

WARMAN®
Centrifugal Slurry Pumps

Excellent
Minerals
Solutions



Mill Circuit Pump Manual



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Introduction

Mining is one of the oldest activities of man. It is the selective extraction of ore from the Earth's surface. Man's mining activities began at the start of the Stone Age almost 2.5 Million years ago.

Mining generally implies the physical extraction of materials from the Earth's surface. Mining large volumes of ore is often required to produce relatively small quantities of the desired product or mineral.

Generally, mining is used to obtain minerals or fuels. A mineral can be defined as a substance of natural origin with a defined chemical composition with predictable and constant properties.

A mineral resource is a volume of the Earth's surface with an abnormally elevated concentration of a mineral or fuel. It becomes a reserve if the ore and its content (e.g. a metal) can be recovered using current technology at a cost that allows a reasonable yield on the investment in the mine. Before a mine is considered viable, the cost of production must be sufficiently below the potential selling price of the mineral to produce acceptable returns on the sometimes huge investment required.



Typical copper ore found in Chilean copper mines

In most hard rock mines, the ore is extracted by means of drilling and blasting. First, holes are made in the ore body with hydraulic or compressed air driven drilling machines. Explosives are inserted in the holes and exploded causing the rock to fracture and allow extraction.

In underground mines, special purpose machines with diesel engine powered conveyors are often used to

load the blasted rock and transport it to special, steeply inclined ore paths. The ore is then loaded into special buckets and hoisted to the surface.

If it is mineral bearing ore, it is transported to the processing plant. If it is waste material extracted during the development of the mine, it is usually transported directly to a refuse dump.



Copper Chilean coins made in "Casa de Moneda," the state coin maker

The next stage is crushing, milling and classification of the ore to reduce it to very fine particles, allowing the liberation of the sought after minerals. The first step in this process is to crush the mineral into a suitable size using primary crushing equipment. The ore is then passed into the milling and classification process to reduce it to the fine particle size needed to allow the desired mineral to be extracted.

The milling process is carried out using very large revolving equipment referred to as grinding mills. There are a number of different types of mills — including those which use steel rods or balls as the grinding medium within the mill. These are referred to as rod mills or ball mills. There are others which use just the force of the ore falling on itself to break it down into a smaller size. These are known as Autogenous or AG mills. Another common mill type uses a combination of both autogenous grinding and ball mill grinding—these mills are known as Semi-Autogenous Grinding or SAG mills.

Water is added to the ore during the grinding process. This creates 'slurry', which is then used to transport the ore throughout the remainder of the extraction process.

SAG Mills constitute a recent innovation in terms of ore processing. SAG Mills can currently be up to 11.0 m in diameter by 4.6 m wide and are considered more efficient than Ball Mills. They can substantially reduce the crushing and milling process due to their large capacity and efficiency.

With SAG mills, the mineral is received directly from the primary crusher (not from a secondary and/or tertiary

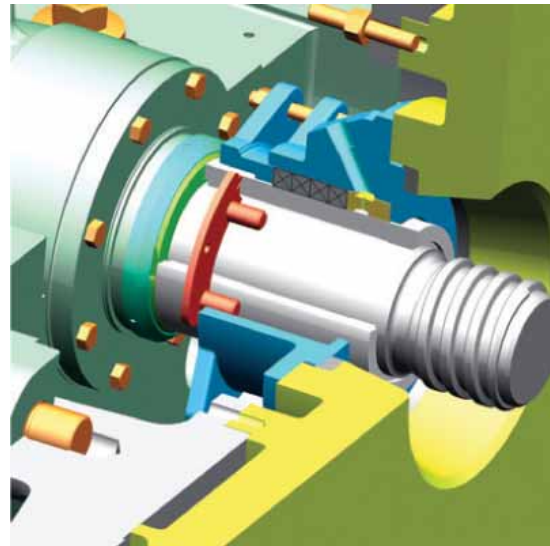
crusher as in conventional milling), reduced in size to around minus 20cm (or 8 inches), then mixed with water and lime. This material is then further reduced in size by the tumbling action of the large particles combined with the grinding action of the large (5" or 6") steel balls added to the mill (hence the name of semi autogenous milling). The steel balls can occupy from 10 percent to 18 percent of the mill capacity. Given the size and form of the mill, these balls are sent into free fall as the mill rotates, providing a combined crushing and grinding effect on the ore. One of the main reasons for the use of SAG mills is the elimination of the secondary and tertiary crusher stages, and the substantial reduction in consumed power over conventional milling.



A typical SAG mill with a smaller conventional ball mill shown in the background

In all mineral processing, the transport of the ore throughout the extraction process constitutes a challenge in itself. Specialised equipment capable of transporting the mixture of ground ore and liquid (the slurry) at a high efficiency, available at a low initial investment and offering affordable ongoing maintenance costs is required. This is why Warman MC Mill Circuit Pumps have become renowned as the heart of the milling process. Their high efficiency, long service life, and low maintenance costs, combined with their ability to be adapted to meet unique and specialised requirements, has made them the world leaders in this critical pump application.

This manual does not set out to be a reference on mineral processing, but is instead designed to briefly describe the Milling Process in order to help pump engineers gain a better understanding of how it all works.



Very heavy duty pump shaft used in Warman MC mill circuit pumps

The Milling Process

Why reduce the ore size?

Minerals are generally dispersed in very small quantities throughout the mined ore. As higher grade ore bodies become depleted, new techniques have been developed which ensure that minerals are still economically mined from lower ore grades. Copper mining in Chile, for instance, is currently carried out on ore bodies with copper head grades as low as 1 percent. Most copper ore bodies in North America have head grades below 0.5%.

To enable the recovery of valuable minerals from the surrounding rock ore, it is necessary to reduce the ore to a very fine size to allow the valuable minerals to be liberated from the surrounding ore.

In a typical copper concentration plant, for example, crushed ore is fed into a SAG/Ball mill circuit with a median size of approximately 12,000 microns. Most SAG Mills are operated in closed circuit with a screen. The screen filters undersized ore, normally minus ½ inch, to a ball mill discharge sump. The combined mill discharges are pumped to undergo classification, normally via hydrocyclones. The fine particles from classification after grinding have been reduced to the required liberated particle size and are then forwarded to flotation. The ore particles which have not reached the required liberated size are returned back to the ball mill for further grinding.

The approximate energy consumption during this process is 20 Kilowatt Hours per Ton of ore processed. This means 20 Kilowatts per hour are required to change the particle size from 12,000 to 200 microns of one metric ton of copper ore.

The large scale of modern SAG milling installations involves substantial capital and operating costs. The crushing and milling process consumes up to 80 percent of the total of energy required to produce copper concentrate, and can constitute half of the cost of the total mining process.

In hard rock ores, three general types can be defined:

released ore: which are the smaller deposits

occluded ore: where the mineral can be released without very fine grinding; and

dispersed ore: which forms the majority of deposits, and requires very fine grinding to liberate the mineral.

Ore characterization

Minerals can be classified by their properties (optical, physical, electrical, magnetic) and by their chemical composition. Minerals can, therefore, be identified by spectroscopic or visual observation; however, chemical

analysis is the only means of identifying the precise nature of the mineral.

Hardness of the mineral

In 1822, a German mineralogist named Friedrich Mohs established a measuring scale to determine the hardness of each mineral, called the Mohs scale of mineral hardness. This scale is widely used today. Each mineral can be compared to 10 comparative minerals ranging from soft to hard. The comparative minerals used are: talc, plaster, calcite, fluorite, apatite, feldspar, quartz, topaz, corundum and diamond.



Tenacity or cohesion

A mineral's tenacity or cohesion is the degree of resistance that it offers to breakage, deformation, crushing, curvature, or pulverization. The following classes of tenacity are defined:

Fragile: A mineral that is easily broken or pulverized.

Examples: quartz and sulfur.

Malleable: A mineral that can be beaten and flattened into laminate or plates.

Examples: gold, silver, platinum, zinc and tin.

Ductile: A mineral that can be reduced to threads or thin wires.

Examples: gold and silver.

Flexible: A material that can be easily bent, but is not able to recover its original form when released.

Examples: plaster and talc.

Elastic: A material that can be bent and can recover its original form when released.

Example: mica.

Fracture of a mineral

When a mineral is fractured, it separates in a number of different ways:

Exfoliation: Describes a mineral that separates with flat and parallel surfaces.

Examples: mica, galena, fluorita and plaster

Laminar or Fibrous: Describes a mineral that displays an irregular surface in the form of chips or fibers.

Example: actinolita.

Conchoidal: Describes a mineral that fractures with a smooth surface and curve, which shows an inner shell.

Examples: sílex and obsidian

Hooked: Describes a mineral where a coarse and irregular surface occurs with acute and indented edges during fracture.

Examples: magnetite and native copper.

Smooth: Describes a mineral that tends to fracture with smooth and regular surfaces.

Dusty-granular: Describes a mineral that fractures leaving a surface with a granular or dusty aspect.

Electricity and Magnetism

Many minerals readily conduct electricity, whereas others are good insulators. (A few minerals conduct electricity moderately and are classed as semi-conductors., a development that has greatly facilitated the dramatic advances in computer technology over the past 30 years.)

There are further mineral behaviors in relation to electromagnetic forces:

Magnetism: Consists of attracting iron and its derivatives. Natural magnets are permanent. Magnetite has been known as a natural magnet for many years.

Piezoelectricity: The capacity to produce an electrical current when pressure is applied. If a force is applied to the faces of a crystal, for instance, it generates electrical charges and, if electrical charges are applied, a deformation of the faces of the crystal takes place.

Example: quartz.

Piroelectricity: Electrical currents in the end of the faces occur when the mineral is put under a change of temperature.

Examples: quartz and tourmaline.

Radioactivity: Certain minerals emit natural and spontaneous particles of radioactivity. Minerals with natural radioactivity have many scientific, medical and industrial applications. Radioactive minerals in their natural form rarely reach dangerous levels.

Example: uranium.

Ore Classification

Minerals are divided into groups according to their chemical compounds. All well-known minerals can be integrated within these groups, as they all include some of these compounds.

Native elements: Those that are found in a free or pure native state without combining or forming chemical compounds.

Examples: gold, silver, sulfur, and diamonds.

Sulfides: Diverse minerals which are combined with sulfur.

Examples: pyrite, galena, blende, cinnabar.

Sulfosalts: Minerals composed of lead, silver and zinc combined with sulfur and some other mineral like arsenic, bismuth or antimony.

Examples: pyrites and proustite.

Oxides: Product of the combination of oxygen with an element.

Examples: oligist, corundum, cassiterite, bauxite.

Hallures: Composed of a halogen with another element, like chlorine, fluorine, iodine or bromine.

Examples: common, halita salt.

Carbonates: Salts derived from the combination of carbonic acid and a metal.

Examples: calcite, azurite, marble, malachite.

Nitrates: Salts derived from nitric acid.

Examples: sodium nitrate, saltpeter or potassium nitrate.

Borates: Constituted by mineral salts or esters of boric acid.

Examples: borax, rasorita.

Phosphates, Arseniates, salts or esters of phosphoric acid, arsenic acid and vanadium.

Examples: apatite, turquoise, piromorphyte.

Sulphates: Salts or esters of sulfuric acid.

Examples: plaster, anhydrite, baryta.

Chromates: composed of chromium, molybdenum or wolfram.

Examples: wolframite, crocoita.

Silicates: Silicic acid salts, the fundamental compounds of lithosphere, which form 95 percent of the Earth's surface.

Examples: silica, feldspar, mica, quartz, pyroxene, talc, clay.

Radioactive minerals: Elements emitting radiation.

Example: uranium

Typical characterization of Copper Ore

To characterize the metallurgical extraction process of copper, you need to consider that the mineral, in its natural state, is found concentrated with a variety of other minerals. The separation process is therefore determined depending on the origin of the material.

Copper coming from minerals that contain pure metal in the native state. The treatment and these rare ore bodies are very straightforward and generally require only a simple gravity process to separate the heavy copper particles.

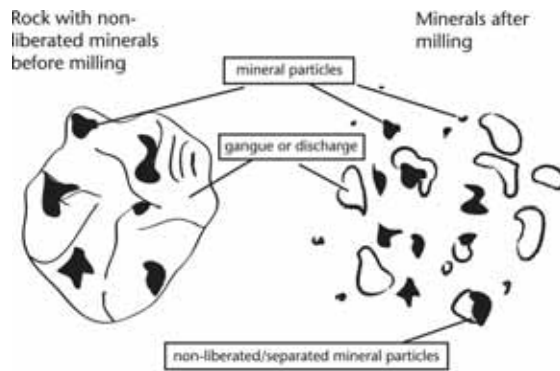


Diagram depicting ore in its natural and ground state

Copper coming from oxide type ores

If the mineral is a rich grade, it can be profitably extracted using a pyrometallurgical treatment which is carried out in a smelter with the addition of a coal-like element reducer. Low grade oxide copper ores are treated using an acid leach hydrometallurgical process.

Copper coming from sulfide ores

In this case, a preliminary flotation process is generally used to concentrate the mineral by separating the sulfide particles from the surrounding rock.

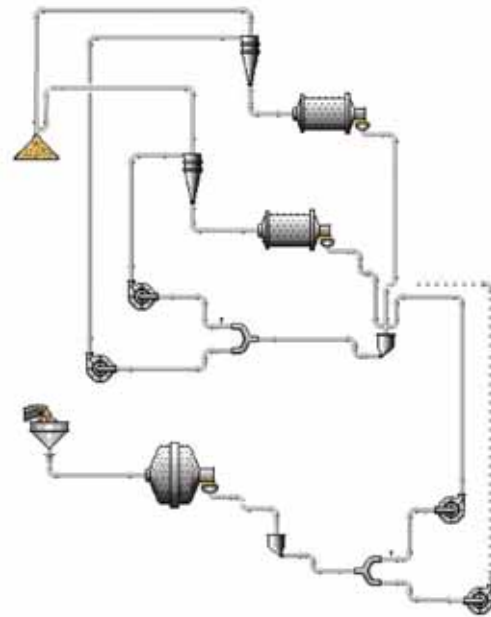
Recent advances in mineral treatment processes have produced technology that now enables the viable extraction of minerals from very low grade ore deposits. This is particularly significant in Chile, where copper deposits are now commercially mined with grades as low as 1 percent. This advance in technology is not only significant for copper mining, but also applies to

many other important minerals (excluding iron and aluminium).

SAG mills (Semi Autogenous Grinding) are now manufactured on a very large scale and have been one of the advances that allows the viable processing of ever increasing quantities of low grade ore. There are a growing number of these large SAG mills being considered for new projects. It is inevitable that an ever increasing percentage of the ore processed around the world will be through the use of SAG mills.

Primary mill circuits types

Plants using SAG mills are now designed with fewer milling streams, but these streams now offer greater capacity. The main advantage over traditional methods utilizing multiple streams of ball and rod mills is the elimination of the requirement for secondary and tertiary crushing, as well as the enormous battery of ball and rod mills often associated with these types of plants. The development of very large SAG mills now enables process plants to have a minimum number of milling streams with continuous and stable operation, which is essential to ensure the profitability of low grade operations.



Typical primary and secondary milling circuit with a SAG and two ball mills in closed circuit

In a typical SAG mill process, two identical mill lines exist, each one with a SAG mill and two ball mills. The mill circuit reduces the mineral until 80 percent passes 115 to 150 microns (depending on the mineral type), meaning that after milling, 80 percent of the ore will pass through a screen with openings from 115 to 150 microns (0.115 mm to 0.150 mm). It is necessary to

reduce the ore to this size to enable liberation of the copper mineral from the surrounding ore.

Once the mineral has been liberated, a flotation process is generally used to separate and concentrate the mineral.



Typical SAG mill in a copper treatment plant

Assuming a plant availability of 90 percent, a typical milling circuit designed to process an average of 60,000 metric tons of sulfide ore per day/365 days a year, would process 21.9 million metric tons of ore in a year. Assuming the ore contains an average of 2 percent copper, and that 92 percent of the available copper is recovered during the process, the end product would be a flotation concentrate containing 30 to 45 percent copper.

Mill concept characteristics

The most common objectives are:

- to maintain a constant plant throughput and particle size output from the mill
- to maximize the processed tonnage — maintaining the size distribution quality of the mill inside the specific limit

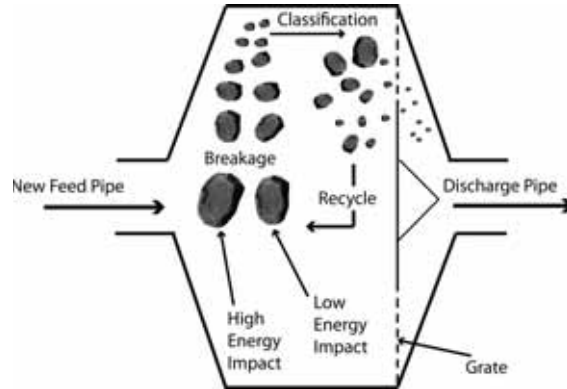
The factors that affect the operation can generally be classified as:

- External variables
- Design variables
- Operational variables
- Control variables

Although not directly controllable, external variables should be identified and compensated by some control process. The biggest obstacles are those associated with the characteristics of the ore feed mineral (hardness, size distribution and density).

