

MM 412/ MM 415 Notes

Ore Preparation

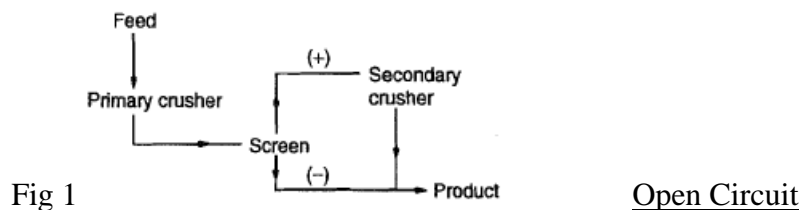
Ores are prepared for the principal chemical treatment by series of relatively cheap processes, mainly physical rather than chemical in nature, designed to effect concentration of valuable minerals and to render the material into the most suitable physical condition for the subsequent operations. In general these processes involve: first, comminution to such a size as will release or at least expose all valuable mineral particles; secondly, a sorting operation to separate particles of ore minerals from those of gangue minerals, and sometimes distinguish several ore minerals one from another.

The size to which ore particles must be reduced is dictated by the requirements of the next stage of the process, these depending on the particle size of the grains of the several minerals in untreated ore.

Crushing

Crushing is the first mechanical stage in the process of comminution in which the main objective is the liberation of the valuable minerals from the gangue. It is generally a dry operation and is usually performed in two or three stages. Lumps of run-of-mine ore can be as large as 1.5 m across and these are reduced in the primary crushing stage to 10 – 20 cm in heavy duty machines.

Secondary crushing includes all operations for reclaiming the primary crusher product from ore storage to the disposal of the final crusher product, which is usually between 0.5 cm and 2 cm in diameter. Crushing is done in open circuit or closed. Both have their applications. When done in open circuit, the product goes to the next stage in comminution (typically a rod mill). Since the product is not screened, the next stage needs to be able to accommodate size fluctuations.



Crushing is done in closed circuit, when crusher flexibility is desired. Here, the product is screened with the undersize moving to the next stage, but the oversize being sent back to the crusher.

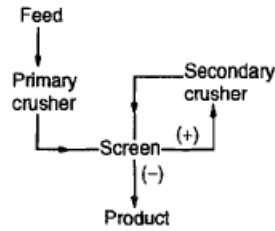


Fig 2

Closed Circuit

The presence of a screen allows the crusher to be used on any size setting at a given time, with the screen (one or multiple) making the final product selection.

In open circuit, the crusher can only operate on the size the next stage can accommodate. When the material is sticky, the crusher can be opened up to avoid choking, without hurting downstream processes.

Types of crushers

Jaw crusher

The most commonly used primary crusher for underground mining operations is the jaw crusher. These crushers may be divided into two main groups, the *Blake* the one commonly used to break the hard gold ore (quartz), with a movable jaw pivoted at the top, giving greatest movement to the smallest lumps; and the *overhead eccentric*, which is also hinged at the top, but through an *eccentric-driven* shaft which imparts an elliptical motion to the jaw. Both types have a removable crushing plate, usually corrugated, fixed in a vertical position at the front end of a hollow rectangular frame. A similar plate is attached to the swinging movable jaw. The Blake jaw is moved through a knuckle action by the rising and falling of a second lever (pitman) carried by an eccentric shaft. The vertical movement is communicated horizontally to the jaw by double toggle plates. Because the jaw is pivoted at the top, the throw is greatest at the discharge, preventing choking. Crushing angles in standard Allis-Chalmers-Svedala Blake-type machines generally are near 0.47 rad (27°).

The reduction ratios at minimum recommended settings and with straight jaw plates average about 8:1. Curved (or concave) jaw plates are designed to minimize choking.

