MINING APPLICATION

INDUSTRY GUIDE

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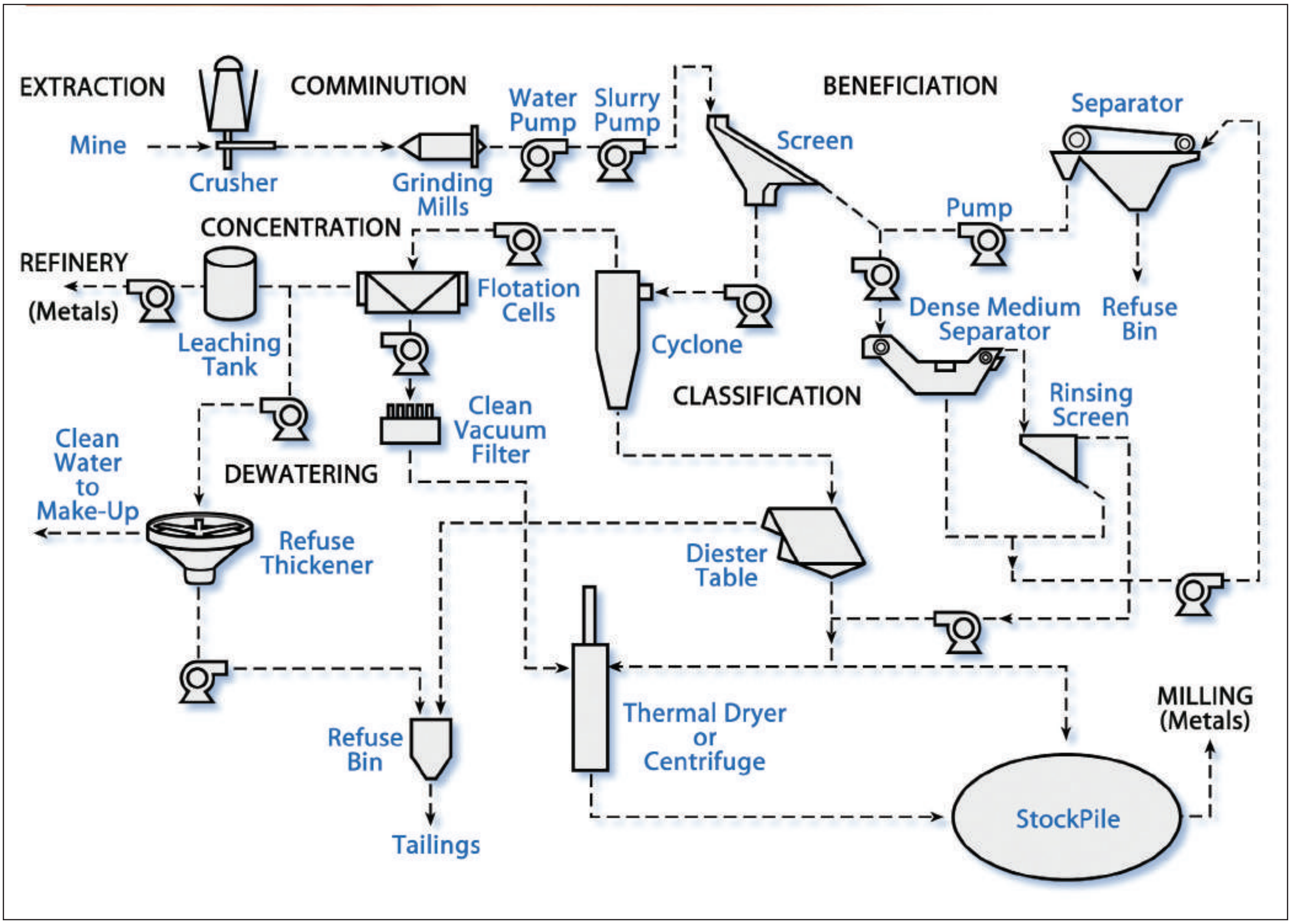
EXTRACTION
Mine
Crusher
COMMINUTION
Grinding Mills
Water Pump
Slurry Pump
BENEFICIATION
Screen
Separator
Pump
Refuse Bin
Dense Medium Separator
CONCENTRATION
REFINERY
(Metals)
Leaching Tank
Flotation Cells
Cyclone
CLASSIFICATION
Rinsing Screen
Clean Vacuum Filter
Clean Water to Make-Up
DEWATERING
Refuse Thickener
Diester Table
Thermal Dryer or Centrifuge
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Tailings
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StockPile