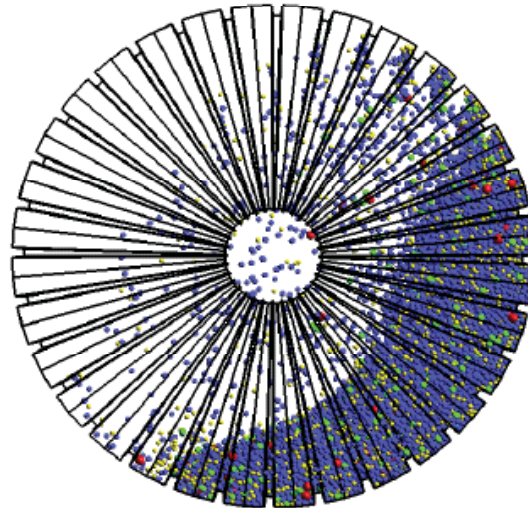
Design variables are related to the characteristics of the installed plant and equipment. Some of the more important include the speed of the mill, the size of mill feed, the weight of the ball load, the opening of the screen and the spigot and vortex diameters of the classifying hydrocyclones. Except for the mill speed,

the design variables are not generally used as variable process controls. They generally are varied from time to time to accommodate periodic changes in the ore characteristics.



Outline of the process inside a mill showing the introduction of new feed and the discharge of ground ore

Some SAG mills have variable speed drives allowing the mill speed to be varied to account for operational variations in ore characteristics. Other variables which are controlled to respond to changes in the ore characteristics include the new ore feed into the mill and the flow of water addition to the mill. This in turn controls the slurry density at the mill discharge.



Kinematics of particles ([Millsoft] software)

The flow of additional water to the mill is an important control variable to produce variations in the internal load of the mill, and to maximize the output capacity of the mill. This, however, has an immediate impact on the power drawn by the mill and the quantity of ore fed to the mill to enable a constant slurry density to be maintained. This is required to ensure a stable process operation and to avoid damage to the mill and pump linings.

The following variables are measured continuously in SAG circuits for control purposes:

- Power consumption of the mill
- Hydrocyclone pressure
- Mill rotational speed
- Flow and particle size distribution of new incoming ore being fed to the mill
- Solid percentage and size distribution at the hydrocyclones
- Slurry flow and density to hydrocyclones
- Level of the mill pump feed sump
- Flow of additional water to the mill
- Noise level of the mill

Autogenous or Semi Autogenous Mills without a centre shaft and pinion drive

This type of mill drive was designed to meet the demands of the market. They are larger mills driven by more powerful motors (11,000 Hp for a 32 foot mill or 7,000 Hp for a 36 foot mill) and are capable of processing 30,000 tons a day.

Advantages: The mill has greater capacity as the transmission is driven via an induction motor rather than a mechanical drive, thus eliminating mechanical drive restrictions and the need for lubrication. However, it is necessary to ensure proper maintenance and alignment of the pinions.

Disadvantages: There will be higher mill costs as the mill is required to be housed in a clean, dry environment. Maintenance and alignment is more complicated with this very specialized and difficult system. The change-out of mill liners is also more difficult. The speed can be modified by varying the power of the mill.

There are three variables during the operation of the mill:

- The output density,
- the power consumed, and
- the sound emitted by the mill.

The density: The solids output by the mill are usually around 70 percent by weight of the slurry.

The power: It is measured by the ammeter of the motor when there is a discharge. The variation of amperage indicates a lack of feed.

The sound: The sound of balls or bars gives an indication of the load inside the mill.

Ore feeding into the mill should be uniform. This is usually achieved using conveyor belts, which control the feed of ore to the mill, ensuring optimal retention time

to achieve the required grind size. If the retention time is too long, this will generate too many fine particles.

The time of residency of the material can be calculated as follows:

$$[T] = \text{it Loads (Tn)} / \text{"V" feeding}$$

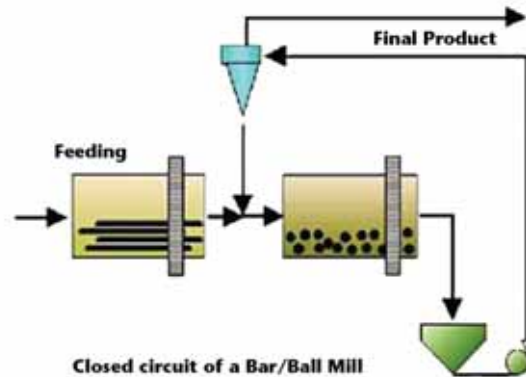
In practice, to determine the time of residency of the load, NaCl is added to increase the conductivity of the water; then the increased conductivity is measured at the exit. This gives an indication of the residency time within the mill.

Others methods are the use of copper sulfate for volume measuring to determined their residence and the radioactive method to determine the time of residency of the load in the mill; a nuclear density gauge is also used to measure the density.

The mean load of the mill depends on the volume occupied in the mill formulated as: Volume of the mill load divided by the useful volume of the mill

Classification and its effect in the circulating load

The classifier is an apparatus that takes the discharge of the mill and separates the particles that have been reduced to the requisite size from those that have not yet been sufficiently reduced (i.e. oversize).



Simple milling circuit

The speed of the mill determines the rising action of the ore and balls within the mill. Mills with variable speed drives generally work within 60 to 78 percent of their critical speed. The mill critical speed is the rotational speed at which the centrifugal force forces the material to the interior mill walls and impedes the waterfall action required to achieve the required grinding action. The variation of the mill speed is an important variable in the control of the mill operation. The mill operator must ensure that the mill linings are protected from direct impact by the mill balls. This is achieved by maintaining an ore bed in which the balls can land during the waterfall action. If the mineral is softer, it is milled

more quickly. When softer ore conditions exist and the mill is running at normal speeds, it is difficult to maintain an ore bed in the mill and to prevent the circuit from becoming diluted and producing too much fine material. In this case, the operator should reduce the mill speed so as to maintain the ore bed within the mill. If the ore is harder, the operator should increase the speed of the mill, thus increasing the waterfall action of the balls and adding greater energy to grind the harder ore. The mill operator can also use the speed of the mill to protect and prolong the life of the mill liners.

Metallurgical concept in the process

In the milling process, there are variables can affect the results of the plant. Some of these variables can be controlled within the process and some cannot.

Controlled variables

The feed of new ore to the mill is part of the overall milling system, impacting the mill fill level and the power consumed by the mill.

The increase of the mill fill level will also impact the milling operation as it is a kinetic process wherein the mass of milled and discharged ore is proportional to the mass inside the mill. To balance an increase in the feed of new ore to the mill, the quantity of ore inside the mill should also increase.

SAG mills can typically contain up to a 14 percent fill of balls to increase the productivity of the mill, though 10 percent is more common. The determination of this variable is most commonly ascertained through testing, as it is very difficult to accurately predict or calculate in advance. Most formulas are determined empirically. The ability to simulate the internal dynamics of the mill offers the possibility to determine with more accuracy the required load of balls and the variation in the waste rate, as well as other operational variables.

Efficiency, d50, P80, bypass, recirculation

Hydrocyclone classification

The common value of measure for particle separation between fines and coarse particles is the d50 sizing, commonly referred to as the cut size of the hydrocyclone.

The d50 is the particle size diameter for which 50 percent by mass reports to the underflow. Solids progressively larger than d50 size have a probability of greater than 50 percent of reporting to the cyclone underflow.

Another measure of separation in a cyclone is the proportion of liquid reporting to the underflow compared to that in the feed. This is referred to as the water split and is commonly denoted (Rf).

Classification Efficiency Curve

The classification efficiency curve is typically in the form of an "S-shaped" curve, passing through the cut point and intersecting the "Y" axis (percent reporting to underflow) at a value equal to the water split. The water split ratio can vary considerably depending on the operating conditions and the cyclone geometry, and can be manipulated accordingly. As such, it is common practice to remove the effect of the water split ratio from the efficiency definition by correcting the recovery curve so that it passes through the origin.

The corrected efficiency curve is defined by the following efficiency equation:

$$R_c = \frac{R_a - R_f}{100 - R_f}$$

Where

R_c = Corrected efficiency

R_f = Water split ratio

R_a = Actual water split ratio (a percentage)

Note: *The corrected efficiency curve also defines a corrected d50 value denoted d50c. The d50c is a useful value used to compare performance of different cyclones for a particular application.*

Operational variables

The operational variables are factors external to the cyclone which affect the performance of the cyclone.

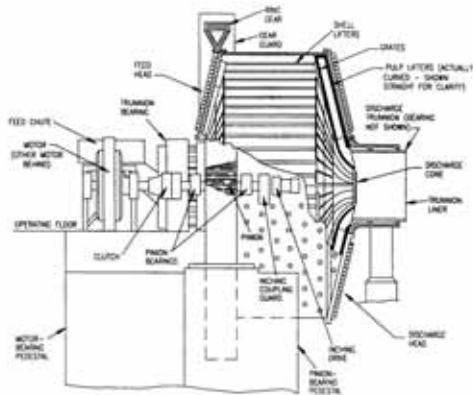
Feed solids concentration:

The Feed Solids Concentration is usually expressed as a percentage of solids by weight (C_w). The proportion of solids in the slurry feed has a substantial effect on the classification performance of the cyclone. Generally, the higher the percentage of solids, the coarser the cut size (higher d50). For example, an increase of solids from 5 percent to 20 percent by volume will approximately double the value of the cyclone cut point.

Feed Pressure:

The required feed pressure for correct cyclone operation varies and depends on the cyclone size and the specific application. It is important that a pressure sensor is either located in the cyclone feed distributor or the feed pipe adjacent to the entrance of the cyclone to continuously indicate the feed pressure.

The feed pressure must be maintained within the cyclone design operating range, usually 50 to 150 kPa depending on the application. A change in the feed pressure will affect the cyclone classification performance and the water split ratio of the cyclone.



Typical SAG mill

Specification of mills:

Pilot testing is sometimes used as a preliminary means of establishing design capacity and power requirements. Small pilot circuits are used with the same characteristics of the full scale operation in areas such as the distribution of balls and the action of the classifier. This method is generally very expensive

Simulation can be used to predict the performance of a mill using concepts such as the speed required to break particles in the mill. These inputs can be fed into a mathematical model, understanding the process of size reduction and classification to simulate the likely performance of the mill.

Empirical methods such as the BOND method are often used, calculating the dimension of the mill required to process the tonnage of a specific ore to achieve a size reduction from F80 to a product with a size distribution of P80. For this method to work, index WI is used. The advantage of this method is that it gives a reasonable approach.

It is known that the work achieved by the mill is read with an ammeter to determine the maximum tonnage that can be put through a mill. The work index can give

an idea of the hardness of the material to be milled, as well as other factors that can affect the mill performance — such as energy consumption, the load of balls, or the mill lining system.

The size of the primary product fed to the mill depends on the efficiency of the primary crushing circuit prior to feeding the mill. The feed size has a direct influence on the operation of the mill.

Circulating load: The classifier is an apparatus that separates the discharge from the mill into fine particles small enough to proceed downstream and particles still too large to proceed — generally referred to as oversize particles. This classification usually takes place in a hydrocyclone. When the oversize particles are returned to the same mill for further grinding, this part of the grinding load is referred to as the circulating load within the mill.

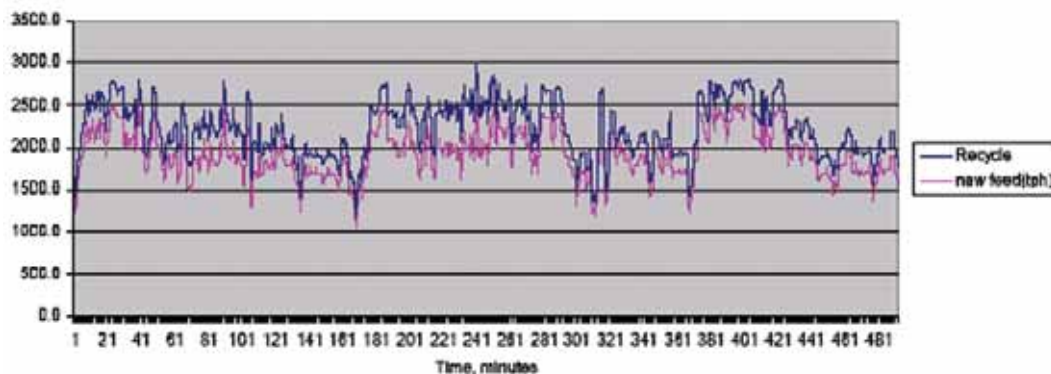
Mills can be arranged either in an open or a closed circuit. In an open circuit, the ore passes through the mill only once with the classifier directing the oversized particles to another, secondary mill. A mill is said to be in a closed circuit when the classifier returns the oversize particles back to the entry of the same mill. Mills of this type are said to have a circulating load with the circulating load expressed as a percent of weight of the new ore being fed to the mill. Circulating loads of 300 to 400 percent are not uncommon in this type of milling circuit.

Control of the mill circuit

The main variables that influence the control of the product are:

- changes in the feed rate of new ore into the mill
- size distribution of the particles being fed to the mill
- changes of hardness of the ore
- volume added water.

For continuous analysis, control sensors are used in the classifier to control the particle size and slurry percentage, to achieve the optimum particle size for maximum recovery of the sought-after mineral.

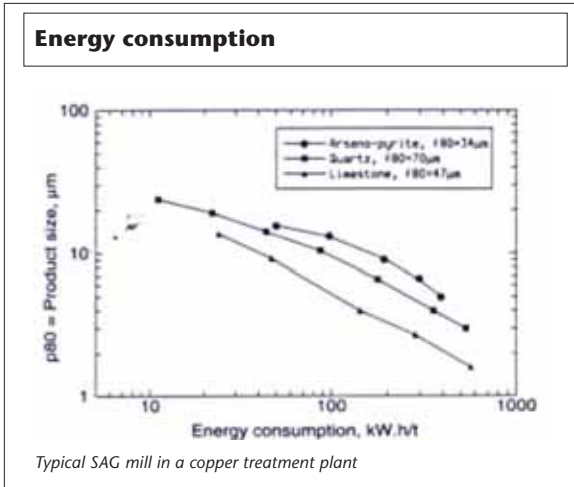


Typical SAG mill in a copper treatment plant

Power consumption v. ore milling

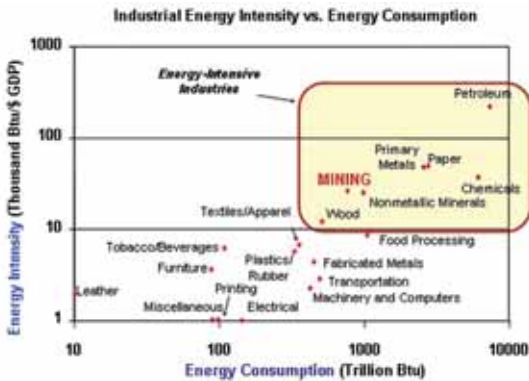
The power consumed by a mill is directly linked to its efficiency. The efficiency of the mill is directly influenced by the fill level, which in turn depends on the mechanical properties of the material, and their behavior inside the mill.

Typical consumption						
Level	Power (KW)		KWH/TMS		TMS/HR	F 80 SAG
	SAG M.	Ball M	SAG M	Ball M		
Full Auto	7095	3810	19.0	10.3	381	81283
Semi Auto 4%	8474	4204	12.3	6.0	700	53065
Semi Auto 10.5%	10621	4232	8.9	7.4	1193	87871
Semi Auto 12.3%	10998		11.3	8.0	976	108540



Typical SAG mill in a copper treatment plant

International studies establish the energy consumption according to the following distribution:



Investigation of the Effect of Feed Size

Circuit Surveys with Secondary Crushed Feed

Prior to conducting surveys, the SAG mill was ground out to determine ball load. Two surveys of the grinding circuit were then conducted with the objective of collecting data for mass balancing and producing a model for the circuit using JKMC's JKSimMet process simulator. The summary results of mass balancing for surveys-1&2 are given in the following chart:

During these surveys, the SAG mill load and power draw stayed reasonably stable while scats rate fluctuated slightly. Immediately after finishing the survey, the SAG mill was crash stopped for total mill load measurement.

Breakage and Work Index tests

There are two types of ore characterization tests, which must be done on representative samples of SAG feed material. These are:

Drop weight tests: These are carried out to determine the impact breakage characteristics of rocks. These tests produce two parameters as the output: A and b. Although the individual A and b parameters are input to the model, Axb gives a clearer indication of ore hardness with respect to SAG milling. The smaller the Axb, the greater the resistance to impact breakage in a SAG mill.

Abrasion tests: These are carried out to determine the abrasion resistance of particles in a SAG mill environment. This test produces a single parameter as its output: ta. The smaller the ta, the higher the resistance to abrasion breakage.

A detailed explanation of these tests can be found elsewhere (*Mineral Comminution Circuits, T.J Napier-Munn et al, 1996*).

The size range of the rock samples collected from the SAG mill feed conveyor did not cover the full size range required for JK breakage tests as the feed material was very fine. Therefore, samples for breakage tests were collected from individual ore stockpiles on the ROM pad. The estimated ore blend of SAG feed material during the surveys is given as follows:

- Intrepide open pit ore: 40 percent
- Leviathan open pit: 20 percent
- Santa Anna open pit ore: 20 percent
- Junction underground ore: 20 percent

The drop weight test that was conducted on the feed sample was modified as the feed material did not have sufficient coarse particles. Also, using the measured ore breakage parameters for each ore type, blended ore breakage parameters for the feed Axb and ta were estimated.

