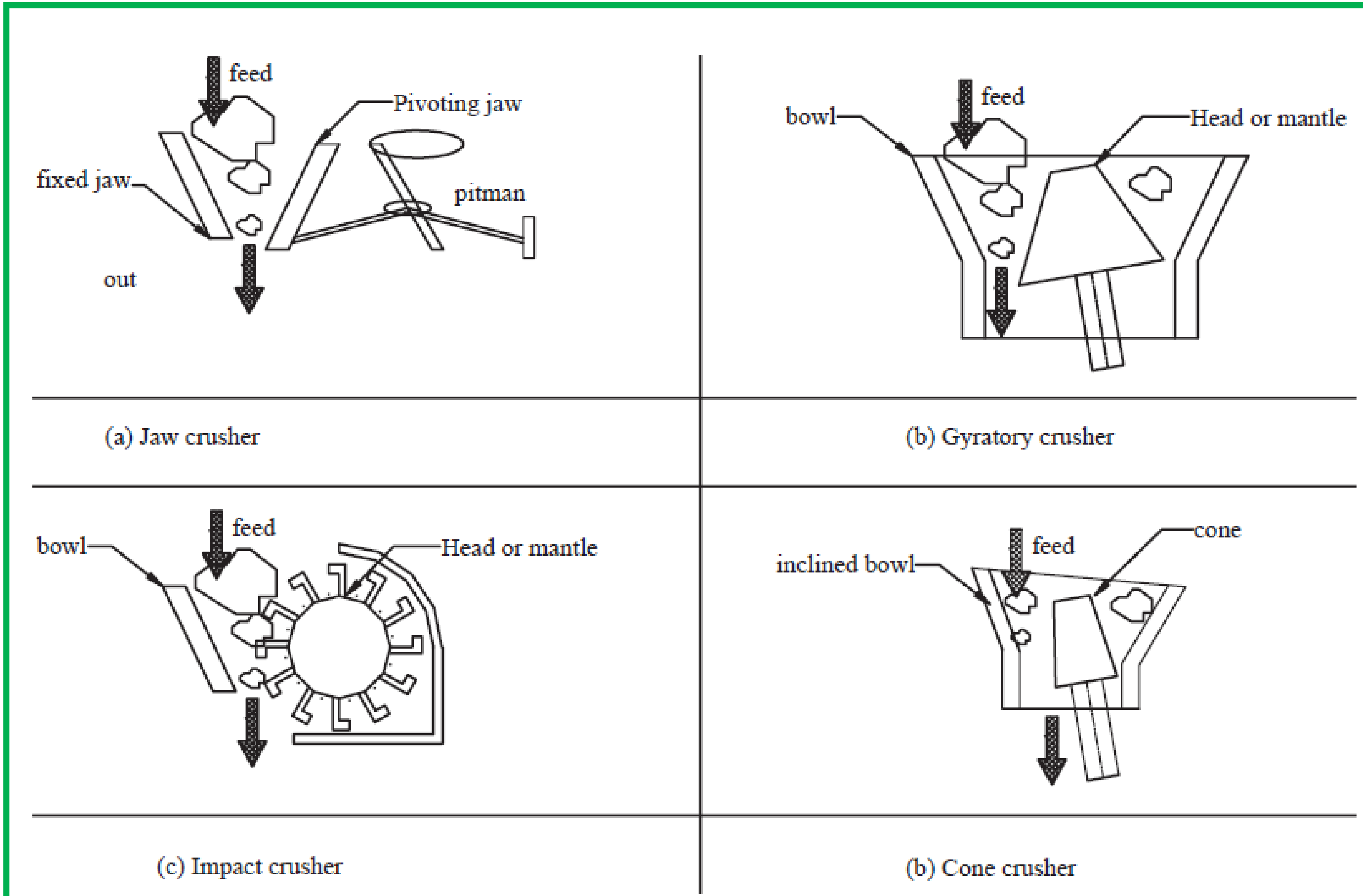
IMPACT CRUSHERS

It uses plate hammer on the rapidly rotating rotor to generate high-speed impact to crush the materials in the crushing cavity, and casts the crushed materials along tangential direction to impact plate at the other end of the crushing cavity. The materials are crushed again, and then, they return to the plate hammer to undergo the process above repeatedly. The materials are bumping with each other when being sent between the plate hammer and the impact plate. The materials become cracked, loose and then comminuted by knocking by the plate hammer, impact with impact plate and bump between materials. The materials with grain size smaller than the gap between impact plate and plate hammer will be discharged.

These machines operate on the principle of a set of rotating hammers hitting against the rocks. The hammers are fixed to a cylinder. The feed is from the top and as the rocks feed in, they fall between a breaker plate and the rotating cylinder. The hammers produce the required impact to chip the rocks. Impact crushers work best on rocks that are neither abrasive nor silica-rich, as these cause rapid wear of the hammers. Metso Minerals manufactures impact crushers for primary and secondary crushing.

CRUSHERS


feed
Pivoting jaw
fixed jaw
pitman
out
(a) Jaw crusher
feed
bowl
Head or mantle
(b) Gyratory crusher
feed
bowl
Head or mantle
(c) Impact crusher
feed
cone
inclined bowl
(b) Cone crusher

GRINDING

In industrial practice, most comminution operations are closed circuit except primary crushing. A comminution circuit is said to be closed when it operates in series with a size classifier and the coarse fraction of the classifier is re-circulated back into the comminution unit. A secondary crusher with a vibrating screen and a ball mill/rod mill with a hydrocyclone are most common closed circuit comminution operations in mineral processing plant practice.

Most industrial grinding circuits are operated under wet conditions. This circuit ensures a steady output of desired sized particles with a suitable distribution. The mass flow rate of the output of this circuit must remain reasonably constant with a pre-set value of the representative size (d_{80}).

GRINDING

There are two main forms of grinding:

- Dry grinding when the water content is <1% by volume
- Wet grinding with the addition of >34% water by volume

Between 1% and 34%, the slurry is very difficult to handle and grinding is inefficient. In some plants, an initial grinding process may be followed by some form of classification such as flotation or magnetic separation, which in turn is followed by a second grinding process. This approach tends to eliminate at an early stage a good portion of the gangue .

It is not possible to achieve the particle size needed through a single grinding phase unless coarse output is required. When a coarse product is required, crushed materials are transported to a rod mill via a conveyor belt and the output is delivered from the rod mill. This is essentially an open circuit.