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INTRODUCTION

The intent of this application guide is to familiarize the user with the systems, processes and equipment found in mining operations—more specifically, to help the user identify Chesterton product application opportunities and the respective operating conditions. For example, it will help the user identify typical erosion- corrosion control techniques, sealing solutions in all facets and the many applications for cleaners and lubricants. This manual presents potential solutions for areas in the plant where conventional methods are not performing adequately and where upgrades are possible.

Mining processes may initially appear complex, but in the overall scheme of things if the basic steps in the process are understood, any mine can be dissected into small recognizable pieces.

Exploration

All mining operations begin with exploration, that is, the mineral to be mined (ore) must be found and the size or extent determined (deposit). If the deposit is of economic significance, the decision is made to begin excavation or development.

Mining

Excavation or extraction of the ore is referred to as mining. This can take place on the earth's surface or underground. Once ore is extracted, it is sent to the mill for processing (milling).

Milling

The ore is then processed through comminution, beneficiation, classification, separation and dewatering. Crushing, grinding and particle size reduction (comminution) is the first step in the milling operation. Some milling processes end here. Pulverizing ore into fine dust is another step that takes place in the separating or classification stages. Here again, some processes end here while other mineral processes require more refinement or purification (refining).

Frequently, mining and milling may be geographically separated from one another, so a mine may not provide milling opportunities and vice-versa. Mining is always located with the economic resource, while milling can be either local or distant from the mine. When milling is not local to the mine, a third support operation must exist. This operation will include ore transportation and can be accomplished with either off-road hauling equipment, pumps and piping, or conveyors.

Mining, by definition, is the extraction of minerals from the earth's crust for the economic benefit of mankind. Historically, the first mining artifacts date back before 100,000 BC and without question, mining has played a major role in the development of civilization. The eight ages of man's development: Old Stone Age, New Stone Age, Copper Age, Bronze Age, Iron Age, Coal Age, Petroleum Age and Uranium Age are all based on man's mining and metallurgical development.

Mining, one of the two primary industries, is a raw material supplier for the secondary industries, agriculture being the other and oldest. Mining is found in almost every corner of the world. The extraction of these natural resources can exhibit various degrees of technological sophistication. Smaller operations, run by individual miners, will have only the most rudimentary of tools where as, the large mining giants will be extensively mechanized.

Natural Resources

The mineral resources of the world are found within the earth's crust. Minerals combine to make rocks, which are the basic constituents of the continental and oceanic crust. Some of the minerals within the rock have economic use while others do not and are referred to as gangue. If the minerals of value are found in high enough concentration for economic extraction, then it is called an 'ore deposit'.

The first challenge in extracting these valued resources is finding them. The second is how to remove the resource economically and ethically. The third is how to process it for use. Since mining is a business enterprise, it must perform each of these steps profitably. Fortunately, for the mining companies, geologic, hydrologic and tectonic forces have manipulated the earth's surface for five billion years and concentrated the minerals for extraction. If these natural influences did not take place, all of the minerals would be randomly dispersed throughout the crust and it would be cost prohibitive to extract the mineral.

As a result of nature's influences, minerals are concentrated into low to high quality ores. Of course, the larger the deposit, the easier it is to mine. The decision becomes fundamental. However, some of these minerals occur in nature in their primary form as pure minerals, such as gold, while others are chemically combined as sulfides, oxides, carbonates, etc., which can complicate processing. In some cases, the valued mineral is diluted with other gangue minerals, which make separation even more difficult. The methods for finding, mining, and milling ores are universal throughout the world. Some small companies or third world mining operations, which lack the financial resources, may be less mechanized and more primitive in their methods, but the methodology is the same.