The calculated ore breakage parameters for the ore blend during surveys were then used in the model. Table 3 below shows these parameters:

Effect of Coarse Ore Simulation Results

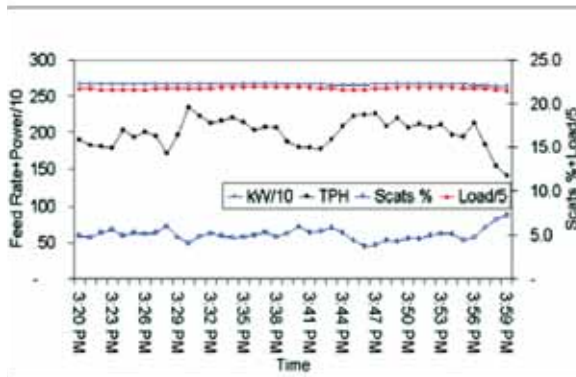
Mass balancing and model fitting of the survey data with fine feed produced good results. Simulation scenarios were conducted to investigate the performance of the SAG mill with varying feed size. The simulation results are summarized in *Table 4*.

Simulations predicted throughput rates between 180 TPH and 210 TPH with the coarse feed. In these simulations, the discharge grate open area was kept at 30 percent, which is the current practice.

Circuit Surveys with Coarse Ore

A SAG mill ball charge level of 14 percent was targeted for the trials with coarse feed. To achieve this target, SAG mill ball addition rate was reduced before the surveys. A grind out was performed immediately before the circuit surveys to confirm the target ball volume load had been achieved. Secondary crushing was stopped to reduce the level of the main stockpile. Any fine ore that had been left on the stockpile was pushed aside from the top of the feeders to make room for coarse feed.

The Primary Crusher Closed Side Setting (CSS) was set to 100 mm. Two plant surveys were conducted under steady state conditions. In the first survey, recycle scats were returned to the SAG mill. For the second survey, they were removed from the circuit. Process flow data were collected from the plant distributed control system. Immediately after finishing surveys, the SAG mill was crash stopped for change of the volume measurements. Rock samples were collected from the SAG mill feed conveyor for feed size determination and ore characterization.



Mass flow trends for survey with no scats return to SAG

SAG mill operation was relatively stable with coarse feed during both surveys. As expected, slightly higher throughput rates were achieved when the recycle scats were not returned to the SAG mill. Table 5 summarizes operating conditions for both surveys. Due to the lower feed rates, only one ball mill was operated during coarse ore trials.

Breakage and Work Index Tests

Ore blend was sourced from three different sources during the coarse ore trial. The composition of the ore blend was as follows:

- Junction underground ore: (33.3 percent)
- North Orchin open pit ore: (33.3 percent)
- Intrepide open pit ore: (33.3 percent)

As previously described, samples of SAG mill feed material was subjected to JK breakage and Bond Ball Mill Work Index tests.

Additionally, each ore type which formed the ore blend was sampled from the crusher ROM pad for ore characterization tests. The results are summarized in *Table 6*.

(add table)

The SAG mill model, which had been derived for fine feed, was modified to include the breakage rates for coarse particles. The resultant model was used to investigate the performance of the grinding circuit under a number of conditions. The most promising results are being further investigated to determine any potential for application. The main parameters, which will be investigated in these simulations, are:

- Increase in discharge end grate open area
- Pebble port size, number, and position
- Effects of scats crushing
- Effects of scats crusher closed side setting
- Ball charge, total charge
- Feed size and ore hardness
- Increased SAG mill discharge screen

In the preliminary simulations, the SAG mill discharge end open area was increased from 3.0 percent to 7.5 percent. It is also assumed that all the open area was provided by 75 mm pebble ports. Scats crusher closed side setting was set to 10 mm. The results of the most promising simulation showed the following:

Throughput rate: 345 TPH

Scats rate: 91 TPH (26 percent of new feed)

Power draw: 2,500 kW

Cyclone overflow P80: 118 micron

The SAG mill ball charge and total charge were kept to 14 percent and 21.5 percent respectively in these simulations. Results produced an overall specific power consumption of 18.8 kW/t, giving a calculated work index of 21.1 kWh/t. This operating work index, calculated from the simulation results, compared well with the actual operating work index of 21.8 kWh/t.

Typical values inside the process

Factors that affect the mill efficiency

Several factors affect the efficiency of ball mills. The density of the slurry feed should be as high as possible, but guaranteed an easy flow through the mill. It is essential that the balls are covered with an ore layer. If the slurry is too diluted the metal to metal contact of the balls increases, increasing ball wear and reducing efficiency. The normal operating range of ball mills is from 65 percent to 80 percent of solids by weight, depending on the ore. The viscosity of the slurry increases with the fineness of the particles, therefore, the fine milling circuits may need to be operated at lower densities.

The efficiency of the mill depends on the surface area of the mill. The balls should be the smallest possible and the load should be distributed in such a way that the biggest balls are heavy enough to mill the biggest and hardest particles in the feed. A balanced load, or seasoned charge, will consist of a wide range of ball sizes and new balls added to the mill are generally of the larger size. Very small balls leave the mill together with the milled ore and are generally separated by passing the discharge over a screen.



Trommel screen separates particles discharged from the mill

Excess water in the mill

Excess water washes the balls and reduces the mineral being hit by the balls, thus increasing wear and reducing milling efficiency. It also causes the slurry in the mill to flow too quickly through the mill, reducing the available grinding time to grind the ore to the desired size.

Excess water in the mill results in:

- increased production costs
- low density
- reduced mill efficiency
- low output tonnage of the mill
- excessive consumption of balls and mill liners
- unscheduled stoppages for slack fasteners, ruptures of fasteners, fall of interior liners.
- high mill cost

Insufficient water in the mill

Insufficient water in the mill causes the slurry to advance slowly, becoming more and more dense. The balls don't mill as mud tends to cake around them, preventing the desired grinding impact between the balls.

The lack of water in a mill results in :

- thick and bad mill
- unscheduled stoppages
- high density
- poor milling operation caused by mud sticking to the balls muffling the blows
- reduced tonnage output in the mill

The required frequency and quantity of additional balls loaded into the mill depends on the following

- time of operation of the mill
- tonnage of ore milled
- size of the ore at the entrance of the mill
- particle size required by the plant
- hardness of the feed ore

The maximum and minimum loads of the mill can be limited by the following

- lack of water in the mill
- poor regulation of the feed rate
- maintenance of the lifter bars and the internal lining system
- excess load in the mill

Very low density in the discharge of the mill can be due to

lack of water in mill

- tonnage increase in the mill
- poor regulation of water in the mill

Tonnage losses in the mill are caused by:

- unscheduled mill stoppages
- poor operation of the feed conveyors
- uncentered feed conveyors
- faulty rollers in feed conveyors
- slack electronic switches in the feed conveyors
- faulty feeding due to continuous layer in the chute

Assembly of the mills

- The centre of the motor must be very level.
- The centre of the electric motor and the drive pinion must be properly aligned.
- The gear wheel must be properly aligned.
- The drive pinion and gear wheel must have engagement within tolerance accounting for the rotation of the mill.
- Fasteners, nuts, cotters and all material that influence the gear alignment must be correctly fitted and tightened.

The best product for the next process

After slurry is discharged from the SAG mill, it passes into the trommel screen. The trommel screen consists of a cylinder, attached to the mill, fitted with a screen with grooves generally around 13 mm wide by 50 mm long. Particles smaller than this size pass through the screen into the pump feed sump, where it is picked up by the mill pump and pumped to the hydrocyclones. These hydrocyclones are usually located high up in the mill building above the mill. This material contains not only the finely milled mineral, but also most of the water of the slurry in the discharge of the SAG mill. Spray water is also added to improve the efficiency of screen. Once in the pump feed sump, this finer material enters the classification circuit, while the material that cannot pass through the trommel screen is usually lifted by the rotation of the trommel into a discharge chute. This material is discharged on a belt to be recycled back to the mill.

Each SAG mill is usually driven by two large, variable speed synchronous motors driven through variable frequency controllers. Each motor is coupled to a drive pinion by means of pneumatic clutches. The use of a variable speed drive allows the operator to optimize the efficiency and the yield of the mill, while minimizing the damage to the mill as load conditions vary. There is no such operational control available with fixed speed mills.

The SAG mill discharge enters the cyclone feed pump (mill pump) to be pumped to the hydrocyclones for classification. Fine particles meeting the size criteria for down stream processing, typically 115 to 150 microns, are discharged from the overflow of the cyclone with the coarse underflow returning to the milling circuit for further grinding.

Basic slurry pumping and system evaluation

Introduction

This section is not intended to be a definitive reference on hydraulics and slurry pumping. Excellent references such as the Weir Minerals Slurry Pumping Manual are available elsewhere which deal with this complex topic in much more detail. The purpose of this section is to explain some of the general terms and basic parameters used in mill circuit slurry pumping and pump selection to enable readers unfamiliar with this engineering field to better understand references to slurry pumping made throughout this manual.

Slurry

In solids handling via pumping, solid matter is mixed with a liquid carrier (usually water) to form slurry, i.e. a mixture of liquid and solid particles, large or small.

Slurries can be divided into two general groups: Settling slurries or Non Settling slurries.

Settling slurries are formed by coarser particles and tend to form an unstable mixture requiring particular attention to flow and power calculations. These coarser particles generally have higher wearing properties and cover the vast majority of mill pumping applications. These types of slurries are generally referred to as being heterogeneous.

Non-Settling slurries entail very fine particles which can form stable homogeneous mixtures. These slurries usually have very low wearing properties and are not normally found in milling circuits.

In calculations associated with slurry pumping in this manual, the following symbols are used: the SG (Specific Gravity) of the solids is S , the SG of the liquid is S_w . The SG of the mixture is S_m . Two additional parameters are used: Concentration of solids in the mixture by weight C_w [expressed as a percentage] and Concentration of solids in the mixture by volume C_v [expressed as a percentage].

There are five inter-related variables, which are used with slurries. *Table 3.1* lists all the equations for calculating any one of the variables from other known values.

For water use $S_w=1$.

Divide all C_w and C_v values by 100 – (if expressed as percentages) – before using them in the tabulated equations.

For any slurries, when any three of the five variables are known, the fourth and fifth may be calculated from the equations shown.

Flow rate

The volume of slurry to be transported in a pipeline by a mill pump over a specific period of time defines the flow rate required in any given mill pumping application.

In mill circuit pumping, the flow rate (Q) is generally determined by a correlation of the following four factors :

The solids Specific Gravity (SG)

The tonnage of solids being fed to the mill (TPH)

The concentration of solids required in the slurry mixture (C_w percentage or C_v percentage)

The recirculation load of solids within the mill

Head

All centrifugal pump output can be determined in terms of flow rate (Q) and head (H).

Head is the term used to indicate the theoretical vertical height over which the flow rate is lifted above (or below) the pump centerline.

The Total Head (H) requirement at a nominated flow rate for any given mill pumping system will comprise a number of factors including the following key elements:

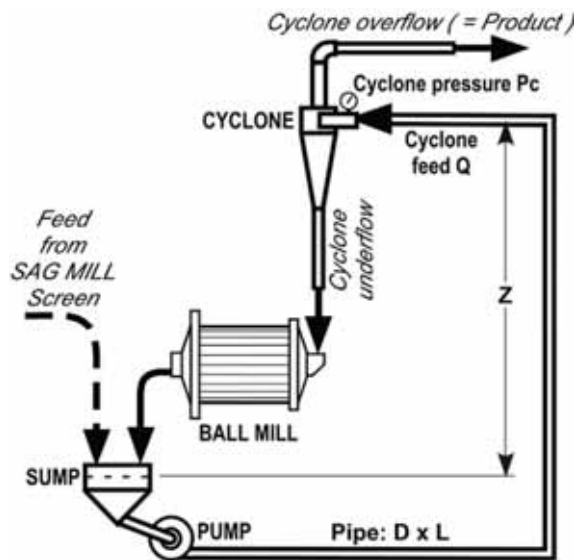
Static head (Z) – the actual vertical height over which the slurry is to be lifted from the free surface of the liquid prior to the intake of the pump of the pump to the slurry discharge point

Pipeline system friction loss (H_f) – Friction loss caused as the slurry drags against the inner surface of the pipe system. This is expressed as an equivalent head which must be added to the static head to determine the total head required to be developed by the pump.

Cyclone pressure (P_c) – The terminal pressure required at the cyclone to achieve the desired cyclone performance – this is also usually converted to equivalent head and, likewise, must be added to the static head to arrive at the required total head of the pump.

The pipeline system

The pipeline system is defined as every element of the system used to transport the slurry from the free surface of the liquid prior to entry into the pump to the free slurry discharge at the end of the pipe system. The total pipeline system will included all straight pipe, bends, valves, enlargements, contractions, tank entry points and anything else included between the entry and discharge points. When estimating the friction loss within a pipe line system, all these elements must be taken into account.



Typical ball mill, pump and cyclone circuit

Head and Efficiency correction factors

Centrifugal pumps are tested using clear water as a means of determining the basic performance characteristic of each specific pump type, model and variant. When solids are introduced into water to form slurry, the solids will have a varying impact on the performance of the pump compared to when it is operating on clear water. This can be partially explained by the fact that the carrying liquid (usually water) needs to pass around the particles at a slightly faster velocity than the particle to maintain the particle in suspension. This slip between the liquid and the particle is virtually non-existent in very fine particles, but becomes more pronounced as the particles become larger. Slip also becomes more pronounced as the particle density increases. Losses within the pump also increase as the slurry concentration increases.

There is no scientific method for calculating the impact of slurry on the performance of centrifugal pumps, but empirical methods have been developed which enable reasonably reliable estimates of the impact of specific slurry type on the clear water performance of a centrifugal pump.

These corrections to both pump head and efficiency are known as the head (HR) and efficiency (ER) correction factors. They are applied to the calculated system requirements and the clear water performance of the pump to arrive at the required pump head and power requirements to pump that particular type of slurry. The key factors used in assessing HR & ER are: particle size (usually expressed as the d50 sizing), the solid's SG, and the concentration by volume of the slurry.

Typical HR and ER correction factors for large mill circuit installations can range from 0.8 to 0.95.

Limiting settling velocity

Most slurries containing particles predominantly greater than 50 microns are generally considered settling (heterogeneous), which is the case in virtually all mill circuit pumping applications.

Slurries containing solid particles essentially coarser than 50 microns are transported in suspension by a liquid in a pipe, providing the average velocity— V , is no less than the limiting settling velocity V_L . At any velocity below V_L , solids are deposited in the pipeline. This results in increased pipeline friction head loss with reduced flow rate and may lead to a blockage of the pipeline.

In most mill pump applications, the pipeline length is relatively short with the majority of it being sloped upward or vertically. Large particles are less likely to settle against the direction of the flow and the selection of the optimum pipeline velocity is less critical than for longer slurry pipeline applications. Sufficient pipeline velocity is still required to maintain a turbulent flow and carry large particles which can sometimes include metal ball scats or fragments often found in mill circuits. A pipeline velocity above 3 m/s is generally used for larger mill pump applications.

Net Positive Suction Head (NPSH) considerations

Cavitation is a phenomenon that adversely affects the performance of a centrifugal pump and must be avoided during normal operation. The onset of cavitation in a pump, at any given speed and flow rate, is brought about by a particular combination of temperature and pressure at the pump suction flange. The absolute total head is called the Net Positive Suction Head or NPSH. The letter P tells us that NPSH, by definition, can never be a negative number.

Vapor Pressure is the pressure acting on a body of liquid at which the liquid boils at a particular temperature.

Water passing through a centrifugal pump is subjected to low and high pressure zones. The lowest pressure exists at the eye of the impeller. If this pressure falls below the vapor pressure, local boiling takes place, generating masses of tiny vapor bubbles within the liquid just past the leading edges of the pumping vanes. If this condition exists within the pump, it is said to be cavitating. This condition can cause damage to occur in some pumps. Most mill circuit pumps are made of highly erosion-resistant materials and physical damage within a mill circuit pump due to cavitation is rare. Cavitation does, however, cause the pump performance to deteriorate with reduced head and efficiency, adversely impacting the pump output.

As most mill circuit pumps are positively fed from gravity sumps, cavitation is not normally a problem unless the pump is drastically undersized. Cavitation can become a real problem with mill pump installations operating at high altitude. In these situations, the reduced

atmospheric and vapor pressure can lead to cavitation in mill circuit pumps in spite of the fact that the pumps may be positively fed from a gravity sump.

Where a mill circuit installation is proposed at a location that is greater than 1,000m above sea level, careful consideration must be given to the calculation of the NPSH available to ensure that the chosen pumps will operate under those conditions without cavitation.

Pump system and duty evaluation

The required duty and proposed pumping system must be fully determined prior to any consideration being given to selecting which pump best meets the duty requirements. As mentioned at the beginning of this section, this manual is not intended as a definitive reference for detailed slurry pumping calculations.

Key factors required to fully evaluate a specific duty and pump system can be summarized as follows:

- Required pump flow rate
- Solids SG, concentration and sizing
- Installation altitude, liquid temperature and pH
- Inlet and discharge static head
- Full details of the proposed pipe system to enable the calculation of the system friction loss and minimum velocity
- Required cyclone feed pressure.
- Details of available power

For more details on this topic refer to the Weir Minerals Slurry Pumping Manual.