GRINDING

Grinding machines in the mineral industry are of tumbling mill type. These mills exist in a variety of kinds such as **ball, rod, pebble, autogeneous, semi-autogeneous, etc**.

Grinding action is induced by relative motion between the particles of media - the rods, balls or pebbles and the particles themselves. High compression roll mill and fluid energy mills are recent developments in comminution technology.

There are two different types of motion of media particles in the mill, namely, **cascading and cataracting** generating from the tumbling motion of the mill.

When the particles move along the inner surface of the mill shell, lifted up, loses contact with the surface and travel downward in a trajectory through the empty space inside the mill resulting in an impact on contact with the the inner surface again, the motion is called **cataracting**. This motion produces fewer amounts of fines.

Different milling machines

Autogenous Mills

Autogenous mills operate without grinding bodies; instead, the coarser part of the ore simply grinds itself and the smaller fractions.

Different milling machines

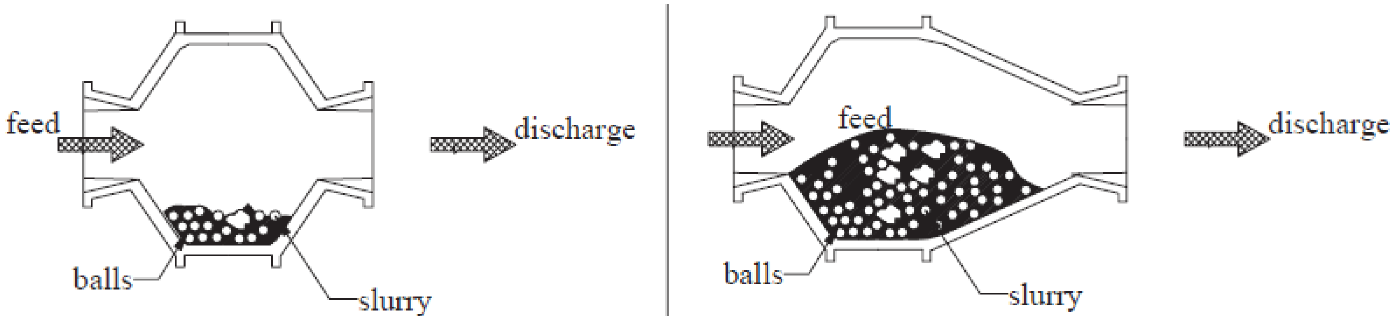
Semi-Autogenous Mills

In ***semi-autogenous mills*** (which have become widespread), 5 to 10 percent grinding bodies (usually metal spheres) are added.

Different milling machines

Autogenous and Semiautogenous Mills

Autogenous and semiautogenous (AG and SAG) mills are extremely large mills with a maximum diameter of 12.2 m (40 ft).



Cascade mills (wet and dry grinding)
- Used for autogneous and semiautogeneous milling in closed circuit
- Primary Grinding with minimum retention time for very fine output
- Diameter to length ratio 2:1

(b) Conical shape mill
- Suitable for fine discharge

The shape of ball grinding mills is determined by the type of discharge and ore.

The large diameter of these mills maximizes the impact forces. Although the feed is typically 150–180 mm (6–7 in) in diameter, the output can be as fine as 0.3 mm (0.012 in). Particles tend to cleave along their natural grain boundaries. Six to ten percent of steel balls are added on a continuous basis to the feed to assist grinding through a separate entry. Wet milling and grinding is less dusty and less noisy than dry grinding. The feed and output trunnions are on opposite sides. The trommel on one side catches the steel or high chrome balls to prevent them from falling into the pump box.

Different milling machines

AG vs. SAG

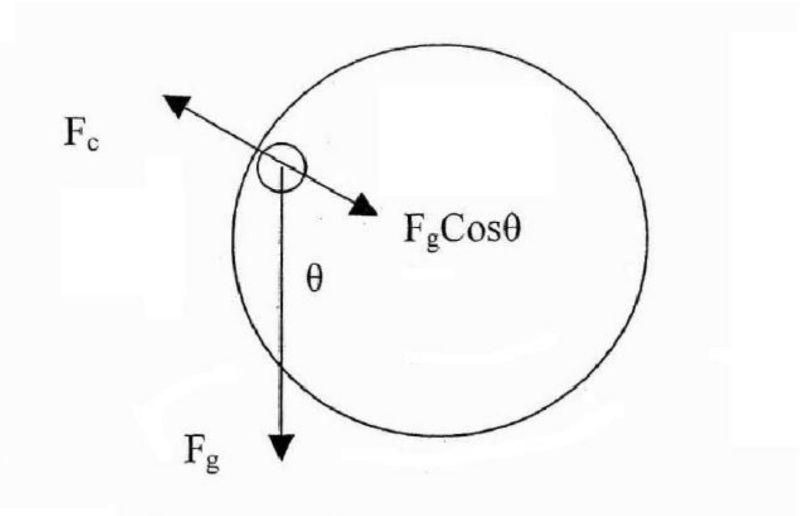
- Autogenous – self-breaking
- AG mill – fully autogenous
- SAG mill – semi-autogenous
- AG and SAG mills, coarse particles (ideally about 20 % of 10 cm to 25 cm) are very important since they are part of the grinding media

- In SAG mills large balls (10 cm to 15 cm) are added (typically 6 to 12 % volume loading) to enhance the grinding action, especially for critical sized material.

- Other common option is to combine AG mill with screens and cone crushers to break critical size in the circuit

GRINDING

When the media particles move up and then roll down along a parabolic path while remaining within the bulk itself, the motion is called **cascading**. This motion generates fines and to be minimised to the extent possible. Clearly, at lower rpm of the mill cascading is predominant and higher speed is necessary for cataracting motion. However, this is restricted by the critical speed, a very crucial parameter, of the mill.