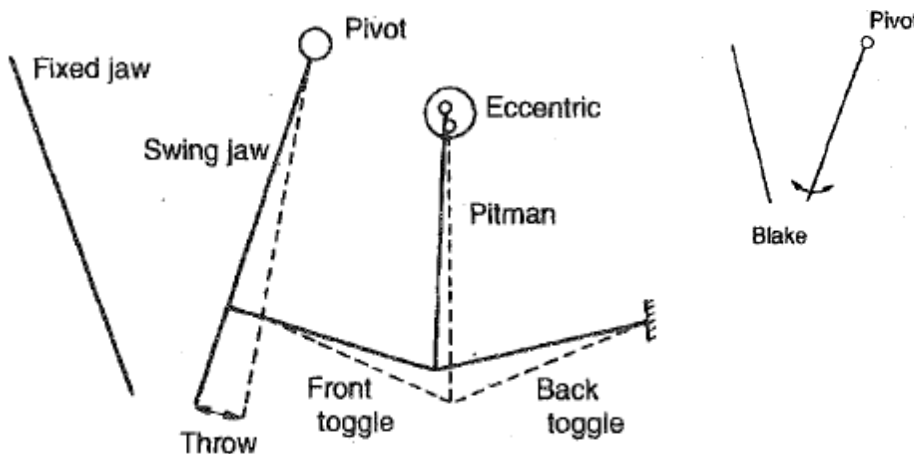


Fig 2.3 Blake jaw crusher (functional diagrams, source B.A Wills)

Cone crushers

Normally, heavy-duty short head crushers are employed to crush pebbles. Power and crusher cavity level are the key variables for monitoring and controlling crusher operation. Crusher product size is adjusted by changing the closed side setting.

Secondary crushers are much lighter than heavy duty, rugged primary machines .the maximum feed size will normally be less than 15 cm in diameter. The most commonly used primary crusher is the cone crusher.

The main components of a typical cone crusher are;

- The *feed inlet* funnels the ore into the crusher.
- The *feed distributing plate* spreads the feed uniformly around the crusher cavity.
- The *bowl* forms the outside of the crusher cavity. It can be moved up or down to adjust the gap between the bowl liner and the mantle.
- The *bowl liner* protects the bowl from wear.
- The *mantle* protects the cone from wear.
- The *cone* (or head) forms the inner side of the crusher cavity. It is the moving part of the crusher that effects crushing.
- The *spring release* protects the crusher from damage due to tramp metal or other non-crushable material.
- The *crusher cavity* (often called the *feed pocket*) is the space where the ore inside the crusher is located.
- *Eccentric and Pinion* The eccentric is the shaft that provides the circular movement to the cone.
- The *dust seal* prevents dust from reaching and damaging the cone bearing.
- The *bowl adjustment ring* acts as a giant nut into which the bowl is screwed. The bowl is raised or lowered by turning it (like a screw).

Cone Crusher Types

There are two main types of cone crushers: standard and short head. They differ by the shape of the cavity.

The **standard crusher** cavity is wider to accommodate larger feed size material. This cone has “stepped” liners which allows coarser feed than in the short head. They deliver a product varying from 0.5 cm to 6.0 cm

The **short head crusher** is designed to crush finer material and to produce a finer product. It has a steeper head angle than the standard, which helps prevent choking from much finer material being handled. It also has a narrower feed opening and a longer parallel section at the discharge, and delivers a product of 0.3-0.2 cm

Crushing Action

The crushing head rotates in the bowl with an eccentric motion. As the head approaches the bowl, particles are nipped and broken between the mantle and the bowl liner. The figure in the appendix shows a simplified view of a cone crusher, looking downward. The outer circle represents the stationary bowl covered by the concaves and the inner circle represents main shaft covered by the mantle. The main shaft rests in the eccentric bushing at the base of the crusher. The eccentric rotates as the base of the main shaft moves in a circular path around the crusher centre line.

Viewed from the side, the motion of the main shaft is like a pendulum. As the gap closes, ore is nipped and broken. When the gap between the mantle and concaves increases, broken ore is released and falls lower in the crusher cavity, where the gap is narrower. Ore that is fine enough falls through the crusher and is picked up by a feeder or conveyor belt. Ore fed at the top of the crusher fills the vacant space.