Mill Circuit Pumps

Introduction

The mill circuit pump is often described as the “heart” of the milling circuit —nothing moves in a milling circuit without the mill circuit pump.

Mill circuit pumps are almost universally of the centrifugal type, specifically designed for this most aggressive duty. Due to the size and type of particles normally required to be pumped by a mill circuit pump, erosive wear within the pump is the most critical design consideration. Some mill circuit pumps have been known to operate for as little as 500 hour cycles due to the extreme wear experienced within the pump unit. Large state-of-the-art mill circuit pumps, such as the Warman MC, can often achieve +5,000 hour cycles in SAG / Ball mill applications due to their superior wear resistant materials and hydraulic designs specifically developed for these very arduous duties.



Warman 400 mcr mill circuit pump

Critical factors for mill circuit pumps include :

Predictable wear life of the complete wet end – Most mill circuits operate over pre-determined milling cycles with periodic scheduled maintenance shutdowns. Unscheduled stoppages outside this cycle can equate directly to lost production, running into millions of dollars per hour in large plants. Any unscheduled stoppage caused by the mill circuit pumps can therefore be very costly and far outweigh the cost of individual failed components or even the complete pump unit. It is essential that the complete pump give reliable and predictable wear life within the set milling cycles of the plant. If a planned milling cycle is set at 4,000 hours, it is essential that every component of the mill circuit pump is capable of

consistently running in 4,000 hour cycles without stoppage. Even a small component failure during this time would be equated to a complete pump failure.

Sustained output and efficiency throughout its wear life

– Due to the extreme wear that mill circuit pumps are subjected to during their normal cycle life, the internal hydraulic profile of the pump can change dramatically through its service life as it moves from new to fully worn condition. These dramatic changes in the internal profile of the pump and the impeller can have a profound impact on the output and power consumed by the pump. It is essential that the mill circuit pump can not only operate at a high efficiency when in new condition, but also sustain a high efficiency throughout its full wear life. Large mill circuit pumps can be fitted with drive motors of up to 2000kw and every point of pump efficiency can be equated to many thousands of dollars in power costs. Warman MC mill circuit pumps, for instance, are designed not only to sustain their efficiency throughout their wear life, but also have a patented side liner adjustment feature which enables the running clearance within the pump to be maintained to the optimum position even while the pump is in operation.



New Warman mill circuit pump impeller compared to a worn impeller after pumping 5 million tons of ore. The worn impeller efficiency had reduced by just 3 percent during its wear life

Ease of maintenance and part replacement – Due to the nature of programmed milling cycles as described above, most mill circuit pump maintenance and overhauling is done during the very short mill shut down period. Mill circuit pumps must therefore be very easy to maintain with readily available replacement parts necessary to carry the pump through to the next maintenance cycle quickly and easily fitted.

Large Warman MC mill circuit pumps have the facility to remove and replace the entire wet end of the pump in one single piece in the space of a few short hours, when rapid change outs are required to meet plant maintenance requirements.

Lined versus unlined mill circuit pumps

All mill circuit pumps are of the centrifugal type and can be broadly divided into two categories of lined and unlined pumps.

Lined pumps include replaceable inner liners made from either resilient elastomer or a very hard cast alloy, housed within an outer supporting casing. The casing provides the overall structural strength of the pump allowing the inner liners to be worn to their fullest extent without compromising the strength and pressure rating of the pump.



Warman 450 MCR elastomer lined mill circuit pump on SAG mill service

Unlined pumps, on the other hand, are manufactured in hard cast alloys which not only provide adequate wearing capability to achieve an acceptable service life, but also maintain sufficient pressure ratings even when in a weakened worn condition, thereby preventing the pump from bursting or cracking during operation.

There are pros and cons for the use of both styles in specific situations. Previous traditional thinking tended to categorise lined pumps for ball mill applications, while rubber liners and unlined hard metal pumps were for AG and SAG mill applications. The rationale behind this traditional thinking was that rubber liners provided superior wear life in applications with relatively small particles, but would not stand up to the larger particles typically found in AG and SAG mill applications. Large unlined metal pumps were commonly used in these applications, allowing very thick metal sections to be cast into the casing without the constraint of a surrounding casing.

Dramatic advances in elastomer technology and pump design have now enabled elastomer lined pumps to move into the previously all metal domain of SAG mill circuit pumping. The very thick and specially formulated elastomers available today, for instance in the Warman

MCR range, consistently outlast metal pumps in most SAG mill duties with lined rubber pumps becoming very much the standard for this service.



Warman 550 MCU unlined mill circuit pump in service

Unlined metal pumps still have their niche, but they are becoming more rare as elastomer technology continues to advance to withstand cut damage and provide superior erosion resistance to ever increasing particle sizes.

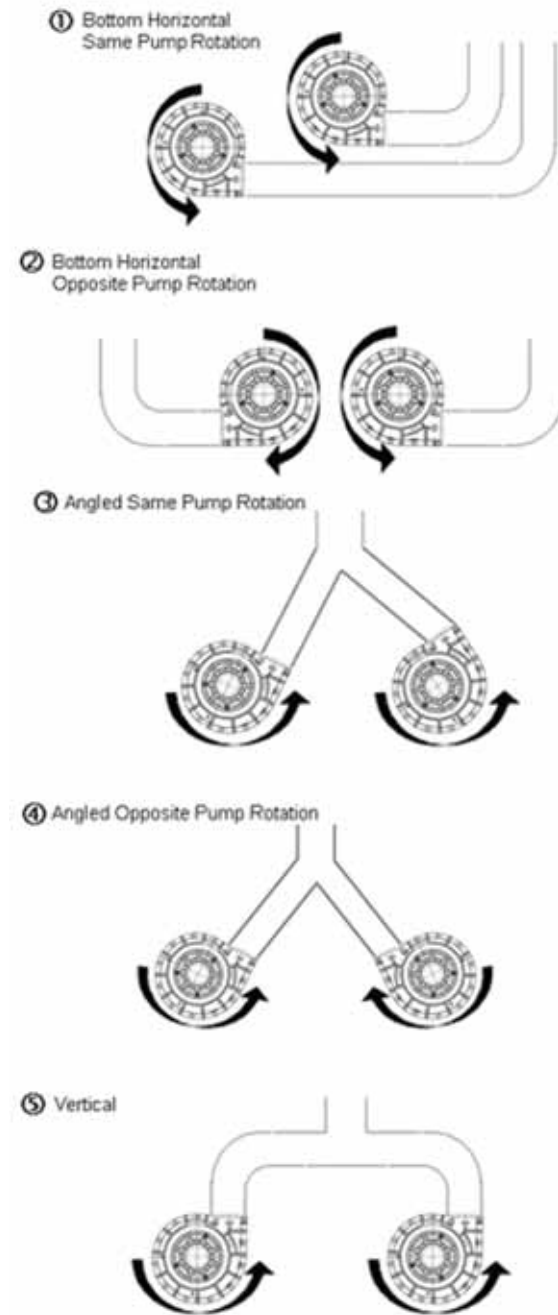
Pump Discharge Orientation

Debate often rages as to the optimum discharge orientation for mill discharge pumps, particularly when two or more pumps are located immediately adjacent to each other and/or when operating with standby pumps installed. There are many conflicting factors that can influence this decision such as:

- Convenience and simplicity of the plant layout
- Installation
- Access
- Design and position of the feed sump
- Location of the classifying cyclones
- Overhead lifting
- Maintenance
- Pump performance and wear
- Piping layout and wear
- System drainage

Most typical alternatives are shown in the diagrams on the the opposite page.

Some of the advantages and disadvantages of several common discharge orientations can be summarized as follows:



Bottom horizontal discharge with the same pump rotation

This is generally considered to be the best layout from a pump performance and wear point of view. It tends to preclude the accumulation of coarse solids and mill ball scats within the pump. A sliding bed of entrapped coarse solids and mill ball scats can often build up within mill pumps with vertical or sloping discharge orientation thus increasing wear within the pump, increasing the risk of blockage and impacting on pump output.

One disadvantage of this arrangement is that the discharge piping must travel through a full 90° turn before heading vertically to the cyclone cluster. This could potentially increase pipe wear if the pipe bend radius is too tight. However, long radius elbows will reduce this effect.

Bottom horizontal discharge with opposite pump rotation

This arrangement is sometimes preferred for plant layout reasons and also provides the wear and performance benefits outlined above. You do, however, have to have two different impellers and pump bearing assemblies due to reverse impeller threads between the two pumps. The remaining parts are interchangeable between the pumps. The differing pump rotations can also pose a risk of incorrect motor rotation during installation, potentially exposing the pumps to reverse start-up damage. Care must be taken to check this prior to pump commissioning..

Upward angled discharge with the same pump rotation

This arrangement is commonly used where an operating and standby pump are installed sharing the same single discharge pipe up to the cyclone cluster. It provides a convenient piping layout but can, in some circumstances, allow the formation of an entrapped sliding bed of coarse solids which can contribute to premature wear within the pump.

Upward angled discharge with the opposite pump rotation

This arrangement is sometimes used for plant layout reasons, but has the disadvantages outlined above combined with the disadvantages outlined for arrangement 2.

Vertical discharge with the same pump rotation

Sometimes used for smaller pump installations where operating and standby pumps are connected to the same, common discharge pipe. This arrangement is not recommended for larger mill pump installations.

Total Ownership Cost

In determining the cost of owning an item of capital equipment, such as a mill circuit slurry pump, many different factors need to be considered.

While the initial purchase cost is obviously important, it generally represents only a very small proportion of the overall Total Ownership Cost (TOC) incurred during the lifetime of the pump. The TOC includes, not only the cost of the replacement parts required to periodically refurbish the pump, but also includes other less visible costs such as the cost of power consumed, the cost of providing the required maintenance, the cost of lost production caused by unexpected or longer than necessary production stoppages, and numerous other hidden costs which are not often taken into consideration during an initial or subsequent purchase decision.

With an understanding of the cost structure of the plant in which the pump is operating, and predictive or actual data on the wear of the various component parts, it is possible to build a comprehensive picture of the total life cost of owning the pump. Weir Minerals have developed a Total Ownership Cost (TOC) model to enable comparative evaluation of the estimated total life costs of different pump units.

The Weir Minerals TOC model

The TOC of a slurry pump is the sum of the various costs:

- capital costs - Cc
- energy costs - Ce
- maintenance costs - Cm
- service water costs - Cw
- inventory costs - Ci
- availability costs - Ca
- overheads - Co

$$TOC (\$/y) = Cc + Ce + Cm + Cw + Ci + Ca + Co$$

Full details of the Weir Minerals TOC model can be found in Weir Minerals Technical Bulletin No. 32.

Example calculation

Weir Minerals have set up a spreadsheet (QikTOC) which enables ownership cost to be easily predicted between alternatives and various scenarios. The TOC (in \$/y) for each individual pump is calculated by summing the individual costs. If the pump has a standby, then the actual operating hours per year for each pump must be used in calculating the part consumption and number of change-outs, etc.

Example of TOC calculation		
Total ownership cost	Cyclone feed costs	Cyclone feed costs
Capital	\$26,800	13%
Energy	\$129,946	61%
Water	\$392	0%
Maintenance	\$50,617	24%
Inventory	\$1,669	1%
Availability	\$0	0%
Overhead	\$3,944	2%
TOC (\$/Y)	\$213,400	
TOC (\$/T)	\$0.13	

The overall TOC can be normalized for tons solids handled by the pump (\$/t/pump) or for tons processed by the plant (\$/t overall) as shown in the example.

TOC Summary

TOC analysis is a very useful tool for continuous improvement of mill circuit pump costs. It enables a reference to be determined using all the costs that are incurred. Changes to the pump or system can then be planned with an estimate of the potential savings in mind, and a measured base from which to judge results.

TOC analysis is also useful for comparing different pumps at the time of purchase to ensure that the lowest cost (not necessarily lowest price) unit is selected.

Mechanisms of wear

Abrasion

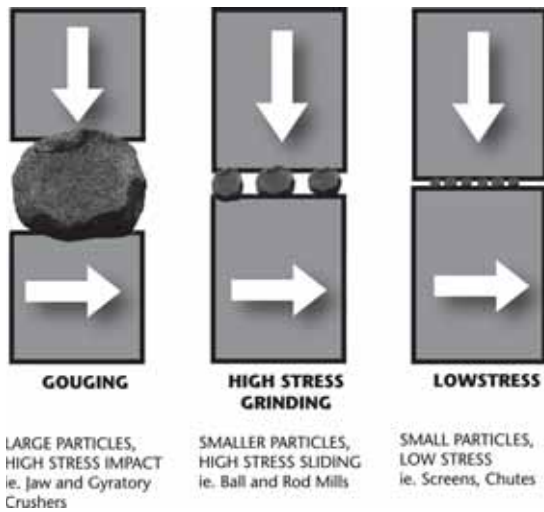
Abrasive wear occurs when hard particles are forced against, and move relative to, a solid surface. The 3 major types of abrasive wear are:

- Gouging
- High Stress Grinding
- Low Stress Grinding.

In a centrifugal mill circuit pump, abrasion only occurs in two areas:

- Between the rotating impeller and the stationary throatbush, and
- In between the rotating shaft sleeve and the stationary packing.

Abrasion, although often used to cover all types of wear, is quite distinct to erosion.



Three main modes of abrasive wear

Erosion

In mill circuit slurry pump applications, the dominant mode of wear is erosion. Erosion is a form of wear involving the loss of surface material by the action of particles entrained in the fluid. Erosion involves a transfer of kinetic energy to the particle, which does not occur in abrasion.

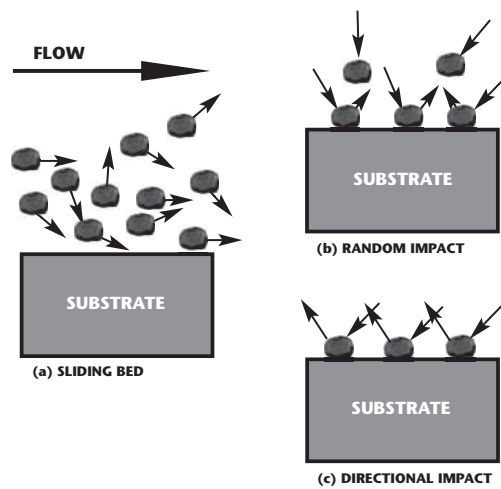
The transfer of kinetic energy from the particle to the surface results in a high contact stress. While the overall contact pressure at each impact site is small, the specific contact pressure is high, because of the irregular shape of the particles.

There are three basic types of erosion

- sliding bed
- random impact
- directional impact.

Pump impellers, side liners and volutes wear due to quite different mechanisms:

- Pump impellers are subjected to a combination of direct impingement (on the leading edge of the vane and at the base of the vane where it joins the back shroud), sliding bed wear and low angle impingement (along the vanes and further inside the passage between the shrouds).
- Side liners are mainly subjected to sliding bed wear and some low angle impingement.
- Volute are subjected to direct impingement on the cutwater and sliding bed erosion around the periphery.



Three main modes of erosive wear

Corrosion

The corrosion of metal results from the breaking down of essential properties due to chemical reactions with its surroundings. In the most common use of the word, this means a loss of electrons of metals reacting with water and oxygen. Since deterioration depends on electrical factors, as well as chemical factors, it is an extremely complex phenomena. The basis of the corrosion process ($Fe \rightarrow Fe^{3+} + 3e^{-}$, in the case of iron) corresponds to the action of the anode in an electrochemical wet battery cell. At the surface of the anode, an electrical charge is transferred from the metal to the liquid (electrolyte). The electrons removed from the region of the anodic reaction flow to the cathode, which then serve as the source of electrons for the cathodic reaction. The electrode reactions vary greatly, depending on the nature of the corroding material and of the corrosive environment.

There are many different types of corrosion, some of which are: uniform; galvanic; crevice; pitting; intergranular; selective leaching; stress and erosion/corrosion. The latter is the most important in slurry applications because the two effects (erosion and corrosion) work together and are often difficult to identify separately.

Warman MC range of Mill Circuit Pumps

The Warman MC range of mill circuit pumps is the culmination of more than 60 years of experience though prior Warman and ASH Pump models operating in many thousands of mill circuit applications throughout the world.

Unlike its predecessors, the Warman MC range has been specifically designed just for mill circuit applications.

Since its introduction, the Warman MC range has become the clear leader worldwide in arduous mill circuit applications. This enviable reputation has been hard won through many proving-trial installations where Warman MC mill circuit pumps have consistently outperformed all other brands.

The Warman MC range boasts three different model variations.

- Type MCR – This designates the fully cased rubber liner version which is the most commonly used MC type used in mill circuits
- Type MCU – This designates the uncased, all metal version of the MC range generally used for applications where rubber liners cannot be used. (See figure 4.3)
- Type MCM – This designates a fully cased, metal lined version used in some specific cases where clients prefer to use a fully cased pump, but where rubber liners have proven unsuitable.

Note: *this model variation is currently only available in the 750 size).*

MC range features are as shown in the following brochure:

WARMAN®
Centrifugal Slurry Pumps

MC Mill Circuit Duty

Excellent
Minerals
Solutions



Warman MC mill circuit duty slurry pumps are designed for the most aggressive duties and provide excellent wear life and reliability.