Forces on a media particle in a tumbling mill

GRINDING

When a media particle is moved up the two forces acting on it are the centrifugal force F_c and the gravitational force F_g. Balancing them in the radial direction and simplifying,

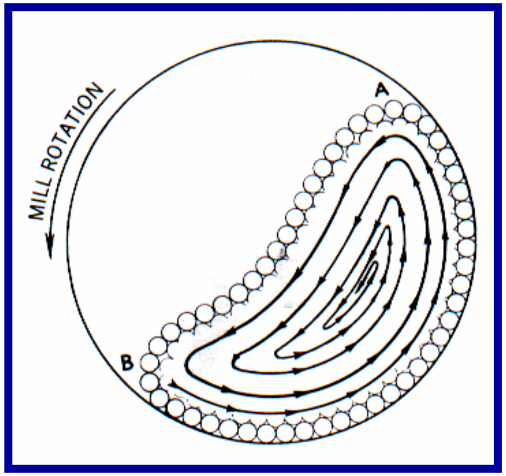
$$\omega = \left[\frac{2g}{D_m}\right]^{1/2}$$

where ω is the angular speed and D_m is the mill diameter. Expressing angular speed in revolutions per minute,

$$N_c = \frac{42.3}{D_m^{1/2}}$$

This is the critical speed of the mill beyond which the media particles will remain centrifuged at the wall resulting in no impact or grinding action. Thus, the mill must be operated below the critical speed.

Common choice: 65 – 80% of critical value.



GRINDING

Grinding of the crushed ore is almost always performed in cylindrical rotating mills, which are filled about half full of steel or iron balls, steel rods, or some other form of grinding medium. The grinding medium might also take the form of ceramic balls, flint pebbles, or for autogenous grinding, the fraction of ore between about 50 and 200 mm in diameter. In semi-autogenous grinding, steel balls about 125 mm in diameter are charged into the mill to occupy approximately 8 to 10% of the mill volume and supplement the grinding produced by the large pieces of ore in the mill. The interior chambers of all these mills are lined with easily replaceable liners whose thicknesses range from 50 to about 250 mm when installed. Wear of these liners, as well as the wear of the grinding balls and rods, is a major item of expense in most ore processing operations.

The crushed ore fed into the grinding mills is almost always mixed with water so that the grinding is done in a slurry containing about 75% solids. The ore is ground to at least 0.3 to 0.7 mm in diameter, although some operations require the ore to be ground to finer particle sizes (e.g., 0.04 mm). The ground ore is then passed through the classifiers, from which incompletely ground ore is returned to the grinding mills, while the rest is passed on to the separators.

Primary grinding can also be performed in two stages. The first stage might use a rod mill, with rods 75 to 100 mm in diameter, which reduces the ore from 15 to 25 mm down to about 1.5 mm. After this grinding operation, the ore goes to a ball mill where it is reduced to about 0.3 mm in diameter or finer. Autogenous or semi-autogenous grinding may in many instances be followed by a second stage of grinding in a ball or pebble mill.

Wet versus dry grinding

Because of the dust problems associated with grinding solids (health, explosion, and fire hazard, mechanical losses, etc), grinding is usually carried out in water.

Presence of water in the product does not harm subsequent separation processes, since most of these operations are carried out in water.

Wet grinding advantageous - requires less power per ton of material ground than dry grinding. Dry grinding consumes more energy because the fine particles adhere to the balls, forming a layer that causes the solids to occasionally slide between the balls without fracture.

The disadvantage of wet grinding, however, is that there is more wear.

GRINDING

In the context of comminution, grinding refers to the reduction of small pieces after crushing to fine powder

- Accomplished by abrasion, impact, and/or compaction by hard media such as balls or rolls
- Examples of grinding include:
  - Ball mill
  - Roller mill
  - Impact grinding

MILLING

Milling produces a particular particle size distribution and deagglomeration of fine powders.

Physical processes include impact, shear between two surfaces, and crushing by a normal force between two hard surfaces.

There are two broad types of ceramic raw materials that require milling. These are classified as lumpy and powdered ceramics. Lumps result from mining, fusion, and sintering. These are usually premilled by the supplier and are available in various screen sizes. Depending on your requirements, these may require further milling in the lab. Mined materials include talc, shale (clays), bauxite, and quartz. Fused materials include fused alumina, magnesia, mullite, and zirconia.

Some materials are more difficult to mill than others. Generally, the order of difficulty from the most difficult to the least difficult is densefused materials, sintered materials, and precipitated powders. Although one might not expect this, glasses are very difficult to mill to micrometer sizes, but they are easy to crush to granules.

Applications of the milling process

Abrasives Animal products Brewing industry Chemical Confectionery Food processing Fuel preparation Metal power Mineral preparation Paint preparation Paper Pigments for colour industry Abrasives for grinding Cement and Limestone Grain milling Laboratory milling Pulverised coal for power generation Glass, sand, lead oxide, potash and arsenic for glass making	Petroleum products Pharmaceuticals Plastics Printing ink Rubber Textiles Sintering Refractory materials for investment casting Tungsten power and dry lubricants Dry powder opacifiers for ceramics industry Carbon black for rubber Powders for the detergent industry Colour coating of polymers for the plastics industry Aggregates for the construction industry Fertilisers Salt Charcoal for briquetting

Material Characteristics

When a material is to be milled there are certain characteristics which have to be taken into account. These include the following

Hardness

- Brittleness
- Toughness
- Abrasiveness
- Stickiness
- Softening and melting temperature
- Structure (e.g. close grained or cellular)
- Specific gravity
- Free moisture content
- Chemical stability
- Homogeneity
- Purity

MILLING

Hardness of minerals is expressed on Mohs scale - a numerical index ranging from 1 for talc (the softest mineral) to 10 for diamond (the hardest known material). Table 2 below shows Mohs' scale of hardness.

1	Talc Graphite	Can be scratched with a fingernail and by any stone rated 2+
2	Gypsum Bismuth Lepidolite Chlorite	Can be scratched with a fingernail and any stone rated 3+
3	Calcite Celestite Barite	Can be scratched with a knife and any stone rated 4+
4	Flourite Malachite Platinum	Can be scratched with a knife and any stone rated 5+. Will scratch any stone rated 3-.
5	Apatite Dioptase	Can be scratched with a knife and any stone rated 6+. Will scratch any stone rated 4-
6	Feldspar Pyrite Amazonite Hematite	Can be scratched with a knife and any stone rated 7+. Will scratch any stone rated 5-.
7	Quartz Tourmaline	Will scratch glass and any stone rated 6-. Can be scratched by stones 8+.
8	Topaz Spinel	Will scratch glass and any stone rated 7-. Can be scratched by stones 9-10.
9	Corundum (ruby, sapphire)	Will scratch glass and any stone rated 8-. Can be scratched by diamond.
10	Diamond	Will scratch glass and all stones 1-9

Operating Variables

- Size, type and angular velocity of the mill
- Size and type of media
- Size of feed
- Loading of the mill
- Physical characteristics of the media
- Agglomeration of feed and product
- Viscosity
- Temperature
- Milling atmoshpere

Milling Performance

The choice of a mill may depend on

- ultimate capital cost,
- mineral properties,
- capacity,
- reduction ratio and final size requirement,
- power requirements and type of power supply,
- wet or dry product,
- continuous or batch operation,
- period of a milling cycle,
- portable or stationary equipment required

Contamination

- Fresh atomic surfaces constantly created during mechanical milling, so contamination by O_2 & N_2 is a real problem:
  - Argon commonly used as an inert environment (impurities in Argon can be a problem though)
  - Can be useful – mechanical milling invented as means of creating metals with uniform dispersion of oxide for strength.