Screens

The most common way to determine particle size is by screen analysis. A screen is sometimes called a sieve. It is made of a woven wire mesh. The size of the screen is given by the width of one opening, or by the number of openings in one linear inch (2.54 centimeters). A 65-mesh screen has 65 holes per inch. A 200-mesh screen has 200 holes per inch. Vibrating screens classify particles based on their ability to pass through deck openings. Screens are simple devices to operate. The only adjustments are feed rate and wash water rate. Overloading, under loading, blinding, and screen deck holes are the most common problems. Design variables such as deck area, opening size, deck slope, vibration amplitude, and frequency are used to set the performance of screens for normal operating conditions.

Purposes of screen sizing are to;

- To scalp off the coarse end of a long range product, usually for further reduction.
- To cut off the fine end from crusher feeds and thus save power and over grinding.
- To grade broken rock products into commercial sizes, as for road metal, ballast, concrete aggregate, sands and the like.
- To perform a step in a concentration process, e.g. to size before jigging.

Grinding

Grinding is the final stage in the comminution process for the production of liberated mineral particles for the mineral separation process. AG and SAG mills are used to grind very coarse material (up to 30 cm). Rod mills are used for material up to 3 cm. Ball mills are used for fine grinding. They are often preceded by an AG, SAG or rod mill.

The typical ball mill is a barrel-shaped vessel rotating on its horizontal axis. It has special replaceable cylindrical liners, lifters, and end plates and is loaded to just under half full with balls of steel or cast iron. A “pulp” of ore with 20-35% by weight of water is fed into it and discharged axially, the overflow carrying the ground product. In some designs a grate is provided with holes between 3 and 10 mm in diameter to control the size in the overflow, preventing the early escape of coarser particles and loss of steel balls.

The tumbling mill is the heart of the grinding circuit. Its purpose is to break ore into small particles using grinding media (steel balls for example) which fall on the ore. Breakage events inside the mill produce particles fine enough to liberate valuable mineral from gangue. The four basic types of tumbling mills are classified by the type of grinding media used. They are:

- i. rod mills
- ii. ball mills
- iii. Autogenous (AG) mills
- iv. Semi-autogenous (SAG) mills

Mill

A tumbling mill can be divided into three parts:

- The mill itself
- The drive assembly
- The lubrication system

The main components of a typical tumbling mill are labeled in Figure 2.

- The *feed chute* introduces ore into the mill. A seal between the stationary feed chute and the rotating mill prevents leaking. A spout feeder is the simplest and most common type of feed chute.
- *Lifters* promote the tumbling action of grinding media by keying the charge. Sometimes, a lifter and liner are combined in a single piece.

- *Liners* protect the shell from wear. Liners, which can have different shapes, can be made of metal or rubber. Rubber liners can be more expensive than metal but they are lighter, which simplifies maintenance.
- The *shell* holds grinding media and ore. The shell is a cylinder fitted with a flat or conical head at each end.
- *Trunnion* provides entry and discharge points for slurry. Trunnions are usually lined with spiral flights. The spiral inside the feed trunnion pushes the feed inside the mill. The spiral inside the discharge trunnion of overflow discharge mills keeps the charge inside the mill. Trunnions are where the mill is normally supported. Some large mills are supported on the shell rather than on the trunnion.
- The *trommel screen* prevents large rocks, tramp metal, or grinding media from leaving with the product. Ground product passes through the screen holes while large objects are ejected by the spiral flights of the trommel. The trommel is sometimes sprayed with water.
- *Grinding media* are loose objects that move freely inside the mill. They break ore with their tumbling action. Steel rods, balls and large pieces of ore are common types of grinding media.

Mill Discharge

There are two main types of mill discharge:

- overflow discharge
- grate discharge

In an overflow discharge mill slurry overflows through the discharge trunnion. It is used for all rod mills to provide an entry point to add new rods. This type of discharge allows broken rods to be ejected from the mill. Most ball mills also use an overflow discharge.

In a grate discharge mill there is a grate that prevents coarse material from leaving the mill through the trunnion. This type of discharge is mainly used for AG and SAG mills to retain coarse ore particles inside the mill.

Tumbling Motion

Tumbling mills break particles by tumbling grinding media onto the ore. There are two types of tumbling motion: cascading and cataracting.