Warman 400 MCR

- Large diameter, low speed, high efficiency impellers
- Latest wear resistant materials
- Interchangeable elastomer or metal liners, or unlined metal
- Simple “full face” side liner adjustment
- Self centering stuffing box design
- Fast “one-piece” wet-end changeout on larger sizes

Hydraulic experience and latest material technology make Warman MC the best choice for mill circuit applications

Warman MC pumps easily manage large size particles in dense abrasive slurries and are specifically designed for the most severe slurry applications such as ball mill and SAG mill cyclone feed and water-flush crushing in mineral processing plants. They are also suitable for use as slurry transfer pumps on arduous applications such as gravel dredging or coarse coal cyclone feed.

MC pump hydraulics are based on more than 25 years of fundamental and applied research and backed up by wear performance field trials. Unique design and wear evaluation software ensures high efficiency and optimum life.

Warman MC designs incorporate the latest in hard alloy and elastomer technology, extending wear life in highly abrasive and corrosive slurries.

The MC range is engineered to enable different material combinations

MCR pump – elastomer liners inside ductile iron outer casing with metal impeller and metal or elastomer throatbush and frame plate liner insert

MCU pump – all metal unlined hard white iron casing with metal impeller, throatbush and frame plate liner insert

MCM pump – hard white iron metal liners inside ductile iron outer casing with metal impeller, throatbush and frame plate liner insert

Left: Chile's large copper plants continue to improve their installations. A 550 MCR pump has replaced a North American manufacturer

Middle: 450 MCR installed at a gold plant in North America

Right: Copper gold installation in Australia using the 550 MCR pump



Right: Three Warman 550 MCR mill circuit pumps being installed at a copper mill along with Cavex hydrocyclones, Isogate slurry valves, and Vulco wear resistant rubber lined tanks, piping, hoses and spools



Engineered for severe duties, the Warman MC pump draws on years of proven mill circuit application experience

South American copper mines pioneered the use of rubber in large mill pumps and the majority of these plants now use Warman MCR elastomer pumps for mill discharge (cyclone feed) duties. In trial after trial, Warman elastomers have outperformed all competitors' cast metal pumps.

The advantages are many as Warman MCR elastomer liners:

- handle coarse particles and last longer
- handle ball scats with ease
- are lighter in weight and safer for maintenance
- are lower in cost than heavy metal parts

So whatever the preference – for a rubber or metal pump – the Warman MC pump will ensure the best wear life.

Lined or unlined mill pump options ensure the optimum cost solution for your application

The outer casing of the lined MCM all metal pump ensures slurry containment and allows a safe shutdown in the event of a liner crack. This provides a low risk alternative to plants concerned with casing breakage due to mill ball overflow.

The unlined MCU metal range perfectly fits duties such as dense media circuit applications in the coal washing industry. Very thick metal casings, an impeller design for larger particle passing, and the "full face" adjustment feature ensure extended life with coarse coal slurries.

With the range of designs available, the MCU can be used in even the largest of the new high capacity coal washing plant installations. The MCU metal cased design can also be used for gravel pumping type applications. Longer wear life and lower operating costs are ensured.



Above top: A gold plant in Canada replaced a competitor's pump with a 150 MCR

Above bottom: 450 MCR at a copper installation in South America



Left: A large copper gold installation in Argentina has upgraded our existing 450mm pumps to the latest 450 MCR design



Left: Cover plate of a 550 MCR about to be installed at a copper plant

Right: One of two new 550 MCU pumps installed at a copper plant in Brasil

Warman MC pump's unique design allow interchangeability of materials to optimise wear life



Only one pump manufacturer allows operators the flexibility of all-metal or all-rubber lined or a combination of both

The MC is the only pump for mill circuit applications that has interchangeable materials from a wide range of hard alloy and compression moulded elastomers. This enables optimum materials selection for each specific application ensuring the wear characteristics for each component are balanced.

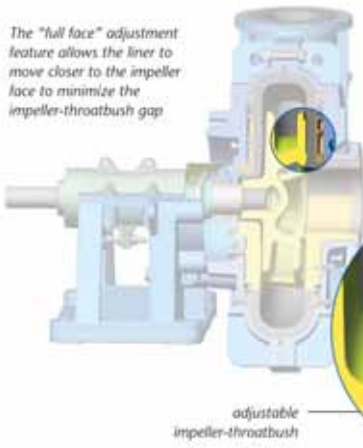
Warman MC mill circuit duty slurry pump has a number of unique features

Reduced recirculation is achieved by the deep expelling vanes on the front of the hard alloy impellers. Expelling vane tip turbulence is minimised by the patented extended shroud feature that traps tip vortices and prevents localised scouring on the throatbush face.

Internal liners can be fully worn before replacement as the split outer casing provides structural integrity and high operating pressure capability.

Split cover and frame plates allow easy access for replacement of the impeller and throatbush.

"Full face" adjustment extends wear life



The "full face" adjustment feature allows the liner to move closer to the impeller face to minimize the impeller-throatbush gap

In addition to deep expelling vanes on the impeller, adjustable throatbush and frame plate liner insert are necessary to maximize part life. As slurry moves through the throatbush-impeller gap from the high pressure at the impeller periphery to the low pressure of the impeller eye, local high velocities can cause wear at the face or around the impeller eye.

The Warman MC's "full face" adjustment feature extends wear life by minimizing the impeller-throatbush gap across the whole face of the throatbush. This provides gradual pressure reduction and minimal recirculation so any possible wear is distributed evenly, unlike sacrificial wear rings used by some manufacturers at the impeller eye that may focus wear and cause premature failure.

The "full face" double adjustment for throatbush and frame plate liner insert is easy to perform, even during operation, ensuring long liner life and optimum efficiency. Once clamping screws are released, adjusting screws can be rotated sequentially to move the liner closer to the impeller face.

“One-piece” wet end changeout ensures minimum mill downtime

Larger MC pump wet ends can be changed out and replaced as “one-piece”. By adjusting the throatbush and frame plate liner inserts tight against the impeller, mounting bolts can be removed, the impeller can be unscrewed from the shaft and the outer casing, liners and impeller pulled off as “one-piece”. Impeller and liner inspection can then be completed at a more convenient time in the workshop.



Above: A new innovative quick change device has been developed for faster removal of the larger MC range pump wet ends. A 650 MCR wet end being removed in Santiago, Chile



Stuffing Box Centering

Adjustable stuffing box allows for centering of the stuffing box and lantern restrictor to the shaft sleeve. This may be adjusted after piping loads have been applied to the pump to compensate for associated casing displacement.

Left: Orange centering tool pins align stuffing box to the sleeve

MC features save time and money

Easily adjustable throatbush allows maintenance of the impeller seal face clearance without the need to adjust bearing assembly or drive.

Easily adjustable frame plate liner insert allows maintenance of the drive side clearance and sealing performance to protect the stuffing box.

Large, open internal passages reduce internal velocities thus reducing wear.

A large diameter shaft with the shortest possible overhang and heavy duty roller bearings housed in a removable bearing cartridge extends bearing life.

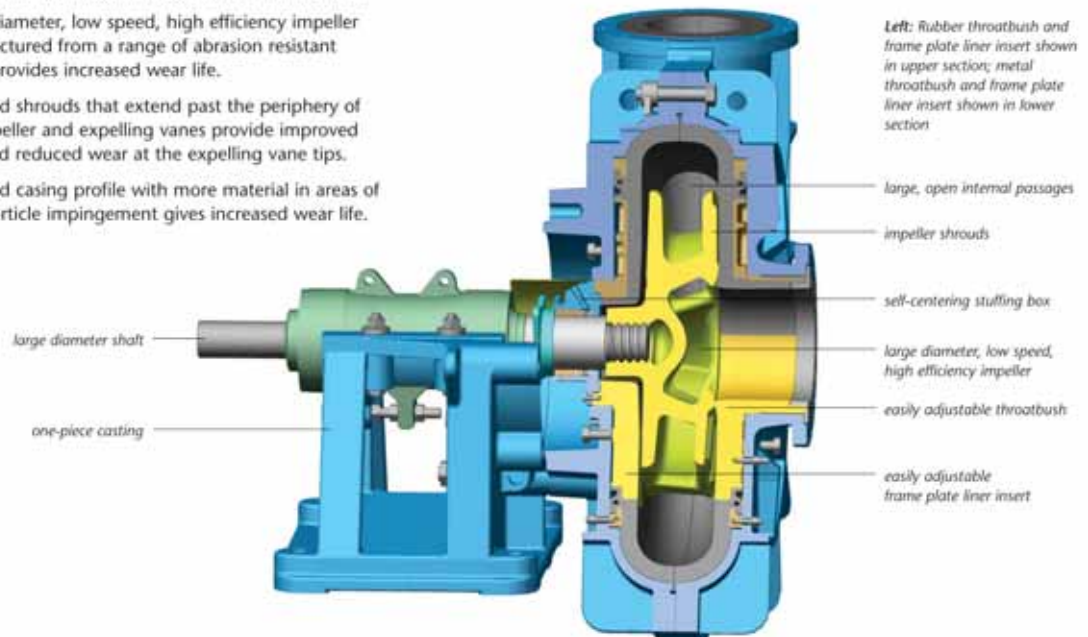
Large diameter, low speed, high efficiency impeller manufactured from a range of abrasion resistant alloys provides increased wear life.

Patented shrouds that extend past the periphery of the impeller and expelling vanes provide improved flow and reduced wear at the expelling vane tips.

Patented casing profile with more material in areas of high particle impingement gives increased wear life.

Simple impeller adjustment using a robust one-piece casting cradle that the bearing cartridge assembly can slide onto reduces set-up time.

Reversible casing allows the discharge orientation to be either “right vertical” position (standard) or “left vertical” position, and so gives greater flexibility to the plant layout designer. The only additional parts required to effect the changeover are the clockwise rotation impeller and shaft.



Left: Rubber throatbush and frame plate liner insert shown in upper section; metal throatbush and frame plate liner insert shown in lower section

large diameter shaft
one-piece casting

large, open internal passages
impeller shrouds
self-centering stuffing box
large diameter, low speed, high efficiency impeller
easily adjustable throatbush
easily adjustable frame plate liner insert

Warman MC mill circuit duty slurry pump is available in a range of sizes.

Product information software developed by Weir Minerals Pump Technology Center

Weir Minerals product information software is available on CD from the local sales office or for download at weirminerals.com.



Technical reference sections are available on the CD version of wiCAT.

Above: A 550 MCR pump about to be installed at a copper plant in Chile

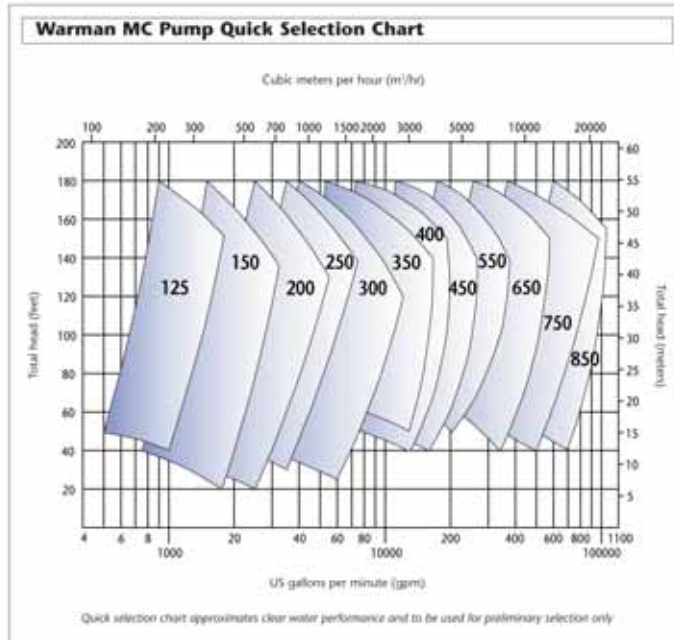


Above: A 350 MCR which replaced a competitor's pump in Mexico



Left: 400 MCR pump undergoing performance testing at Weir Minerals North America test laboratory in Madison, Wisconsin

Below: 400 MCR pump after assembly at Weir Minerals North America. Pump destined for installation at a copper plant in Arizona

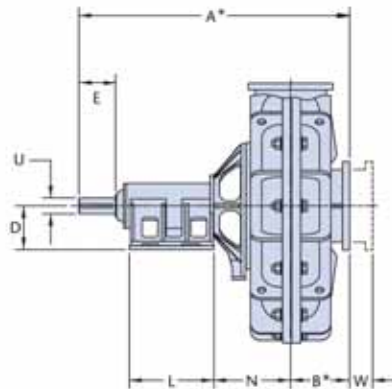
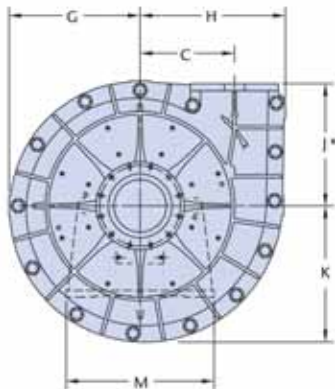


Three photos below: Sequence showing the fit up of a 400 MCR wet end

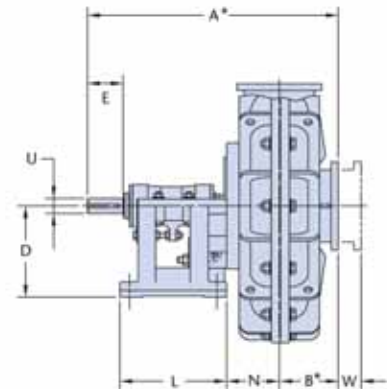
Above: 350 MCR for a large Russian iron ore dressing plant

Warman MC Pump Dimensions (millimeters)																		
Fixed bearing assembly																		
Pump	Size	Type	Frame	A*	B*	C	D	E	G	H	J*	K	L	M	N	U	key size	W
125	(6x5)	MCH	M80	1240	206	240	205	220	378	412	385	384	380	620	389	80	22x14	64
150	(8x6)	MCU	M80	1283	243	351	205	220	533	569	532	554	380	620	190	80	22x14	400
200	(10x8)	MCR/U	M100	1670	335	485	255	290	700	728	745	740	453	880	547	100	28x16	460
250	(12x10)	MCR/U	M100	1742	390	560	255	290	824	868	850	847	453	880	563	100	28x16	350
300	(14x12)	MCR/U	M120	2142	381	629	310	316	940	1020	879	980	699	1048	651	120	32x18	870
350	(16x14)	MCR/U	M120	2168	404	697	310	316	1030	1123	970	1077	699	1048	655	120	32x18	390
400	(18x16)	MCR/U	M150	2541	510	801	405	344	1148	1281	1156	1199	770	920	687	150	36x20	450
450	(20x18)	MCR/U	M150	2485	580	930	405	344	1293	1431	1207	1345	770	920	761	150	36x20	850
550	(26x22)	MCR/U	M180	2870	680	1025	450	349	1406	1550	1322	1479	824	1200	880	180	45x25	850
Adjustable bearing assembly																		
Pump	Size	Type	Frame	A*	B*	C	D	E	G	H	J*	K	L	M	N	U	key size	W
125	(6x5)	MCH	EEAM	1200	206	240	457	222	378	412	385	384	448	622	240	85	22x14	64
150	(8x6)	MCU	EEAM	1247	243	351	457	222	533	569	532	554	448	622	265	85	22x14	400
200	(10x8)	MCR/U	FF	1670	335	485	610	290	725	752	745	740	705	990	383	120	32x18	460
250	(12x10)	MCR/U	FF	1742	390	560	610	290	824	868	850	847	705	990	399	120	32x18	350
300	(14x12)	MCR/U	GGAM	2010	381	629	851	357	940	1020	879	980	876	1219	393	150	36x20	870
350	(16x14)	MCR/U	TU	2262	404	697	900	350	1030	1123	970	1077	1050	1460	502	150	36x20	390
400	(18x16)	MCR/U	TU	2412	510	801	900	350	1148	1281	1156	1199	1050	1460	520	150	36x20	450
450	(20x18)	MCR/U	TU	2468	580	930	900	350	1293	1431	1207	1345	1050	1460	520	150	36x20	850
550	(26x22)	MCR/U	U	3180	680	1025	900	455	1406	1550	1322	1479	1375	1440	610	240	56x32	850
650	(30x26)	MCR/U	U	3343	758	1200	900	455	1645	1853	1554	1755	1375	1440	709	240	56x32	730
750	(36x30)	MCM	V	4106	850	1500	1250	445	1910	2290	2250	2130	1875	2040	765	280	63x32	890
850	(40x34)	MCR	V	4200	900	1500	1250	445	1990	2245	2050	2060	1875	2040	800	280	63x32	890

* Includes compression of rubber flange joint.
 Consult outline dimension drawings for size and location of mounting holes. Dimensions are for reference only.
 Note: Casing dimensions are symmetrical around vertical centerline should the "left vertical" pump orientation be used.



Fixed bearing assembly



Adjustable bearing assembly

Warman MC range significant installations



Case History 1

PT Newmont Nusa Tenggara (PTNNT) Batu Hijau, Sumbawa, Indonesia

Trial Objectives

The purpose of the trial was to evaluate the rubber lined Cyclone feed pump to match the total plant shut maintenance strategy of four x thirteen (13) week.

Other factors to be reviewed included power consumption.



Mining Operations Description

Batu Hijau is an open pit Copper and Gold mine located on Sumbawa Island Eastern Indonesia. In December 2003, Batu Hijau’s ore reserves were 1 billion tons containing 0.525 percent copper and 0.37 gram per ton gold. At the current production rate, Batu Hijau’s mine life will continue until 2025. PTNNT is currently exploring other parts of its Contract of Work area such as the Elang prospect. PT NNT employees 4,200 people directly, and another 3000 contractors on site.