- Milling with a liquid surface agent can lower particles' surface energy, allowing smaller particle sizes to develop. However, some becomes absorbed into the sample as a contaminant.

- Other source of contamination is from pot/balls:
  - Less "foreign" material tends to be introduced if sample/milling media are dissimilar materials.
  - *Effect* of contamination tends to be more serious if sample/milling media are dissimilar materials
  - Using milling media that are of the same material as the sample is the solution if contamination critical, but compensation to retain balance of alloy may be required.

MILLING

In general, the harder the material, the more specialised and expensive the type of mill used has to be. In addition if a particular mill can be used over a range of hardness scales, the harder the material the lower the throughput for a given size requirement. Another characteristic of a material to be aware of is brittleness, which is the degree to which a material will easily break. Most minerals are brittle, as opposed to metals which are ductile, although some to a greater degree than others. Brittleness does not equate with hardness as brittle materials can be hard or
not particularly hard. Materials which are not brittle to some degree, metals or soft plastics for example, cannot easily be milled.

Free moisture content of a material should be as low as possible for dry milling. In practice this can be a problem, especially in humid regions where the moisture can cause the material to stick to the grinding media. Different mills behave in different ways with moist materials and in some cases drying of the raw materials be required.

DRY MILLING

Production milling is sometimes done dry as this avoids a separate drying step. Dry milling also avoids the formation of hard agglomerates as there is no liquid present. Dry milled ceramics are usually used in pressing operations to make a shape and to consolidate the particles. Crushing and milling are sequential processes for particle size reduction.

Portland cement is dry milled commercially using steel balls for efficiency. An Alumina media about three inches in diameter is used for milling white cement where the color has to be controlled. Hard ferrites are also dry milled in air swept ball mills. Bayer aluminas are dry milled by the producer.

A serious problem with dry milling is that the powder will cake onto the sides of the mill and will not receive further size reduction. Scraping the mill down periodically helps to reduce this caking problem. Another way to reduce the caking problem is to add a surface active agent. It is believed that Bayer alumina dry milling involves the use of ethylene glycol. Bone-dry powders have less of a caking tendency than a powder exposed to humidity. Generally, powders can be dried and immediately put into the mill while still hot.

MILLING

Jet Mills

Jet mills have two opposed jets of air that collide. These air jets also contain the ceramic particles. Often these mills are connected with an air classifier and a cyclone for recovering the fine particles.

This set up is much more capital intensive than ball mills. It is also more difficult to clean between batches. Jet mills require a lot of high pressure air (80 psi). As the particles are in free flight, there is little contamination. However, a white powder will turn grey after milling due to the polymeric mill lining.

WET MILLING

Wet milling is more frequently applied in the laboratory than dry milling. Wet milling is usually used to make a coarse-grained slip or a fine-grained slip.

A slip consists of a liquid vehicle, usually water, and suspended ceramic particles. Fine-grained particles are held in suspension by dispersants and other surface active chemicals.

Settling is basically by **Stoke`s law** where larger and denser particles will settle out faster in a low viscosity liquid. This will be discussed further in a later section.

Wet milling reduces the particle size for fine grained slips and disperses the agglomerates in both fine and coarse grained slips.

MILLING

Advantages of	
Wet Milling	**Dry Milling**
▪ Low power required ▪ No dust problems ▪ Higher rotational speeds ▪ Can wet screen through fine screen ▪ Good homogenisation ▪ Smaller particle size than dry ▪ Narrower particle size distribution than dry ▪ Compatible with spray drying and casting process	▪ Avoids drying of the powder ▪ Avoids reaction of the powder/liquid ▪ Less media and lining wear than wet ▪ Can be started/stopped at any time ▪ Easier to optimise

MILLING MEDIA

Type of Media

Composition of the media includes the following: porcelain, high alumina, pure alumina, TZP, MgO stabilized zirconia, silicon nitride, silicon carbide, steel, modified fused zircon and a variety of mineral products such as flint, agate, or the material that is ground by itself (autogenous milling).

Mineral products are cheap and can be surprisingly wear resistant. When processing fine ceramics, a general rule is to use the same composition of the media as that of the batch, if possible.

For general lab applications, high alumina is perhaps the most commonly used media.

The specific gravity of the media dictates the energy in the mill. High density mill balls have more energy because of their mass.

MILLING MEDIA

Size and Shape

Depending on which media is selected, the size ranges from 1 mm to 3 inches in diameter. The choice of size depends on the material being milled. A general rule is to use the smallest size that has sufficient energy to fracture the particles in the batch.

The best media shape, to obtain optimum grinding efficiency, is debatable in current literature. Most common shapes are spheres, satellite spheres, cylinders, and round-ended cylinders.

Media with sharp edges should be prerun in the mill to round off the edges; otherwise, they will tend to chip and contaminate the batch. Stirred mills present a special problem as the media can pack and overload the drive. In such cases, spherical or satellite spheres are preferred.

HORIZONTAL TUMBLING MILLS

In a horizontal tumbling mill, the actual body of the mill rotates and imparts energy to the grinding medium (balls or rods) and to the slurry. The combination of centrifugal forces and gravity forces from falling media act to create energy transmission by impact against the mineral. There are three categories of horizontal tumbling mills:

1. rod mills
2. ball mills
3. autogenous and semi-autogenous mills

Basically a horizontal tumbling mill is a cylinder lined on the inside with wear-resistant alloy liners. The liners are fixed to the shell by T-bolts and nuts on the outside. The cylinder is carried by hollow trunnions running side bearings at each end.