A handy way to organize the mineral resources is to group them into three categories:

- Metals
- Nonmetals
- Fuels

Rocks, which yield minerals that contain metals, are grouped as follows:

- Precious metals: gold, silver, platinum
- Base metals: copper, lead, zinc, tin
- Steel industries metals: iron, nickel, chromium, manganese, molybdenum, tungsten, vanadium
- Light metals: aluminum, magnesium
- Electronic industry metals: cadmium, bismuth, germanium
- Radioactive metals: uranium, radium

Rocks, which yield non-metal minerals are grouped as follows:

- Insulating material: mica
- Refractory materials: silica, aluminum, zircon, and graphite
- Abrasives and gems: corundum, emery, garnet, diamond, topaz, emerald, and sapphire
- General industrial minerals: phosphates, rock salt, limestone, barite, borates, feldspars, gypsum, potash, trona, clays, magnesite, and sulfur

And, rocks that yield minerals for fuel are:

- Solid fuels: anthracite coal, bituminous coal, lignite, oil shale, and uranium
- Fluid fuels - petroleum oil and natural gas

The mining process takes place in three basic steps:

1. Exploration

- Locate the deposit
- Determine the size and extent of mineralization
- Determine the most economical way to excavate the mineral

2. Mining (Extraction)

- Open up the deposit and implement the means to extract the ore
- Remove ore from the rock
- Transport ore to mill for concentration

3. Milling

- Crush and grind to size, then use various separation techniques to beneficiate the ore
- Remove the ore/mineral through classifying and concentrating to achieve a degree of purification
- Prepare the product for secondary consumption (refining)

EXPLORATION

Exploration is the starting point of any mine and milling operation. Fortunately, the surface geologic, hydrologic influences and tectonic forces, which manipulate the earth's crust provide the driving mechanisms to concentrate minerals. These forces provide the basis for extracting economically valuable minerals from the earth. By understanding the benefits of nature's forces, many new exploration techniques have been developed to make mining easier and more profitable.

Once a resource is found, exploration geologists must determine the extent, location and quality of the ore body. From this information, the mine owners determine the economic feasibility, life and potential profitability of the deposit. If feasible, the method of development and mining will be chosen and the process identified for concentrating and purifying the mineral for consumption. Finally, the environmental impact of development is ascertained. Once exploration is complete, actual development or ground opening begins.

Once the minerals are found, the size and type of deposit is identified. Some deposits are too dispersed to economically extract them, while others are concentrated and show economic feasibility. Even within a deposit, only some of the mineral may be economically profitable for removal (ore) and the other less economically profitable (diluted). Typically, areas within a mine are mapped according to the economic worth. Depending on the market price, certain areas are mined immediately, while other more diluted areas are left for mining when demand and prices are higher.

Mineral deposits can occur in three general forms:

- Veins
- Bedded deposits
- Ore replacement deposits

Veins are cracks, fissures, fractures or faults filled with minerals from a melt or solution. The size and breadth of a vein is extremely variable. The dilution is always a major influence whether the mineral is to be mined. Bedded deposits in coal are inter-bedded between sedimentary rocks so the dilution is easier to mine. These deposits are usually horizontal and can extend over very large areas. In a deposit, the valuable mineral (ore) occurs in a ground mass or matrix combined with gangue. Higher gangue concentration means greater ore dilution. Therefore, the main purpose of the mining process is to concentrate and beneficiate the ore by separating and discarding the gangue material as early in the process as possible. The longer the valuable mineral is in the diluted process, the lower the profitability.

MINING — ORE EXTRACTION

The location and size of the ore body determines whether the mine will be a surface or underground operation. To ensure that a mine will produce safely and economically throughout its working life, i.e., until the entire deposit is removed, it must be developed systematically.

The mine is sectionalized into areas that can be conveniently, economically and safely exploited without endangering miners and neighboring areas. The ancillary processes of haulage, drainage, and ventilation are to be coordinated into a planned, logical layout.

Surface Mining

Surface mining is the preferred method when bedded type mineral deposits occur at or near the earth's surface. This technique offers lower cost and presents fewer development problems. If the deposit is coal, the overburden must be stripped away to expose the coal. This process is called "strip mining". After all of the coal is stripped away, the overburden is replaced and the area re-vegetated.

Surface mining must deal with all of the usual daily temperature, sunlight, and weathering exposures on the earth's surface, so axillary support equipment such as pumps and pipelines are required. Ground water control is an ongoing problem for surface mines, thus flood prevention is a priority.