- Cascading produces attrition breakage which leads to fine particle grinding.
- Cataracting produces impact breakage which leads to coarse particle grinding

The charge is cascading when grinding media roll down from the top of the load to the toe of the load. Cascading generally produces attrition breakage, which enhances fine particle grinding. The charge is cataracting when grinding media are ejected from the top of the load onto the toe. Cataracting generally produces impact breakage which enhances coarse particle grinding. The tumbling motion inside a mill is a combination of cascading and cataracting.

Pulp Lifter Action

In a grate discharge mill the pulp lifter "pumps" fine ore and water out of the mill. Its function is similar to that of a bucket wheel used to pump water.

The grate discharge turns with the mill shell. As fine slurry passes through the grate, it pools in the pulp lifter chamber. When the pulp lifter rotates high enough, slurry flows out of the pulp lifter and the cone deflects it so that it flows through the trunnion.

Grinding Media Type

The most common types of grinding media are:

- balls or slugs
- rods
- very large pieces of ore

Rods, balls and slugs are usually made of steel alloy.

Hydro Cyclone

The cyclone is a classifier. It separates the feed into two streams a stream containing mainly fine or light particles a stream containing mainly coarse or heavy particles Separation takes place because particles of different weights and sizes have different settling rates. The feed to a cyclone can be a mixture of air and particles (as for a dust collector, for example), or a slurry of water and particles. In mineral processing, the cyclones usually handle water slurries.

Classification Model

Cyclone operation is a two-step process:

- Classification, which produces overflow and the underflow streams
- Bypass, where some of the overflow stream is directed to the underflow stream

We assume that particles entering the cyclone are first classified by size. Coarse material goes to the underflow and fine material to the overflow. This process is represented by the classification box. Since the cyclone feed is slurry, water has to be handled. We assume the water goes to the

overflow with the fine particles, however some water does go to the underflow and we call this bypass. This process is represented by the bypass box.

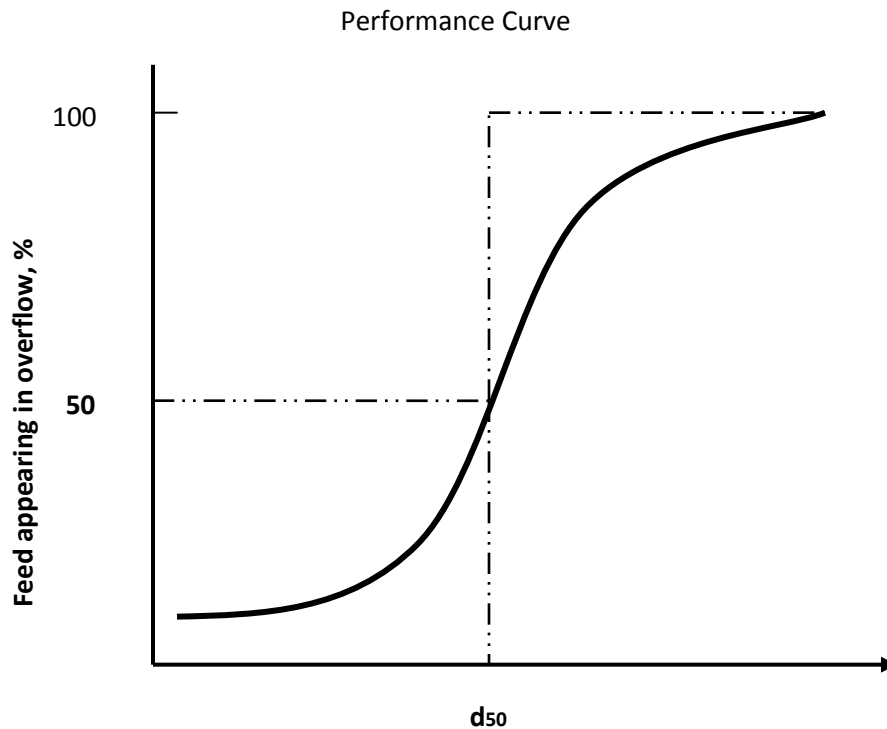
Classification Efficiency

The feed to a classifier contains particles of assorted sizes. It can be sorted with fine particles on the left and coarse particles on the right. In a perfect classifier, all coarse particles would report to the coarse stream, and all fine particles would report to the fine stream. The line that separates the two is called the cut size.