BALL MILL

Major components include:

- grinding balls
- a cylindrical container
- a rolling machine

- Rotation a cylinder with grinding balls causes the balls to fall back onto the ceramic particles
- Speed of rotation determines efficiency of the milling process

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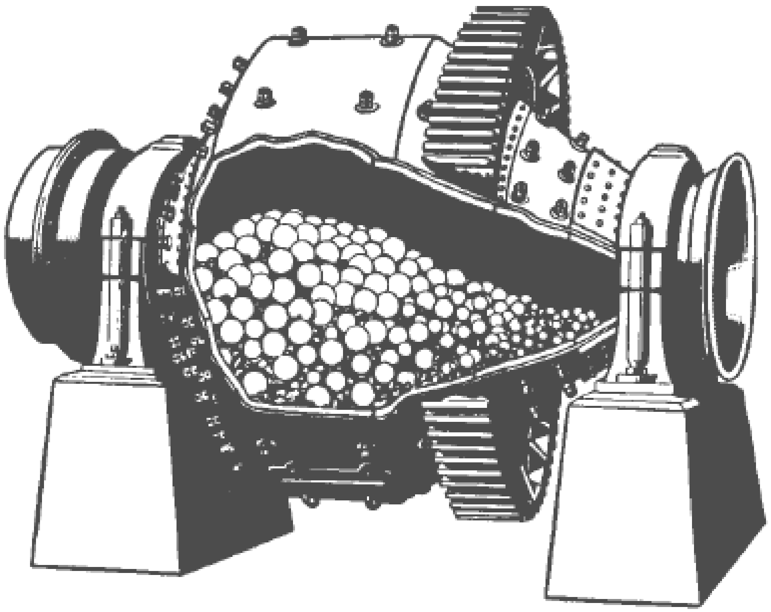
BALL MILL

- A ***ball mill*** is similar to a rod mill but it uses steel balls instead of rods to supply the impact necessary to grind the stone.
- ***Ball mills*** will produce fine material with smaller grain sizes than those produced by a rod mill.



Overview of Ball Milling Parameters

- Type of mill (planetary, attrition, vibratory, rod, tumbler, etc.)
- Speed of mill, relative speeds of pot rotation to disk revolution in a planetary mill

- Composition, size, shape and surface of pot
- Degree of filling pot
- Number, size(s), material (density, elasticity), and surface of milling balls

- Weight, shape, size and composition of starting material

- Macroscopic temperatures of pot, ball and powder
- Microscopic Temperature at collision point
- Milling atmosphere
- Milling time

Ball Mill

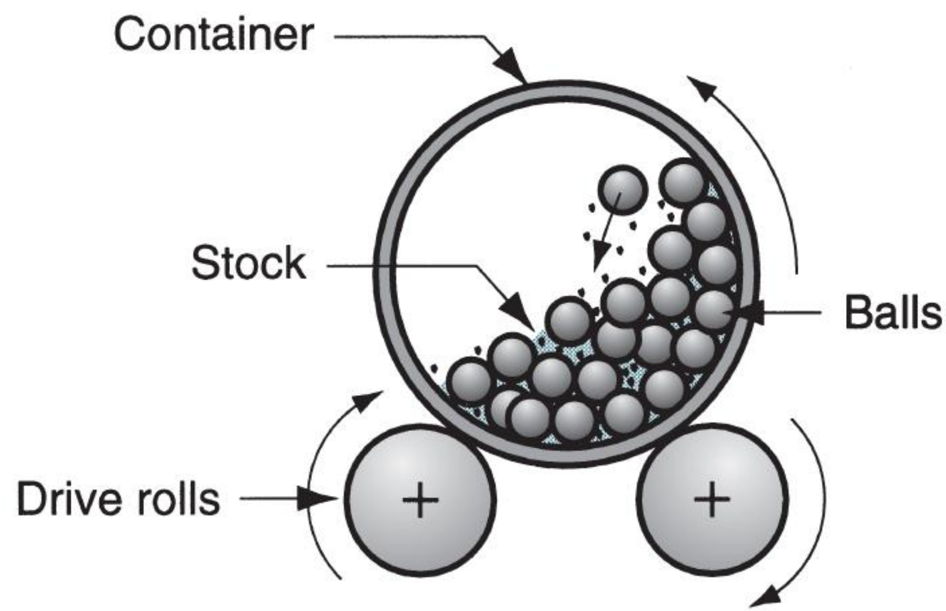
Ball mill is designed for ball milling of various rocks, in particular, auriferous ores prior to flotation.