Installation Details

Run-of-mine (ROM) ore is about 1.2 meters in diameter (maximum size) and is delivered to the crushers by truck from the mine. There are two gyratory crushers operating in parallel. The crushers reduce the ore to approximately 80 percent (P80) minus 175 mm. The ore is conveyed 6.5km to the processing plant.

The grinding circuit consists of two x 36 ft Semi Autogenous Grinding mills and four x 20ft Ball mills. Cyclone feed pumps deliver the 65-70 percent Cw Slurry to four clusters of 9 x 26” Hydrocyclones.

The Cyclone overflow product is forwarded by gravity to a Scavenger flotation system. The product froth is further cleaned, concentrated and washed before being pumped by GEHO TZPM500 Positive Displacement pumps via a 17.6 km pipeline to a filter plant at the port site. Tailings are deposited by deep ocean outfall 3.6km off shore at a depth of 300m.

Duty information	
Flow m ³ /hr	4700 /7300/8000
Total head (m)	33 / 34 / 35
Specific gravity - slurry	1.59
Specific gravity - solids	2.8
Concentration of solids in slurry, by weight	65%
P80 (avg. particle size)	0.85mm
Max particle size	14mm

Pump information	
Model	650 U-MCR
Pump speed	255 / 269 / 275
Motor power	1500 KW

Average wear life (hours)		
Component	Warman rubber liners w/ metal impeller	Competition* all metal
Suction liner (Throatbush)	3360+	1178
Wear ring	N/A	1178
Impeller	2200+	1750
Casing liners	3360	2033
Back liners	3360+	2033

* Average of three pumps
+ Significant residual life

Trial/Operational Results

The all the Wet end components easily achieves the minimum 13 week shutdown period.

R55 Rubber liner components wear very evenly in the coarse particle slurry, without sights of premature cutting and tearing, delivering longer wear life.

Further improvements in Throatbush and Impeller life can be achieved with monitored Throatbush adjustment.

Impeller efficiency was maintained through the complete period of operation with significant reduction in power.

Casing Liners achieve almost two complete operation periods.

Financial Results.

Savings for meeting planned plant shutdown = USD 344k per annum. If one pump continually fails to meet planned shut down.

Savings on wear components =USD183k per pump per year.

The Warman pump had a greater volumetric throughput with the same power consumption as the competitor's pump. Boosting the plant concentrate output.

The Business Conclusion

PT Newmont Nusa Tenggara now have 3 off operating Warman 650 U-MCR pumps plus one being manufactured which converts all Cyclone feed pumps to WARMAN.



Pump casing liner and throat bush at 13 week inspection.

Case History 2

Grupo Penoles Francisco I. Madero Mine, Zacatecas, Mexico

Installation

Grupo Penoles runs an underground mine and concentrator of 8,000 TPD named Francisco I. Madero. The plant is located within the province of Zacatecas in Mexico. Their primary product is Zinc with secondary production of lead.



The mill installation includes one SAG Mill which feeds two Ball Mills. Two Ball Mills feed one sump. Each sump has one cyclone feed pump, plus a standby, feeding a cluster of six 20" cyclones. Four cyclones are in continuous operation.

The original installation was commissioned in July 2001 fitted with two competitive pumps which featured metal impellers and rubber liners.

The competitive units achieved an average of 1,447hrs of operation per pump. Multiple leakage problems in the back liner and stuffing box were common.

Bearings were also failing due to the slurry getting into the assembly. Operating cost was calculated at \$147.00/hr. The pumps were changed to an alternative competitive model.

The first alternative pump had a casing fracture at 464hrs and a failure in the inlet door at 1,789hrs.

Two other smaller, all metal and rubber lined competitive models were installed which failed at 640 and 987 operating hours respectively.

Weir Minerals was invited to provide a solution of improving pump wear life. Our Mexican team surveyed the site and found the real operational conditions at the plant to be lower than the originally specified flow. They determined that the Warman 300 MCR was the right pump for the job, but the on-site engineers were desperate to improve performance as quickly as possible.

The only available option on short notice was a 350 MCR fitted with elastomer liners and an impeller in ultrachrome metal. We took the opportunity and shipped one pump to the site on December 2001. The pump was commissioned in January 2002. Even though the pump was not the optimum choice for the duty, after 1,780hrs continuous operation, the pump had performed so well that the client accepted the pump and allocated Weir Minerals an order for further units. Ultimately, the liners completed 4,000hrs while the Impeller exceeded more than 5,000hrs.

Summary of mill cyclone feed pump testing

Life	Competitive Pump Types Tested (hours)					Weir
	A	B	C	D	E	
Pump						350 MCR
Wet end*	1447	1789	640	897		
Liners / casings					2500	4000
Impellers					2500	5000

Case History 3

Codelco Teniente Mine Rancagua, Chile

Trial Objectives

The main aim was to evaluate our Warman 350 MCR's performance, installed on a ball mill discharge duty, against the original incumbent competitive pump.

Mining Operations Description

Teniente Mine is a division of Copper National Corporation (Codelco-Chile), placed in the sixth region near to Rancagua, at an altitude of 2,700 m above sea level.

The production is 132.000 tons/day, mainly copper concentrate and molybdenum.

Milling production is in the Sewell plant (6 small ball mills), Conventional plant (12 ball mills), and new mill with 2 SAG mills plus a unitary ball mill.

Our 350 MCR was installed on the unitary Ball Mill in SAG Plant N#1.



Installation Details

The grinding circuit of the Plant N#1 is a SAG Mill of 36 x 15 foot and two ball mills of 16 x 24 foot.

The original pump installation had several problems from the beginning, such as bearing housing problems (bearing failures), high wear on the metal lining (suction plate and impeller) and plus the sealing system for

the pump gland. On the sealing system, if the pressure dropped below 45 psi, the seal system would fail, resulting in burnt packing rings and major wear to shaft sleeves.

Test History and Results

Wear life (hours)		
Component	Warman Rubber liners Metal Impeller	Incumbent All metal
Suction liner	2300	1200
Impeller	4300	2100
Drive liner	4300	
Casing liners		2600

Duty information	
Flow m ³ /hr	1700-1900
Total head (m)	27.7-25.6
Specific gravity - slurry	1.7
Specific gravity - solids	2.62
Concentration of solids in slurry, by weight	66%
Solids D50 mm	50 mm

Pump information	
Model	350 MCR
Pump speed	255 / 269 / 275
Motor power	1500 KW

Trial Results

Operational Results

- Higher wear life of our rubber suction liner, lasting 2300 hrs, i.e. nearly double of the Metso metal part at 1200 hrs.
- The wear life of our parts is always consistent, allowing a proper maintenance schedule.
- The high quality of our field services offer a higher availability and reliability of our equipment.
- Less energy consumption compared to the competitor's pump

Financial Results.

- US\$ 30.000 / year estimated only considering the rubber lining per each pump.
- Savings for meeting planned shut downs.
- Increase of production due to a higher availability of the pumps.

The Business Conclusion

Objective achieved with ALL the pumps installed in the SAG plant N#1 now Warman 350 MCR. Furthermore, decision taken to remove the incumbent pumps in ALL remaining mill applications (400 & 550 MCR pumps being installed).

Hydrocyclones

Introduction

The critical role played by the classification device in any milling circuit has been discussed in previous sections. Numerous devices have been used over the years but far and away the most common classification device use in milling circuits is the hydrocyclone. This section covers some of the basics in relation to hydrocyclones.

Definitions

A cyclone is a simple conically shaped vessel with a tangential inlet and two outlets at either end of its axis. Cyclones are a continuously operating classifying (sizing) device that uses centrifugal force to accelerate the settling rate.



Two Cavex hydrocyclone clusters

Hydrocyclone is a sub-class or specialised application of a cyclone whereby the process stream is a liquid, generally with suspended solid particles, i.e.. a slurry. The common purpose of the hydrocyclone is to separate or classify sub-sieve size solid particles according to their size.

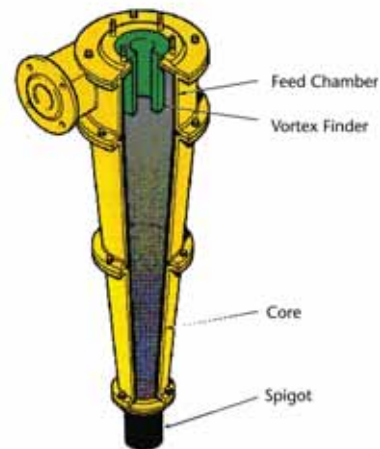
For brevity, this manual will use the term cyclone to mean hydrocyclone.

CAVEX® is the registered trademark name for the range of cyclones developed by Weir Minerals specifically for grinding circuit applications.

Spigot, also referred to as an apex, is the outlet at the apex end of the cyclone. Commonly, it is a simple short cylindrical part, the internal diameter of which is varied to suit the performance required. The size of the spigot has the greatest effect on the underflow density.

Underflow is the fluid stream which discharges from the spigot. Cyclones are most commonly operated in a vertical orientation so that the spigot discharges

vertically downward to produce the “underflow”. In slurry applications, the underflow contains the coarser solids produced at the higher density.



Three main modes of erosive wear

Overflow. Correspondingly the fluid stream, which discharges through the Vortex Finder at the cylindrical end of the body of the cyclone, is referred to as the “overflow”. In slurry applications, the overflow contains the finer solids produced at a lower density

General

The hydrocyclone is a simple device, most commonly used for separating or classifying solid particles in a liquid medium or slurry.

Unlike a screen, which employs a fixed dimensional limit on the particle size allowed to pass, the hydrocyclone separates the solid particles according to their relative settling rates. However, rather than using gravity as the accelerating or settling force as in a settling tank, the separation action in a hydrocyclone is induced by the centrifugal force created within the cyclone body.

The inherent settling rate of a slurry is dependent on particle size grading, shape, viscosity of the liquid, and most importantly, the relative density and concentration of the solid particles in the slurry.

Fluid Flow & Particle Motion in a Hydrocyclone

Except for the region in and just around the inlet duct, the motion of the fluid within the cyclone body has circular symmetry. Most of the incoming fluid moves in an outer helical flow to the outer portion of the cone where it begins to feed across toward the centre. Some of the downward flow leaves through the spigot, while most of the flow reverses its vertical direction component via an inner helical flow and discharges out through the vortex finder.



Internal profile of the Cavex hydrocyclone illustrating the effects of the full circle, three dimensional curvature

A comparatively minor flow pattern short circuits along the top of the feed chamber and around the outside of the vortex finder to join the rest of the fluid in the overflow.

Solids particles within the slurry are accelerated outward toward the walls of the cyclone body by centrifugal force. This force is greatest on the particles of greatest mass (i.e. greatest size or relative density). As a result, the coarser, heavier solids migrate toward, and along, the inner wall of the cyclone to leave with some liquid as the underflow. The finer, lighter solids are largely entrained by the drag force of the liquid and leave the cyclone with most of the liquid via the overflow.

A proportion of all size particles (equal to the water split) will also be entrained by the liquid in the underflow and is considered a bypass or unclassified portion. This portion of fine particles (slimes), misreporting to the underflow, can be reduced by maximizing the underflow density.

Cyclone Separation Performance

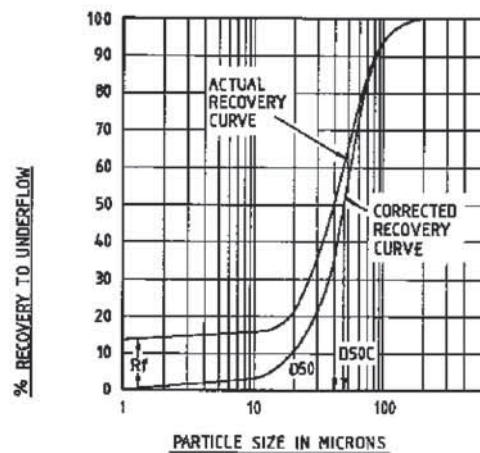
The common measure of the separation between the fine and coarse solids is the d50, commonly referred to as the cutpoint.

D50 is the particle size diameter for which 50 percent by mass reports to the underflow. Solids progressively larger than D50 have a probability greater than 50 percent of reporting to the underflow.

Another measure of separation in a cyclone is the proportion of liquid reporting to the underflow compared to that in the feed. This is referred to as the “water split” and is commonly denoted ‘Rf’.

The efficiency of separation is most usefully expressed as a graph of the percentage of solids reporting to underflow versus the particle size and is referred to as a Tromp Curve or Recovery Curve.

The Recovery Curve is S-shaped, passing through the cutpoint and intersecting the Y axis (percentage reporting to underflow) at a value equal to the water split. This can be understood by considering that all very fine particles are insufficiently distinct from the liquid molecules, and thus will be separated in the same ratio as the liquid separates; i.e. as defined by the water split (Rf).



Typical cyclone efficiency curve

The water split can vary considerably according to the operating conditions and cyclone geometry and can be manipulated accordingly. As such, it is common to remove the effect of the water split from the efficiency definition by correcting the recovery curve so that it passes through the origin.

The corrected efficiency curve is defined by the equation -

$$R_c = \frac{R_a - R_f}{100 - R_f}$$

- Where R_c = Corrected recovery
- R_f = Water split
- R_a = % Actual recovery

Operational Variables

Operational variables are the factors external to the cyclone which affect the performance of the cyclone.

Feed Solids Concentration

Usually expressed as percentage of solids by weight (abbreviated Cw), the proportion of solids in the feed slurry has a substantial effect on the classification performance of the cyclone. In principle, the higher the percentage of solids, the coarser the cutpoint (higher D50). For example, an increase in solids from 5 percent to 20 percent by volume will approximately double the cutpoint of the cyclone.

Pressure

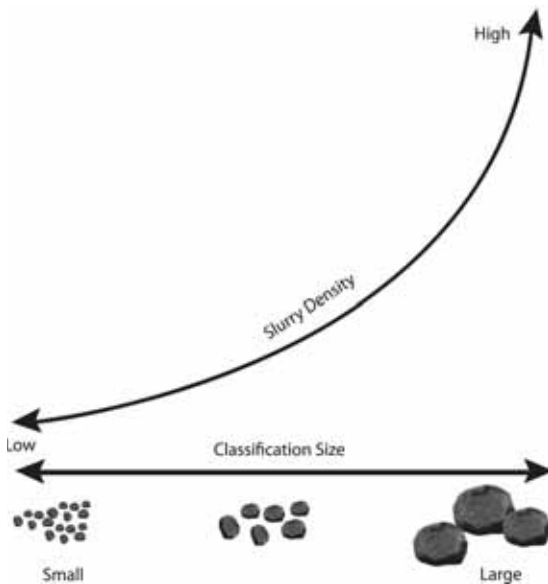
The pressure required for the correct operation of a cyclone varies according to the size of the cyclone and the application. It is important that an accurate pressure gauge be located on the feed distributor or the feed pipe adjacent to the cyclone inlet, to provide a constant indication of the operating pressure.

The pressure reading should be:

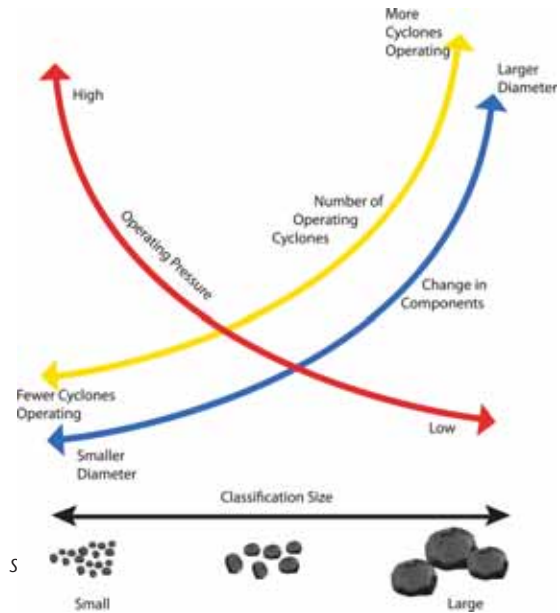
- Steady, indicating a constant feed
- Within the designed operating range, usually 50 to 150kPa depending on the application.

A change in feed pressure will affect the classification performance and the water split of the cyclone.

Generally, the higher the pressure, the finer the separation and the lower the water split.



Slurry density



Cyclone spigot discharge

Cyclone Variables

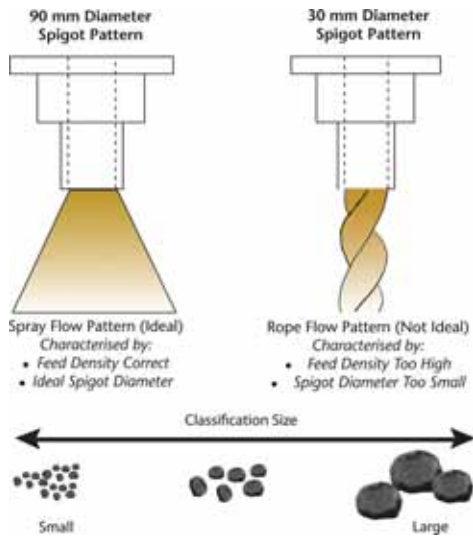
Cyclone variables are the various dimensional options available for each cyclone model and include

- Inlet Diameter
The inlet section is rectangular in shape and is an integral part of the feed chamber liner

The area of the rectangular section is equivalent to the area of a circle, the diameter of which is referred to as the "equivalent inlet diameter" and denotes the inlet size

Some CAVEX® models have a range of inlet diameters from which to select, according to the performance and capacity required.