Contour strip mining is used when mineral deposits follow the contour of mountainous terrain. After the exposed coal is mined, more coal can be moved from beneath the mountain by means of "auger mining". Strip mining is carried out on a large scale, and therefore, uses enormous digging equipment. Walking draglines, power shovels or bucket-wheel excavators are used to strip and dump the overburden. Once exposed, the ore is generally mined with the smaller hydraulic power shovels and assisted with bulldozers and wheel loaders and loaded into off-highway truck. Drilling and blasting are employed to remove tough overburden or break loose-bedded deposits.

Open cut work is a mining process used for the harder industrial minerals, disseminated metallic minerals or replacement deposits removed through surface mining. Because of the difficulty in mining harder materials, the mining depth is generally less than 12 m (40') under the overburden or less than 15 m (50') in thickness.

Bench mining is used when surface deposits are steeply dipping and wide. A series of benches are developed under 15 m (50') in height. The horizontal space below each bench slope is broad enough to catch blasted rock and support large heavy equipment for the removal of the ore. These spiraling benches also serve as a continuous roadway out of the pit.

Quarrying is another type of surface mine. Although they use the same mining principals as used in hard rock deposits, rock is removed from a vertical wall. Surface mining occurs directly within the elements of the environment. Weather, water runoff and high water tables can create flooding issues, which can require a constant pumping of the excavated area using mine dewatering pumps. Also, the area being smaller in scale can cause more damage to the excavating equipment due to direct contact and erosion.

Underground Mining

Underground mines are not vast holes in the ground, but rather systematic developments based on economics and safety. These operations must remain open for the working life of the deposit. Economics and safety are long-term concerns. Underground mines are vast construction operations and are the most mechanized and highly productive mines. Heavy equipment will travel through miles of passageways hauling ore. The ancillary processes of ground control, drainage, power transmission and ventilation are instrumental in the mine operation.

The first step in building an underground mine is to dig a hole into the ground or mountainside to access the ore. Development is the actual boring of the hole. This opening will become the main entrance of the mine and the source of fresh air to the operation below. More shafts or openings may be opened at a later stage as the mining progresses. These passages will serve to bring men and air in and out of the mine as well as remove the ore out of the mine. Development continues throughout the life of the mine and usually continues both horizontally and vertically below the earth's surface and extreme ocean depths.

Shafts, Ventilation Shafts, and Hoists

If a mine is to be located beneath the ground, the main entrance into the mine is called a shaft. The main entrance or shaft is part of the permanent way system; they must be kept open and functional for the life of the mine. In mountainous terrain, the common entrance is called an adit, a slope or an inclined shaft. A vertical shaft or inclined shaft is always noted by the presence of a head frame or windup. This shaft will transport workers on an elevator (lift) in and out of the mine as well as removing the ore out of the mine, and is sometimes called a skip. Some large operations may have more than one head frame to separate man travel and ore removal functions. Shafts are permanent structures that are generally or partially lined with steel walls or concrete. The underground shafts are called winzes, which can connect lower development and working levels.

Shafts also serve another vital function. They bring fresh air in and out of the mine. Some shafts act exclusively as ventilation intakes or exhaust shafts. Due to the continuous drawing of hot air from the mine, which contains grit, dust, chemical vapors and moisture vapors, a severe corrosion and abrasive environment will exist.

Hoists or manlifts must haul men, equipment and supplies in and out of the mine. At the same time, the hoists are used to lift ore from the production areas. The large cages are supported by braided steel cables.

Reference chart 1: Shafts, Shaft Ventilation, and Hoists – on page 33.

Roof and Ground Control

As the underground is opened, the natural response by the surrounding rock is to close. When rock is formed beneath the ground, it can be placed under extreme temperatures and pressures. After it cools, the stresses created during emplacement can remain in the rock. These residual stresses, when relieved, can cause rock to split (jointing) and unload. In addition, the massive weight associated with hundreds to thousands of feet of burial (lithostatic forces) can create high stresses in the rock. And of course, some areas associated with long-term tectonic events (crust moving) will also entrap stresses in the rock. Any or all of these stresses ultimately can cause openings to close.