BALL MILLS

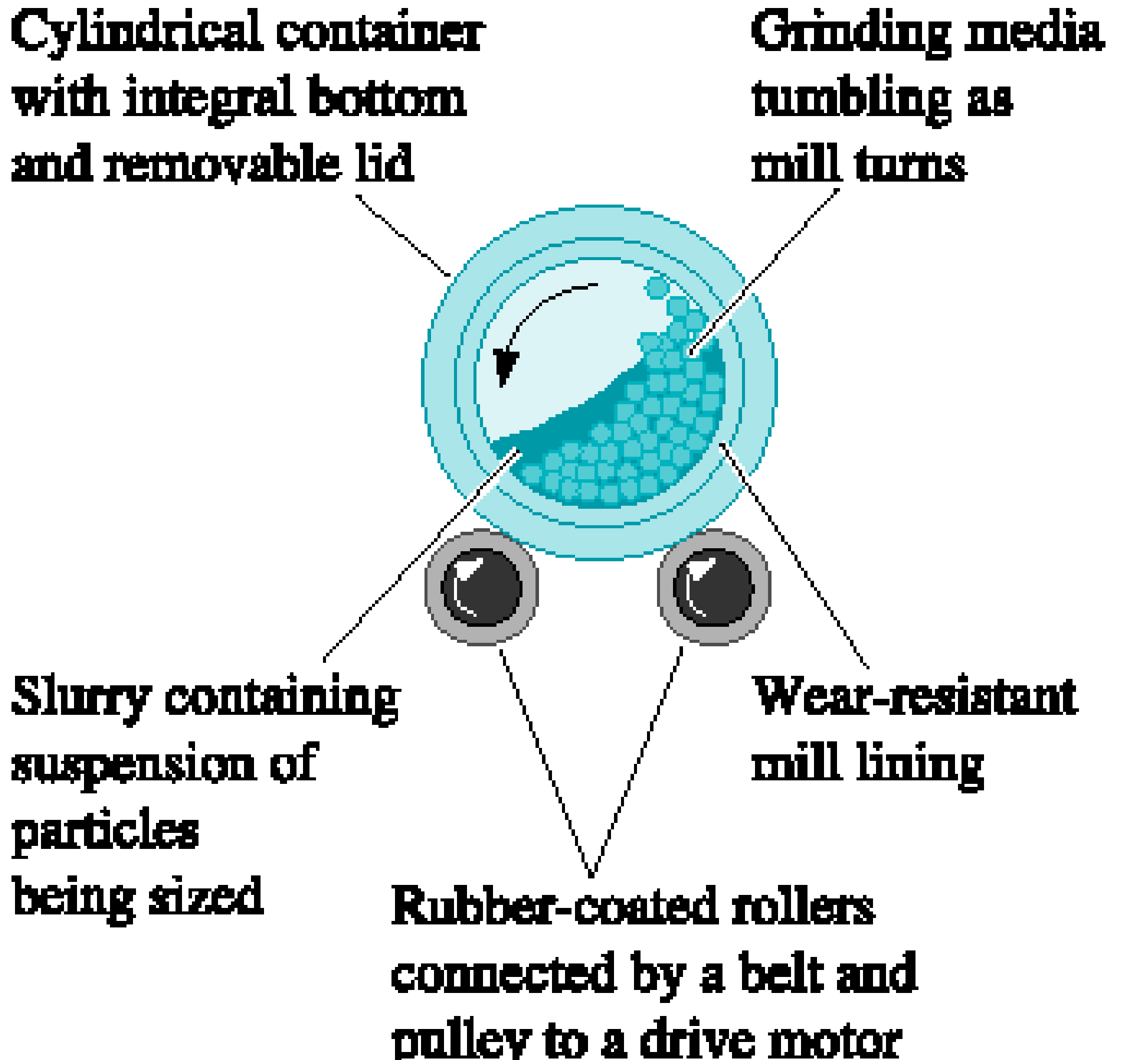
Ball Mill

- Hard spheres mixed with stock are rotated inside large cylindrical container

- Mixture is carried upwards in container as it rotates, then dropped by gravity to accomplish grinding action



BALL MILLS



Cylindrical container with integral bottom and removable lid
Grinding media tumbling as mill turns
Slurry containing suspension of particles being sized
Wear-resistant mill lining
Rubber-coated rollers connected by a belt and pulley to a drive motor

BALL MILLS

In ball mills, metal balls are used as the grinding media. The balls are made of a variety of materials. Steel balls are forged. High chrome balls are cast with 28% chrome and are available from special foundries.

About 1 kg of balls is used per ton of stone. Small balls with a diameter of about 25 mm (1 in) are preferred to larger ones in order to maximize the area of contact between balls and stones.

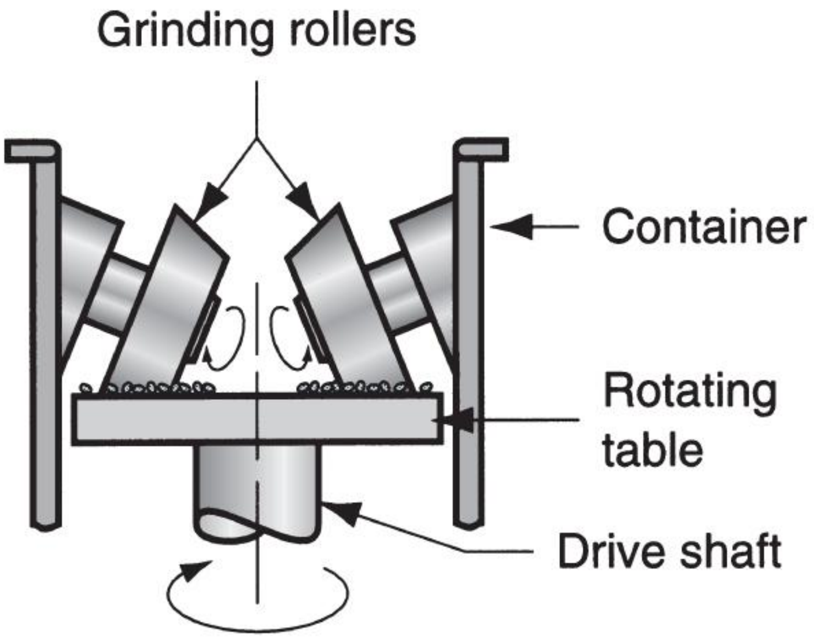
The slurry weight concentration in a ball mill is 65–80%. Excessive concentration will cause the particles to stick to the balls and will decrease the effectiveness of grinding. The ball mill may then “freeze” and spill out its contents, causing costly downtime to empty the mill. For this reason, the weight concentration should not be allowed to exceed 80%. A trunnion at the discharge of the ball mill separates balls from slurry. The balls are then conveyed back to the feed. Balls gradually wear out through repeated feeding to the mill and must be replaced. Ball mills are built in different diameters up to a maximum of 6.5 m (21 ft), and in power drives up to 9650 kW (13,000 hp). Their shape is determined by the type of output.

ROLLER MILL

Roller mills are used for soft grinding of industrial minerals in a dry state.

The mill consists of a rotating table on a vertical axis. Two rollers rotate around their own shafts at an angle with respect to each other. The rollers are spring loaded. The output is diverted to dry cyclones and the oversized material is fed back to the roller mill.

A new generation of high-pressure roller mills has appeared on the market since the 1980s. A very high level of torque is transmitted to the rollers to maximizing the crushing loads. High-pressure rollers are mainly used in cement plants, diamond processing (when the extraction is from rocks, as it is in Canada), and to a certain extent in the field of metalliferrous minerals.



Stock is compressed against flat horizontal table by rollers riding on the table surface

ROD MILL

- A *rod mill* is a circular steel shell that is lined on the inside with a hard wearing surface.
- Rod mill is equipped with a suitable support or trunnion arrangement at each end and a driving gear at one end. It is operated with its axis in a horizontal position. The rod mill is charged with steel rods, whose lengths are slightly less than the length of the mill.

- Crushed stone, which is fed through the trunnion at one end of the mill, flows to the discharge at the other end. As the mill rotates slowly, the stone is constantly subjected to the impact of the tumbling rods, which produce the desired grinding. A mill may be operated wet or dry, with or without water added.

ROD MILL

Rod mills are a type of fine crusher and can reduce the size of rocks down to 1 mm (0.04 in). They perform better than a fine crusher in less than optimum conditions when the feed is damp or contains clay.