In practice, classification efficiency is not perfect. Some fine particles leave with the coarse stream, and some coarse particles leave with the fine stream. If classification gets worse, the 'sharpness of separation' decreases. Sharpness of separation is indicated by the angle of the line. For a perfect classifier, the line is vertical. When sharpness of separation is poor, the line is closer to horizontal. The effects of separation, sharpness and bypass can be represented by a partition performance or efficiency curve. The horizontal axis gives the particle size and the vertical axis gives the fraction of feed particles that go to the underflow.

The cyclone efficiency is represented by a performance curve which relates the weight fraction, or percentage, of each particle size in the feed which reports to the apex, or underflow, to particle size. The cut point, or separation size, of the cyclone is often defined as that point on performance curve for which 50% of particles in the feed of that size report to the underflow, i.e. particles of this size have equal chance of going either with underflow or overflow. The performance curve is shown below.

Fig 4 Performance curve of a cyclone



The partition curve describes how the classifier feed particles are split between the two product streams. When classification is not perfect, the cut size represents the size at which particles have an equal chance of going to either the underflow or overflow.

The partition curve is characterized by the cut size, the sharpness of separation, and the bypass. Sharpness of separation is a measure of classification efficiency. It is represented by the slope of the partition curve. A steep slope indicates near ideal separation; a shallow slope indicates poor separation.

Bypass gives the percentage of fine particles brought into the underflow by water.

Cyclone components

The main components of a typical cyclone are

- The *inlet* directs the feed into the cyclone. Its design creates a circular motion.
- The *vortex finder* collects fine material near the top of the cyclone. Material leaving through the vortex is called overflow. The overflow is usually directed to the next operation. Most of the water in the feed leaves with the overflow. The vortex finder

extends into the cylindrical section to prevent the feed from short-circuiting to the overflow.

- The *cylindrical section* is where classification takes place.
- The *conical section* guides coarse material towards the bottom of the cyclone.
- The *apex* at the bottom of a cyclone discharges coarse or heavy material. The material leaving through the apex is called underflow. On some cyclones, the size of the apex can be adjusted.

The number of cyclones on-stream can be changed to adjust capacity. The valves also allow cyclones to be switched for maintenance.

- The *central feed distributor* directs the feed to each cyclone.
- The *cyclone inlet valves* are used to isolate the cyclones.
- The *cyclones* separate fine or light particles from coarse or heavy particles.
- The common *underflow launder* collects the underflow from individual cyclones.
- The common *overflow launder* collects overflow from individual cyclones.

Vortex Size

A smaller vortex produces finer overflow. Reducing the vortex size restricts the amount of material reporting to the overflow. This reduced volume flow means that the drag forces on particles are also reduced. The settling rate of intermediate sized particles, which might have otherwise reported to the overflow, is now sufficient to overcome drag. These particles can now move to the cyclone wall and down to the underflow. As a result, the cut size is decreased.

Apex Size

A larger apex produces a finer overflow. Increasing the apex size allows more of the slurry to report to the underflow. This reduces the amount of material reporting to the overflow, which reduces drag forces on particles. As a result, the cut size is decreased.

Roping

If the apex capacity is exceeded, a condition known as roping may occur. Normally, the underflow sprays out of the apex. When roping occurs, the air core inside the apex collapses and the spiraling motion is almost lost. The discharge looks like a rope. In extreme cases, roping can lead to blockage. Cyclone blockage is rare, but it can occur if large particles, small grinding media or some other foreign object, blocks a small apex.

Intermittent Flow – Surging

Surging is a problem which can occur from time to time. (This is especially true when there is no level control on the pump box feeding the cyclones.) Surging leads to unstable cyclone operation, since the overflow flows only intermittently. When there is a surge in the feed rate, quite often coarse material incorrectly reports to the overflow. This can have harmful effects on metal recovery and on downstream circuit operation. Cyclone pressure or feed pump power fluctuations are indicative of surging.