- Vortex Finder Diameter
There are a wide range of diameters available for each cyclone model. The vortex finder size has the greatest effect on cyclone performance for any given cyclone size, vis a vis. the smaller the vortex finder, the finer the classification and the lesser the capacity of the cyclone.
- Spigot Diameter
The spigot diameter is generally the most convenient variable to adjust or change and can be considered the "tuning" variable once a cyclone is installed



Cyclone spigot discharge

The spigot diameter has greatest effect on the underflow density of the cyclone. In general, a decrease in spigot diameter will increase the underflow density and improve the efficiency of the classification. However, take care that the spigot diameter is not reduced to the extent that a “rope” condition prevails. A Rope Flow Pattern indicates that the spigot is overloaded and that the volume of solids reporting to the underflow is too high and a larger spigot is required.

Installation requirements

General

The cyclone must be supported by the mounting plate, or mounting feet provided. No external loads should be applied to the cyclone.

The cyclone should be installed in a manner to ensure ready maintenance access, particularly to the spigot.

Cyclones are generally installed with their axis vertical. Cyclones performance is affected when the cyclones are inclined greater than 45° from the vertical. For horizontal or inclined cyclones, a minimum angle of 10° - 15° depending on cone angle between the cyclone axis and horizontal is advised. To ensure the cyclone will self drain on shutdown a minimum angle of 5° is suggested.



Cyclone spigot spray



Rope flow pattern from a spigot with a diameter which is too small

Feed Pump

The majority of cyclones are fed via a centrifugal pump connected to a hopper or tank. The pump and the hopper must be designed to deliver a constant flow of slurry to the cyclone at the required pressure. Fluctuations in the cyclone feed will affect the cyclone’s performance.

Cyclone Feed Pipe

The cyclone feed pipe must be the same diameter as the cyclone inlet flange (or feed matching piece). The length of the feed pipe must be at least equal to 10 pipe diameters. It is not recommended to have any bends closer than 5 pipe diameters ahead of the cyclone.

Isolation Valve

The cyclone isolation valve should be a full bore type, such as a slurry knife gate valve (e.g. a Weir Minerals Iso-gate® WS valve), a pinch type valve, or a standard knife gate valve with polyurethane or ni-hard flow deflector cones. Valves should not be used to throttle the flow to the cyclone as the resulting turbulence will affect the efficient performance of the cyclone and rapidly wear the valves.

Pressure Gauge

It is recommended to install a pressure gauge on the feed distributor or cyclone feed pipe, adjacent to the inlet (refer Section 5.6). The type most commonly selected is a 100mm diameter, stainless steel body, with a full deflection of 0-250kPa. A large diameter (50mm) diaphragm type gauge protector assembly is essential for the effective utilization of the gauge.

Overflow Pipework

Overflow pipework must maintain the diameter of the cyclone overflow connection and contain only large radius bends to direct the flow downward.

Usually, the overflow pipe is short, discharging directly into a collection launder or tank at a level between the cyclone inlet and the spigot.

Note: *The overflow pipes should not be reduced in diameter or directed upward as this will create back pressure and thereby significantly affect the performance of the cyclone.*

Underflow

The cyclone underflow must discharge into an open launder or collection box. No restrictive pipework should be attached to the spigot.

Design of the underflow launder should allow easy visual observation of the spigot discharge spray so that the plant operator is not impeded in checking the underflow condition and detecting any blockages. Access to change the spigot liner should also be considered.

The point of impact of the underflow spray on the walls of the launder is subject to high abrasive wear and should be protected by suitable material.

Cyclone Cluster

If more than two cyclones are required in parallel circuit, the cyclones should be installed in a radial configuration around a central feed distributor to ensure an even flow distribution to each cyclone.

Such configurations are referred to as clusters (also known as cyclopacks, or nests) and are usually integrated with common overflow and underflow launders. In-line manifolds can provide uneven distribution and are usually only considered for use on fine, very dilute slurries.



Typical hydrocyclone cluster

Correct cluster design is an important element in the successful operation of multiple cyclone installations. Weir Minerals can engineer individual cluster design for particular installation requirements.

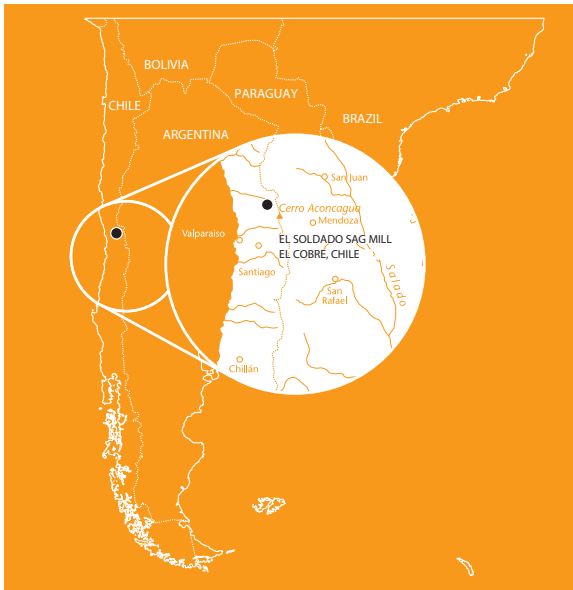
Typically, clusters have four mounting points or feet attached to the overflow tank or underflow tank, upon which the total load of the cluster is distributed.

Case History 1

El Soldado SAG Mill El Cobre, Chile

Current Operation

The El Soldado operation, processes a copper ore which main mineralogical species in order of importance are; Chalcopyrite (40%), Bornyte (30%), Chalcosite (5%), Pyrite (25%). Their two main Facilities are the mine El Soldado and the concentrator plant El Cobre.

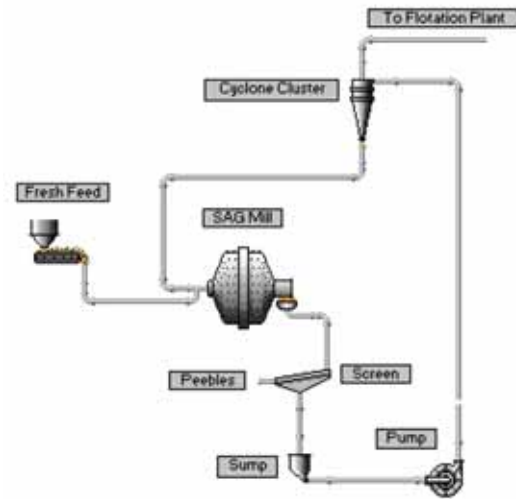


Trial Installation Details

A four month evaluation trial was set, starting in early 2001, in order to compare CAVEX 650CVX against Krebs D26B.

Installation details

This 18,500-tpd operation uses a 34 x 17' SAG mill (15,000 HP) in close circuit with a cluster of 8 conventional 26B inches cyclones, five of them in operation. The SAG mill discharge is screened and the pebbles generated are crushed in a separate crushing plant. The screen discharge is pumped into the hydrocyclone cluster and the cyclone underflow is returned into the SAG mill feed. SAG Plant had one clusters of 8 x D26B. Initially the cluster, was fitted with 6xCAVEX 650CVX cyclones.



El Cobre SAG milling circuit

Trial Results of CAVEX 650CVX

During the last month of year 2000, a test trial using five CAVEX 650CVX was initiated.. The immediate result was a reduction in the number of cyclones in operation from five to four and a reduction in the pressure drop. The first month of operation strongly indicated a reduction of the +65# reporting to the overflow and a reduction in the by pass of fines. The CAVEX cyclone achieved these results with larger apexes (6" v. prior apex 5 3/4") confirming that the ramped inlet geometry of CAVEX increases the air core diameter, increases apex capacity and improves classification efficiency. Cyclones utilizing Cavex technology are less sensitive to roping and produce lower circulating loads.

SAG Mill Circuit Evaluation

CAVEX v. Conventional Hydrocyclones

The Classification Efficiency graphic shows the actual efficiency curve for CAVEX versus conventional hydrocyclones. It can be seen that CAVEX efficiency curve shows a lower by pass of fines and better sharpness of separation.

Statistical Operational Results

TPH SAG to Flotation

An increase in mass flow rate to flotation was also obtained when using CAVEX cyclones.

Trial Results

Just four cyclones were necessary to produce similar cut sizes and the pressure drop was slightly reduced. It was even possible to work with three cyclones, nevertheless it was decided to use four to have more stability in the operation. This means that a 33% increase in cyclone capacity was achieved.

The CAVEX hydrocyclone presented a better Total Classification Efficiency, characterized by a significant reduction on by-pass of fines, typically from 26,2% to 17,7%. Additionally, an improvement of sharpness of separation was achieved.

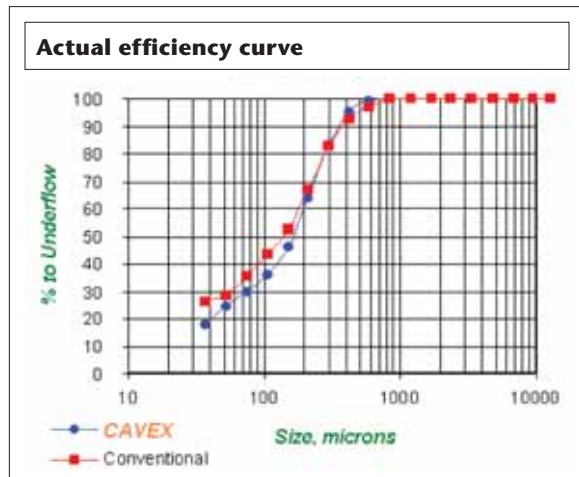
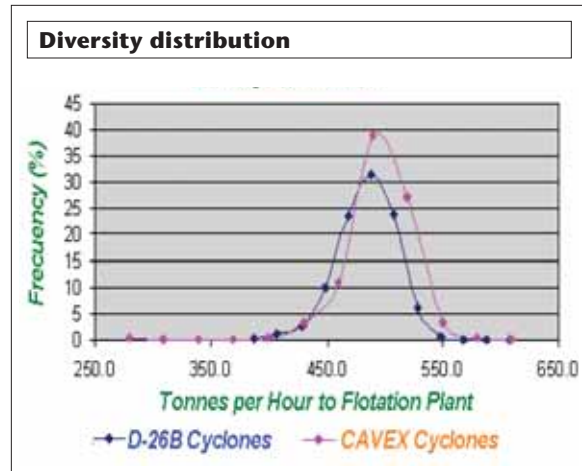
An increase in underflow density was obtained typically from 78% to 82%.

A new eleven inch diameter vortex design was evaluated. The results indicate that a slightly finer cut size was achieved and sharpness of separation was increased.

A significant reduction of pebble generation was obtained, typically from 212 tph to 184 tph, i.e..

An increase in the tonnage to flotation per ton fed to the SAG mill was achieved. The ratio between the tonnage to flotation per tonnage fed to the SAG mill went from 0.688 to 0.723.

Finally a total of 2 percent increase in plant capacity was achieved.



Case History 2

OK Tedi Mine Papua New Guinea (PNG)

Mining/Milling Operations

The Ok Tedi mine is 18 kilometers from the PNG/Indonesian border on Mount Fubilan, where the average annual rainfall is an incredible ten metres. Operations started in 1984 and mine closure is expected in 2010. Ok Tedi is the single largest business contributor to the economy of PNG.

In 2002, milled ore was 90000 tpd with an average grade of 0.82 percent copper and 0.8 g/t gold.



Cavex® trial outline

Ok Tedi required increased capacity of the cyclone installation without extra cyclones and without coarsening the grind.

Installation details

Ok Tedi have two grinding circuits called SAG1 and SAG2. The cyclone trials were conducted in the SAG 2 circuit. Cluster CS01 was fitted with ten CAVEX® 650CVX to be compared with ten competitive units.

Trial results of CAVEX v. competitive units

The following conclusions are from the paper "Evaluation of CAVEX® Hydrocyclone in the Ok Tedi Grinding Circuit" presented by BHP at the Seventh Mill Operators Conference in Kalgoorlie, Australia October 2000

"The Cavex® cyclones are operating with lower feed pressure than the competitive cyclones."

"Re-circulating loads have significantly reduced with the Cavex cyclones."

"Cyclone availability with the Cavex cyclones is high due to significant increase in liner life."

Efficiency curves from trial

The competitive cyclones in CS02 were replaced with an alternative competitive model. Ok Tedi commissioned an external consultant to conduct a survey to compare this alternative competitive model with the Cavex® in CS01. Some comments taken from that report are as follows:

"Two major differences between the CAVEX® and the competitive unit were apparent."

"Firstly, in all tests, the water split in the competitive unit to underflow was unacceptably high."

"Secondly, the scatter in the competitive unit values is much greater than that exhibited by the CAVEX® units"

Trial Outcome

Ok Tedi started replacing the remaining competitive cyclones with CAVEX® X

- SAG 1 circuit -All twenty cyclones replaced with Cavex® 650CVX
- SAG 2 circuit - Ten cyclones replaced with Cavex®650CVX
- Regrind circuit upgrade
- Fourteen Cavex® 500CVX10
- Thirteen Cavex® 400CVX10
- Ten CAVEX® 650CVX in CS01 cluster



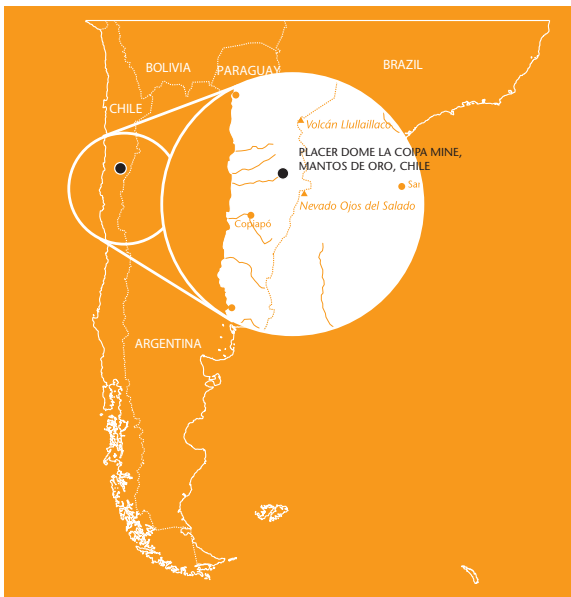
SAG Mill Circuit - Ok Tedi. PNG
Photo courtesy of Ok Tedi Mine CMCA Review

Case History 3

Placer Dome La Coipa mine Mantos de Oro, Chile

Mining Operations Description

La Coipa open pit gold and silver mine is located in northern Chile. The mine employs approximately 440 people and has a projected mine life of 6 years.



Trial Objectives

To allow a maximum P80 reduction in the overflow product, ideally without decreasing the plant capacity, by improving the hydrocyclone classification efficiency.

Installation Details

The processing plant consists of primary crushing, a pre-crushing circuit, (semi-autogenous ball mill crushing) grinding, leaching, filtering and washing, Merrill-Crowe plant and ore refinery. The Merrill-Crowe metal recovery circuit is said to be better than a carbon-in-pulp system for the high grade silver material. Tailings are filtered to recover excess water as well as residual cyanide and metal credits. A dry tailing disposal system was chosen over a conventional wet tailing impoundment for site specific environmental considerations.

The nominal throughput of the plant was over 17,000 tons per day.

The SAG-Ball mill plant had two clusters of competitive cyclones. Initially cluster #1 was fitted with five Cavex® 650CVX cyclones

Efficiency Characteristics

Cavex separation efficiency was better than competitive unit.

Trial results

The CAVEX® 650CVX produced a substantially finer product than the competitive unit without decreasing circuit capacity.

These results allowed the plant to reduce the P80 in 20 percent and keeping the same tonnage

Trial Business Conclusion

Mantos de Oro purchased two clusters of five CAVEX® 650CVX cyclones converting all existing cyclone clusters to Cavex.



Cavex 650CVX10° Hydrocyclone Cluster

Grinding Mill Circuit

The grinding mill circuit is dependent on each individual component operating at peak efficiency. In order to do this, high efficiency components such as Weir Minerals pumps, cyclones, valves, screens and hoses should be utilized.

An efficient cyclone can remove product from being re-circulated. Also on other circuits additional product can be recovered from the overflow, which would normally go to the tailings. The pump should be operating in the peak performance range.

The valves, screens and hoses shall be of low maintenance and long life design. All of this helps to increase the plant profitability.

particles could use. With the elimination of these 'fines,' the feed material will be coarse and create more wear, but overall grinding efficiency should improve.

Percent solids

Most grinding mills run at 50 to 65 percent solids, but some mills, like in the iron ore industry, run at 79 to 80 percent solids. It is best to run at the highest percent solids as possible. Every grinding circuit has optimum percent solids and this should be found by experience. This will get the most efficient grinding and less wear on the mill lining and grinding media. However, if the percentage of solids goes beyond this optimum point, the grinding will immediately stop. Control is very important.

Charge Volume

The designed charge volume should be maintained. Too high a charge volume will affect impact grinding and reduce capacity. Too low a charge volume will result in a lot of attrition grinding and increased wear on the grinding media and lining. In order to maintain the designed charge volume, grinding media may have to be added more frequently.