Typically, the length to diameter ratio of the rod mills is 1.5 to 2.5. Milling occurs by impact of rod against rod. The stones are trapped between the rods and isintegrate. The coarser stones are the first to break. The finer escape milling. Rod mills are not used on closed circuits.

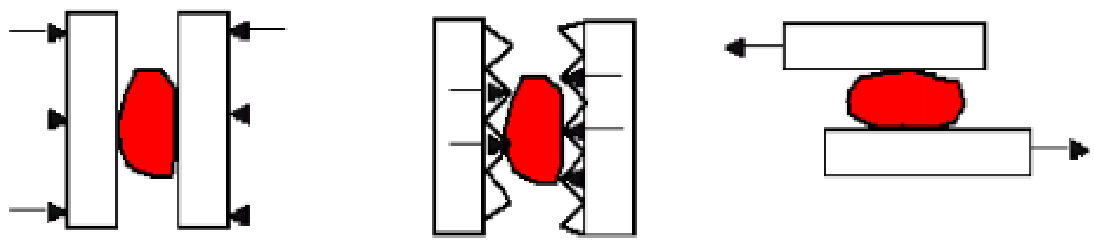
In the last years, the mining industry has tended to replace rod mills with large autogenous and semiautogenous mills

PLANETARY MILLS

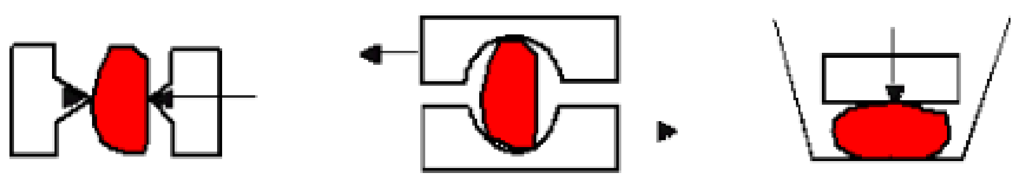
Planetary mills usually consist of four, small, balanced mills in a planetary array. This setup helps achieve higher gravitational forces that help shorten the grinding time. Gearing imparts two rotary motions: around the central axis and around the axis of each smaller mill.

Ways of Size Reduction

Smashing **Breaking** **Attrition**

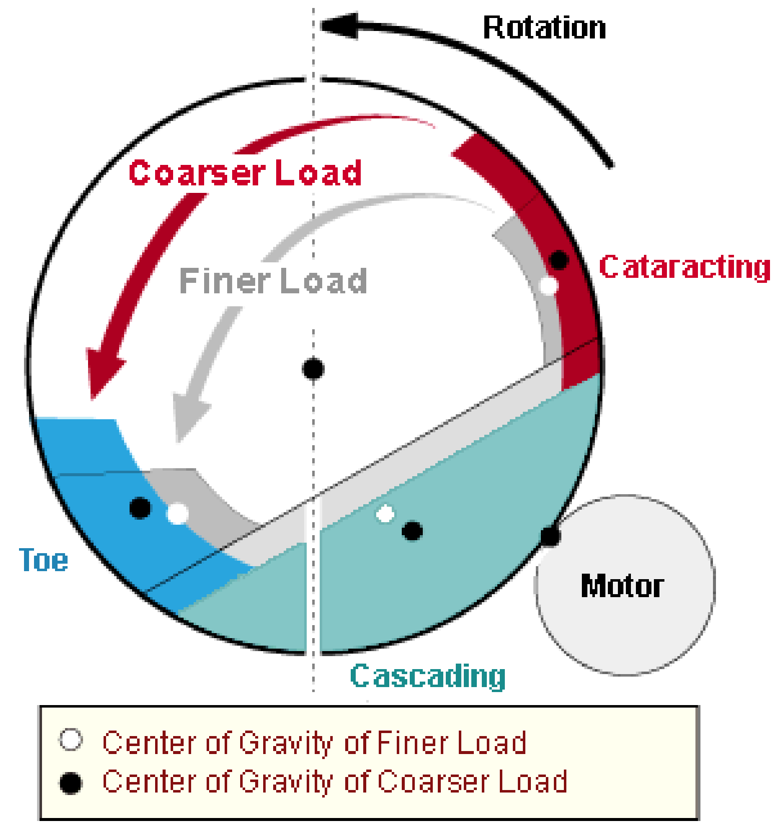


Splitting **Cutting** **Crunching**



Tumbler Mill

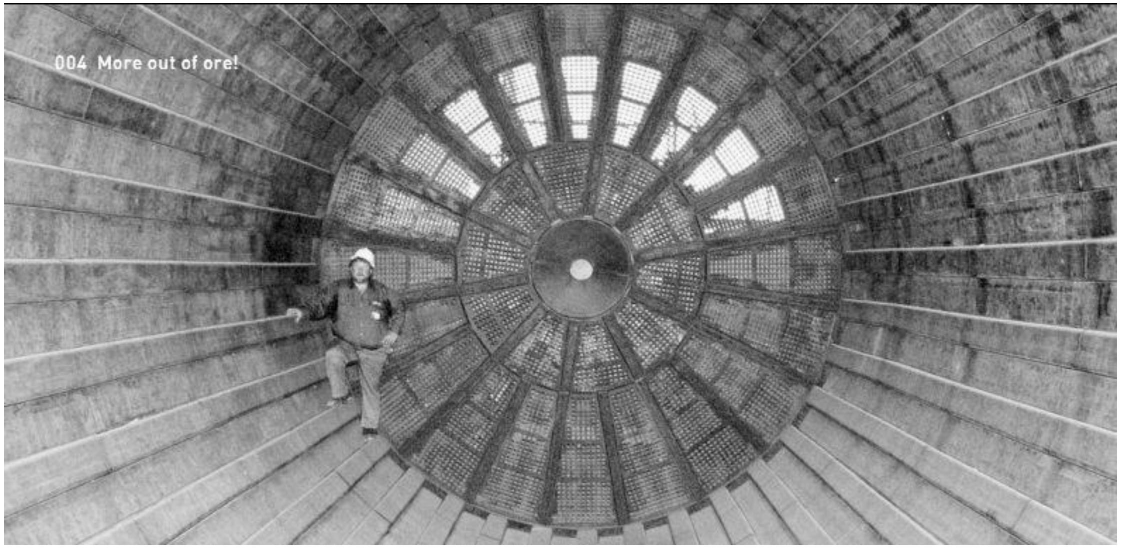
- Motion in a tumbling mill
- Cascading: produces attrition breakage which leads to fine particle grinding.
- Cataracting: produces impact breakage which leads to coarse particle grinding.
- As ore particles become smaller they become less susceptible to breakage by impact; this means that ore must be reduced by attrition
- Speed: critical speed is when the grinding media are pinned to the shell by centrifugal force
- Normally, mill speed is between 55% and 80% of critical speed. Mill speed is usually fixed, but some mills have variable speed drives.