A cyclone is classification device. To get a finer overflow, decrease feed % solids, increase feed rate, or reduce the number of cyclones. These trends hold for cyclones operating in an open circuit. In a closed circuit, the effects are more complicated.

For a long term effect, or if the desired effect cannot be obtained by changing the operating variables, it may be necessary to change a design variable (apex size, vortex size, body size, or

Leaching

In metallurgical applications, leaching is the process of dissolving a soluble mineral or metal from an ore. All metals can be solubilized, or leached, in some manner or another. However, the leaching process requires a variety of lixiviants and operating conditions, which are dependant on the mineralogy of the ore to be processed. Oxide gold and silver ores can easily be leached at ambient conditions in an alkaline cyanide solution. However, refractory gold ores generally require pretreatment in an acidic pressure leach or biological leach circuit.

The process may be used either for the production of a concentrated solution of a valuable solid material, or in order to remove an insoluble solid, such as a pigment, from a soluble material with which it is contaminated. The method used for the extraction is determined by the proportion of soluble constituent present, its distribution throughout the solid, the nature of the solid and the particle size.

If the solute is uniformly dispersed in the solid, the material near the surface will be dissolved first, leaving a porous structure in the solid residue. The solvent will then have to penetrate this outer layer before it can reach further solute, and the process will become progressively more difficult and the extraction rate will fall this is known as the 'shrinking core method'. If the solute forms a very high proportion of the solid, the porous structure may break down almost immediately to give a fine deposit of insoluble residue, and access of solvent to the solute will not be impeded. Generally, the process can be considered in three parts: first the change of phase of the solute as it dissolves in the solvent, secondly its diffusion through the solvent in the pores of the solid to the outside of the particle, and thirdly the transfer of the solute from the solution in contact with the particles to the main bulk of the solution. Any one of these three processes may be responsible for limiting the extraction rate, though the first process usually occurs so rapidly that it has a negligible effect on the overall rate.

In some cases the soluble material is distributed in small isolated pockets in a material which is impermeable to the solvent such as gold dispersed in rock, for example. In such cases the material is crushed so that all the soluble material is exposed to the solvent.

Agitated leaching

Agitated tank leaching is defined as leaching of an ore under ambient operating conditions using a recovery method that does not incorporate extraction of the metal in the same unit operation. The most prevalent use of agitated tank leaching is the recovery of precious metals in conjunction with counter current decantation thickeners. This recovery technology is usually preferred when large amounts of silver are present either alone or with gold.

Even though the most prevalent current application is the recovery of precious metals from alkaline cyanide leach solutions, agitated tank leaching is a recovery method that is important in a number of applications.

Pumps

Pumps are used to transfer slurry from one point to another. A pump increases the pressure of a fluid to give it the driving force required for flow.

In a grinding circuit, the cyclone feed pump is usually a centrifugal pump.

Centrifugal Pump Components.

The main components of a typical centrifugal pump are shown in appendix, right.

- The *motor* provides the energy required to rotate the impeller. Some pumps have a variable speed drive.
- The *pump outlet* discharges slurry at a high pressure.
- The *impeller*, forces slurry outwards. The impeller consists of blades mounted on a rotating shaft.
- The *pump inlet* delivers slurry to the centre of the impeller.
- The *casing* houses the impeller. The cross-sectional area of the casing increases towards the outlet.
- *Liners* protect the casing from wear. There are two liners: one on the drive end of the casing and one on the suction end of the casing. Soft rubber is often used because it is resistant to abrasive slurries.
- The pump *gland seal* prevents slurry from leaking around the rotating shaft. Gland water must be added to lubricate the packing and form a water seal.
- The *shaft* connects the motor to the impeller. The pump shaft is connected to the motor shaft by V-belts. The V-belts are held by sheaves. In fixed speed drives, changing the sheave diameter can change the pump speed.
- The *barrel* houses the pump bearings and provides an oil bath to lubricate the bearings.

Centrifugal Action

Slurry enters the pump through the eye of the rotating impeller, which imparts a circular motion. It is thrown outwards by centrifugal force and travels between the blades of the impeller. The slurry attains a high speed by the time it reaches the edge of the impeller. In the casing, its high-speed energy is converted into pressure energy.