Mill starting and stopping

The normal procedure to start a mill is to start the mill first and after a timed delay, start the feed. Also when the mill is being shut down, the mill feed is shut down first and then after a time delay the mill is shut down. In both of these operations, the mill is running for a period of time without feed. This time delay should be minimized. The feed slurry acts as a cushion between the grinding media, the product media, and the lining. Without the slurry, the lining receives more impact and also the heat of mill is not removed. The result is increased wear on the grinding media and liner.

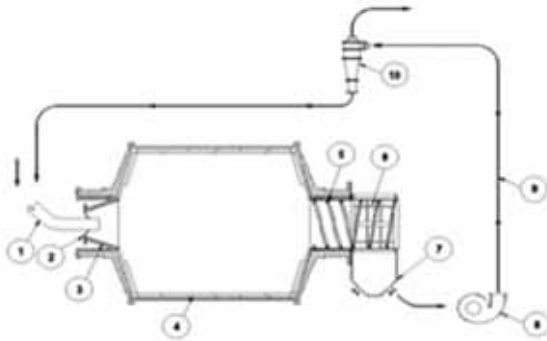
Mill speed

Most grinding mills have fixed speed drives, with the current design point at 75 to 76 percent of Critical Speed. However there are also many mills with variable and fixed speed drives that use higher speeds than this. In both cases, the liner has to be designed so that the trajectory is correct for the highest speed.

Ball Size

The most popular approach used for ball sizing is the Allis Chalmers correlation. This is a good theoretical approach. However, in actual operation, a slightly smaller size make-up ball could possibly be used to crush the largest particle.

Typical grinding mill circuit



- | | |
|-----------------------|-------------------|
| 1. Feed pipe | 6. Trommel screen |
| 2. Feed pipe seal | 7. Sump |
| 3. Feed trunnion | 8. Slurry pump |
| 4. Mill linings | 9. Piping |
| 5. Discharge trunnion | 10. Cyclone |

Grinding Mill Operation

The grinding mill, in itself, is an inefficient machine, but if it is operated according to the manufacturer's specifications it will produce a fairly consistent product size. But if 80 percent of the feed size (F80) is not consistent, then 80 percent of the product (P80) will not be consistent.

The following is a list of items to consider when trying to improve mill performance

Feed size distribution

If there are a lot of fine materials in the feed material going to the grinding mill, considerations should be made to separate these and bypass this grinding step. This fine material occupies volume in the mill that other larger

With a mill operating at its normal condition, take a representative product sample and do a sieve analysis to check the particle size distribution. Start adding the next smaller size make-up ball, while taking product samples and comparing with the original size distribution. If you do not see any change, start adding the next smaller size. Keep doing this until you arrive at a variation in the size distribution. Continue adding this size ball or you may have to go up to the next size to have some consistency. In some cases, you may have a size in the distribution that you want finer. In this case you may want to add two different sizes of grinding balls. With this method, the smallest ball possible is used to reduce the largest particle. When a smaller ball is used more balls can fit into the same volume which means more contacts and more grinding. The void area between the balls is also reduced. Also, with the smaller ball, there is less wear on the lining and grinding media. By decreasing the ball size by 10 mm, the quantity of balls is almost doubled.

Mill liner installation and maintenance

The main reason for mill liner maintenance is to keep the mill running at optimal performance for as long as possible. Less downtime means more mill availability for maximum tonnage. The following are some items that should be checked periodically or during lining installation in order to prevent long downtimes.

Trunnion filler rings

At the junction of the trunnion liner and the inside mill lining, a trunnion filler ring or some sort of packing material is used. Over the last few years, there have been quite a few mills that have worn through at this area because of “Slurry Racing” — the continuous passage of slurry over a given localized area creating a notch or groove wear characteristic. This area should be checked periodically so this racing does not occur. If any racing is seen in this area it should be repaired immediately to prevent mill damage. This is also true for trunnion liners. Some companies have added weep holes at the outside of the trunnion liner to detect any leakage

Tightness of liner

A rubber liner should fit snug against the interior of the mill. If there is any slurry build-up in the mill, it should be removed before a new liner is installed. The mill liner fasteners shall be torqued to the value on the liner drawing and then re-torqued after a few hours of operation to ensure that the liner is properly seated. During liner installation, the lifter bars shall be butted against each other and the all rubber shell plates shall be compressed at approximately 0.75 percent. This will ensure that racing does not occur at the joints and prevent premature liner wear at these areas.

Liner seepage

The rubber liner is designed to be watertight at the bolt holes, manholes, and trunnions. The mill should be stopped as soon as possible at any sign of leakage at any of these areas, and the problem corrected in order to prevent increased damage. Some seepage will get between the lining and the mill shell, but if the liner is installed properly this will not result in racing. If the slurry is very corrosive, a lining material needs to be bonded to the interior of the mill to protect the metal.

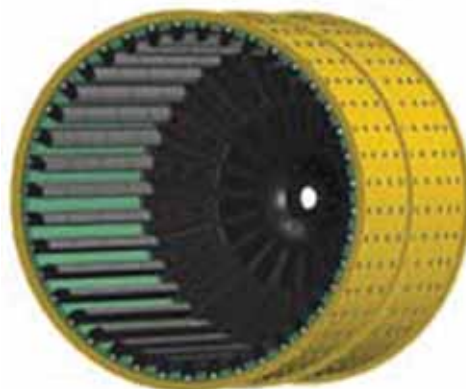
Wear readings

It is very important to know when the mill should be stopped to replace worn liner parts. In order to predict the change out times, periodic liner wear readings should be taken inside the mill. This is done by driving a known length of nails into the rubber plates and measuring the exposed length.

In order to get the profile of the lifter bars, wear profile tools can be obtained from Weir Minerals. Wear readings should be taken at a minimum of five locations. When taking wear readings, the operating hours and tonnages shall be noted in order to prorate the liner life and schedule change out times. Wear Data Sheets can also be obtained from Weir Minerals for recording the information. This can then be shown on a wear profile drawing supplied by Weir Minerals.

Mill liner design

A rubber mill liner is designed to protect the mill shell and create a proper grinding action within the mill charge. In order to get the optimum mill performance; the liner has to be properly designed. The following are some liner design items that require consideration.



Independent components

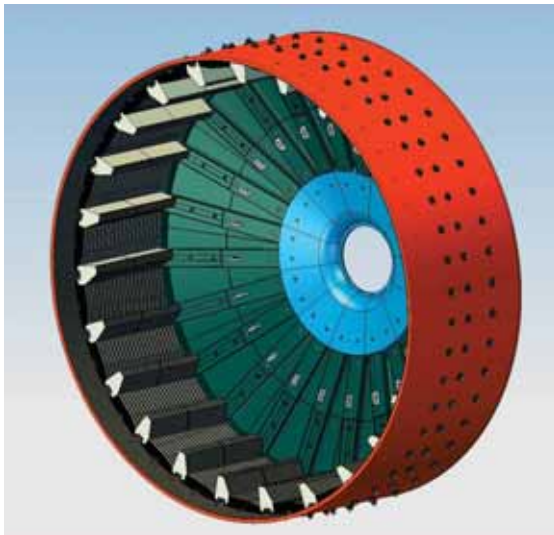
The rubber mill liner is designed with independent components and basically consists of bars, plates and hardware. These shall be designed to be removed independently of each other. The normal liner is designed to use two sets of lifter bars to one set of plates. However, by

taking wear readings and observing the wear patterns, in some cases, by adding additional rubber in strategic areas, a third set of lifter bars can be utilized.

Lifter bar face angle

In order to get the optimum grinding efficiency, the grinding media has to impact at the toe of the charge or below. If it is hitting above the toe of the charge, the media is hitting a bare shell (no slurry) wall and no grinding is taking place. By changing the face angle of the lifter bar, the grinding media can be made to impact at the toe or below.

Weir Minerals has single ball computer programs that can be utilized to show the proper lifter bar face angle. The proper face angle will increase production and prolong liner life.



Ratio of shell plate to lifter bars

The ratio of the shell plate width to the exposed lifter bar height should be around 3 to 3.5 kWh for mills running around 75 percent critical speed. This gives the optimum mill performance and liner life. If a liner design is not close to this ratio, in most cases, it can be brought back to this ratio by adjusting the shell plate thickness or lifter bar width or height. However, there is a proper lifter bar size and shell plate thickness for each set of mill operating conditions. Consult Weir Minerals for this information. The following shows the relationship of the A/B ratio Typical A/B Ratio Chart If the mill speed is higher than 75 percent CS, then the ratio would also increase and the high and low points of the curves would move to the right.

Wide Spacing

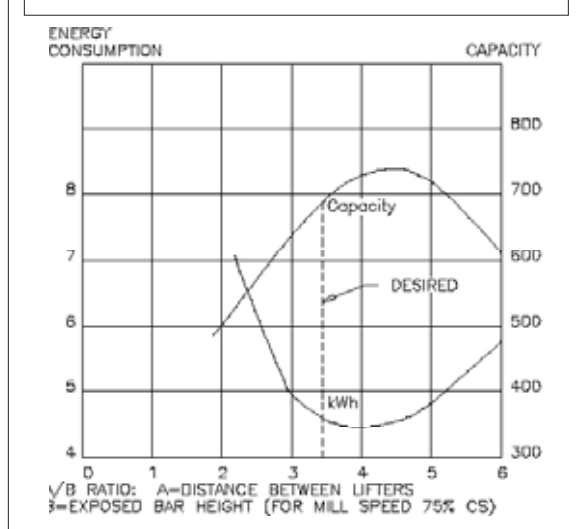
Some grinding mills have existing drilling that produces a very wide space between the lifter bars. In this case, a wide lifter bar could possibly be used to reduce the width between the lifter bars. However, if this is not

possible a step type shell plate could be used to reduce the sliding of the charge. Also a hump could be added in the center of the plate. Below is a typical section of the step-plate design.

Metal Capped Lifter Bars

In some applications, the grinding duty is very severe and a heavier service type liner is required. For this service, a metal capped lifter bar is recommended. Adjacent are some typical metal capped lifter bars.

Typical A/B ratio chart



Line over manholes

On some mills, the manhole areas have seen a problem with leakage and premature wear of the lining materials. This causes excess mill outages and maintenance costs.

Many of the larger grinding mills have mill access through the trunnion openings. In these cases, the manhole openings can be lined over. This will help to increase mill availability and lower maintenance costs.

Even if it is desired to have manhole access for a major relining, the manholes could be a line-over design. If this option is desired, the manhole row is removed first and is the last to be reinstalled. This is assuming the trunnion opening is large enough to make the final exit when the installation is complete.

Conclusion

In the grinding mill circuit there are major components with many variables. In the mill itself, the efficiency is often indicated by the power consumption (kWh/t). The ore type is a key component of this, but the feed size, ball load, charge level and mill speed also play an important part as well as the other variables discussed in this bulletin. Every time one variable is changed, the circuit has to be re-balanced. So only one variable should be changed at a time. Since each component is

dependent on the other, all components selected should be of a high performance calibre, such as WMD pumps, cyclones, valves and mill linings. There are many suggestions for improvement presented in the bulletin. If only one has been selected and made some improvement in the efficiency of the grinding circuit, then the bulletin has served its purpose and its goal has been met.

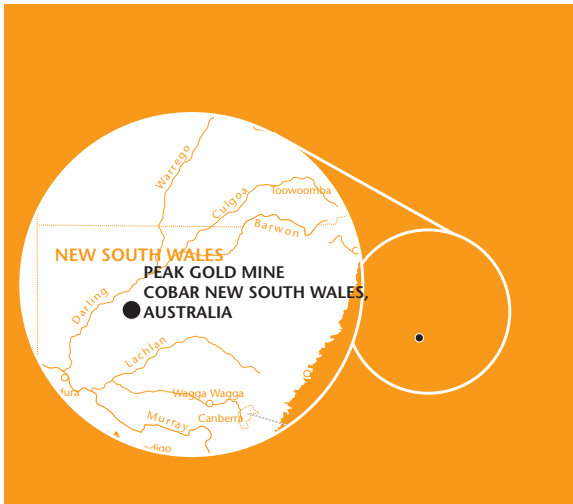


Case History 1

Peak Gold Mine Cobar, NSW, Australia

Trial Objectives

The Peak Gold Mine, located in Cobar New South Wales, Australia was interested in increasing the throughput of their SAG Mill and reducing the total cost of ownership.



Weir Minerals conducted a complete analysis of the SAG Mill lining design & efficiency at the Peak Gold Mine, Cobar NSW. Before an optimal design and materials could be recommended, a complete analysis was conducted for the SAG Mill duty. Factors such as Mill speed, power, throughput, charge volume, feed top size, ore type and product size were considered.

Installation Details

Peak Gold Mine, Cobar NSW Australia

Owner: Peak Gold

Geology: Primary gold sulfide some oxidized ore

Equipment: 6.7m x 2.6m Hardinge® SAG MILL with grate discharge

Media: 125 mm Media Top Size, 30% Fill

Top Feed Size: 200mm, 89 TPH.

Trial Considerations

- System cost
- Service life of components
- Production losses due to relines
- Shutdown duration
- Cost of maintenance

Trial Results

- Increase in mill availability by 33%
- Reduction in lining system weight by 26 tons
- Increased component service life which allowed for longer production time, increased profit and better customer satisfaction
- Improved safety for operators performing the relines.
- Reduced plant noise and improved communication in mill area and better Operational Health and Safety
- Flexibility to alter lining component dimensions quickly and easily to optimize lining system performance
- Continuous improvement by evaluating relative performance of metal cap lifter bars and rubber lifter bars at no extra expense
- Not restricted by weight for system design

Total Cost of Ownership Reduction

Weir Mill Systems metal cap linings were compared to the previous steel lined system and delivered a \$0.21 cent per tonne reduction in cost.

The Business Conclusion

Weir Mill Systems and Peak Gold have worked together to design and deliver a system that has allowed the ability to increase throughput by 4 tons an hour. Peak Gold have ramped up their production and now have a well designed SAG mill lining system that is lighter and focuses on breaking the ore for processing.

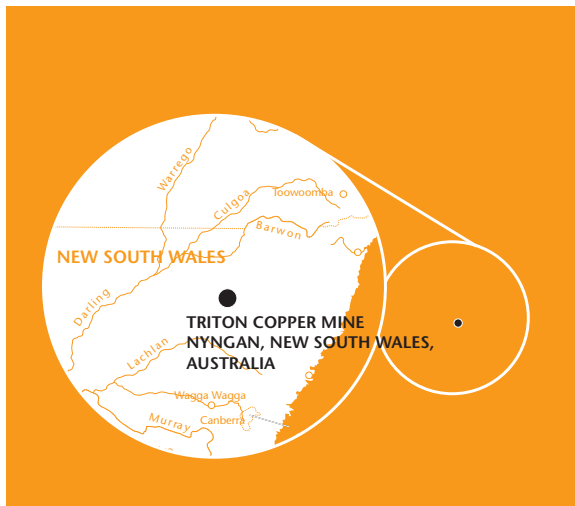


Case History 2

Tritton Copper Mine, Nyngan, NSW, Australia

Trial Objectives

The Tritton Copper Mine, located in Nyngan, New South Wales, Australia was interested in increasing the throughput of their SAG Mill and reducing the total cost of ownership.



Weir Minerals Services - Australia conducted a complete analysis of the SAG Mill lining design and efficiency at the mine. Before an optimal design and materials could be recommended, a complete analysis was conducted for the SAG Mill duty. Factors such as Mill speed, power, throughput, charge volume, feed top size, ore type and product size were considered prior to making recommendations.

A successful conversion has now been completed with our customer currently receiving the financial benefit that Weir Minerals Services - Australia delivered through design analysis and implementation.

Installation Details

Tritton Copper Mine, Nyngan NSW Australia

Owner: Straits

Geology: Primary Copper Sulfide with some oxidized ore

Equipment: 6.7m x 2.1m SAG Mill

Average Head Grade: - Cu 2.6%

Media: 125mm / Media Top Size, 36% Fill

Top Feed Size: 200mm, 120 TPH

Trial Considerations

Direct consideration:

Factors considered were:

- System cost
- Service life of components
- Production losses due to relines
- Shutdown duration
- Cost of maintenance
- Indirect consideration
- Increased Throughput, Increased Safety

Weir Minerals Services have worked closely with Tritton to deliver system that has allowed them the ability to increase throughput by 40 tons an hour. This increase has been possible by having a well designed SAG mill lining system that is lighter and focuses on breaking the ore for processing.

Trial Results

- Performance - comparison based on systems achieving 425,580 tons
- Increase mill availability by 5.5%
- Reduction in weight by 66 tons
- Reline times are reduced by 32%
- Increase component service life, allowing for longer production time, delivering increased profit and customer satisfaction
- Improved safety of operators performing the reline
- Reduced plant noise, improving communication in mill area and improving OH&S
- Flexibility to alter lining component dimensions quickly and easily to optimize lining system performance
- Continuous improvement by evaluating relative performance of metal cap lifter bars and rubber lifter bars at no extra expense
- Not restricted by weight for system design
- Weir Minerals Service Engineer to perform regular inspections and provide informative, real-time condition monitoring report.

Total Cost of Ownership Reduction

Weir Minerals metal cap linings were compared to previous steel lined system and delivered a \$1.09 cent per tonne reduction in cost.

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For further information on Weir Minerals products or services, contact the nearest sales office or visit www.weirminerals.com