Tumbler Mill

Tumbler mill

- Energy depends on diameter and speed of drum
- Primarily used for large-scale industrial applications



Attrition Mill

- Attritors have a cylindrical shell that can be lined with wear resistant materials and a rotating vertical impeller.

- The impeller has cross bars that can be covered with wear-resistant, ceramic sleeves.

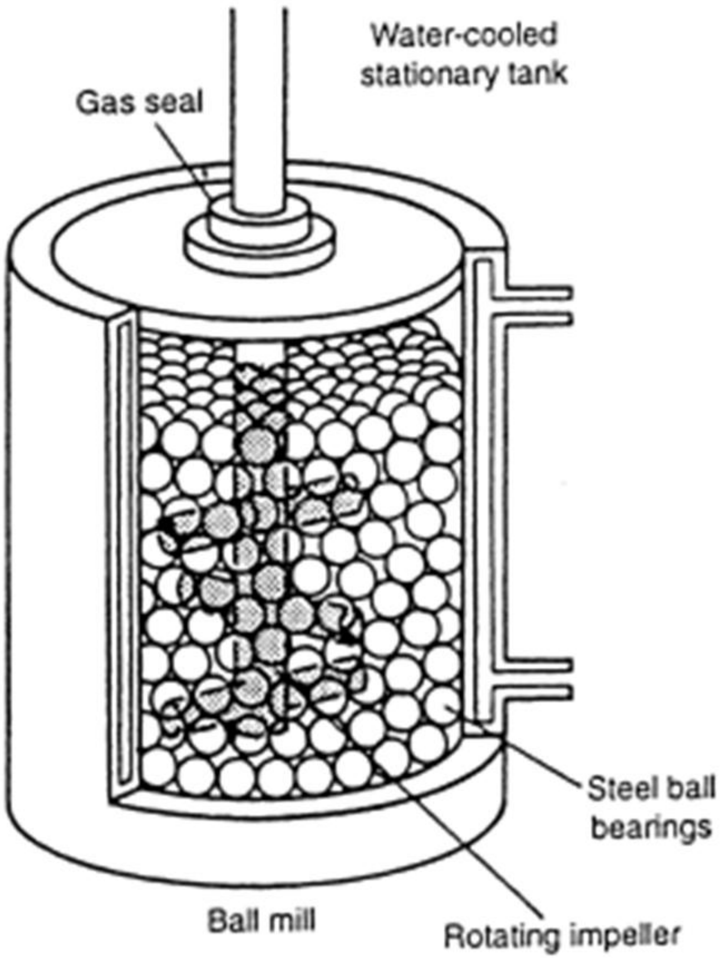
- The attritor is filled about two-thirds full with the grinding media. All stirred mills should use a spherical media as other media shapes tend to over pack and overload the drive.

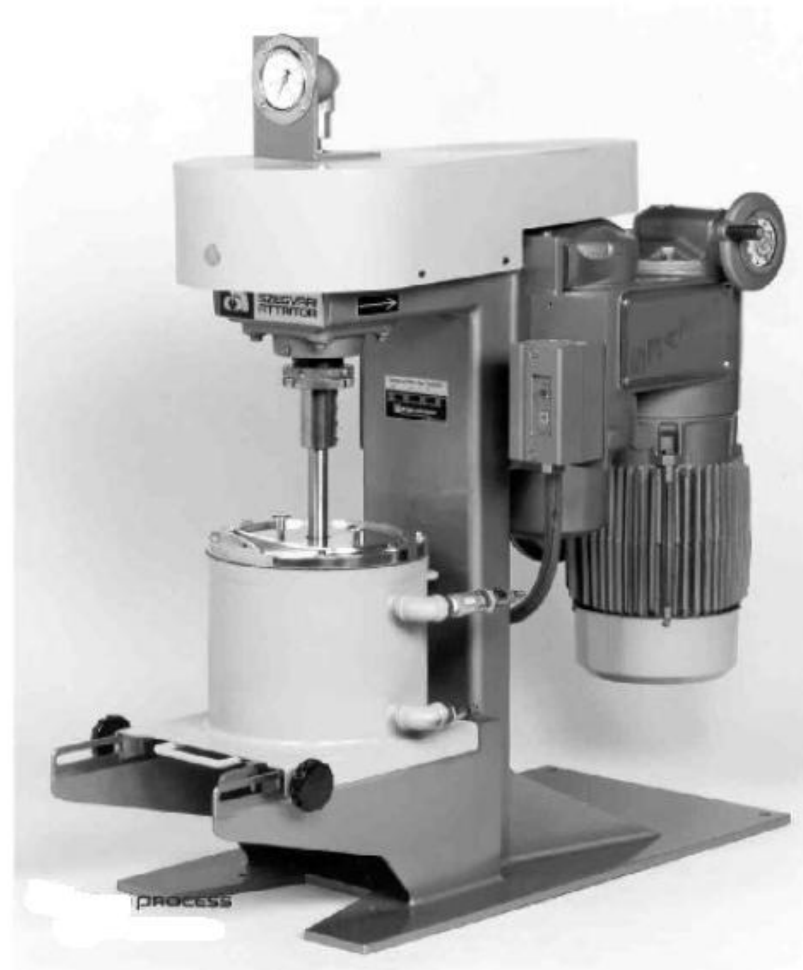
- Stirred mills are much more energetic than ball mills; as such, milling times are reduced.

- Seals and bearings are up out of the batch creating a maintenance advantage. Attritors can be operated in three modes: batch, recirculating, and continuous sometimes in series.

Attrition Mill

- High energy small-industry scale (<100 kg)





Asst. Prof. Dr. Ayşe KALEMTAŞ

Different milling machines

Planetary mill

– Medium-high energy research miller (< 250 g)

THE END

Thanks for your kind attention

Any Questions