In older mines, where most of the mining was done by hand, the openings were kept as small as possible. Modern mines use larger openings and consequently require a higher degree of mechanization. Trucks, muckers or trams carry ore out of the work area and travel at speeds of up to 30 mph. They need very large entries or passageways. Of course, the larger the opening and the deeper the mine, the greater the difficulty in keeping the mine open.

Underground mine openings are places where men work and have a roof or top, a floor or bottom and walls or ribs. If the ribs actually provide some of the roof support as in a 'room and pillar' or 'board and pillar', then the ribs are called pillars. The area of production, where men work, is called a 'room' (coal mining) or a 'drift' (metal mining). The actual surface being mined is called the 'face' (coal mining) or 'stope' (metal mining). Openings, which travel upward from a drift are called 'raises'. Openings running perpendicular to rooms or drifts are called 'cross-cuts'.

No doubt, underground mining can be hazardous for miners. It is for this reason, natural and artificial ground control methods have been developed, and in some countries, are mandated for miner protection. In the US, the Mining Safety and Health Administration (MSHA) mandates that every mine have an approved ground control plan. This plan is periodically inspected to ensure that it is followed.

There are two types of openings: self supported and artificially supported. Self-supported openings use no regular artificial support and are used only in the most competent rock. In the North America, MSHA requires artificial support in every area of the mine in use, so only third world countries may still allow unsupported roofing.

An artificially supported roof incorporates anyone of a number of support methods: timber, roof bolts, resin bolts, cable bolts, yieldable supports, split sets, arches, chocks, etc. A typical, MSHA approved, roof control plan in a coal mine may require 2 m (6') roof bolts every 1.3 m (4') on center. For temporary roofing, support in a working face may require temporary hydraulic supports until roof bolts are installed. Large stopes may use a combination of 20 m (60') cable bolts and, where needed, 2 m (6') roof bolts holding up wire mesh. In the late 1980's, American mines consumed 150 million roof bolts on an annual basis. The adoption of stringent roof supporting procedures has drastically lowered injuries and deaths attributed to roof failures.

Reference chart 2: Roof and Ground Control – on page 33.

Underground Ventilation

Every mine has a problem with stagnant air, which, if low in oxygen content, will lead to miner's death. Ventilators serve to remove the expired air and supply fresh air to the work areas. In addition, coal mines are notorious for the presence of methane gas and dust. Both are explosive in air in the right proportions. In metal mines, silica dusts can lead to silicosis and with radioactive minerals, the hazards with inhalation are obvious. Ensuring good airflow in the mine is critical.

A controlled ventilation system, which quickly brings fresh air to the work face where exposure is at its highest is most desirable. To help achieve this, inactive areas of the mine are closed off with temporary walls called 'stops' or 'brattices'. Only the working areas are served fresh air. Additional airflow is brought directly to the work face using ductwork and air quality is continuously monitored. Return air usually follows the haulage passage way out of the mine.

In deep mines, the ventilation system is supported by an air conditioning system as well. Working conditions are very taxing to miners at temperatures above 90°F (35°C). If the rock temperature exceeds that temperature the air must be cooled. At these depths, temperature, humidity, the presence of corrosive dusts and vapors makes for a highly corrosive environment for miners, equipment and steel supports.

Maintenance is a continual struggle in these deep mines. As mines grow in depth and breadth, the demands on ventilation are intensified. Pumping warm surface air down a rough hole 5000 m (15000') creates friction and higher heat. Combine this generated heat with rock temperatures of 135°F (60°C), body heat and equipment heat loss, it is understandable why a mine will have high ventilation costs. Exhaust shaft and fan houses work to remove the bulk of heat, vapor and dust. Maintenance is high in these areas.

Reference chart 3: Underground Ventilation – on page 34.

Underground Production Methods

There are many methods used for removing ore from rock. Early methods included hand jacking to hand drilled holes followed by blasting. Air powered drills replaced hand drills in the last quarter of the nineteenth century and were replaced by wet drilling methods that eliminated dust problems. Today, drilling, fragmenting and removing ore are highly mechanized.

The method used for removing ore from underground is dependent upon several factors. The geology of the deposit is crucial in selecting a mining method. Factors such as the size, extent, shape, depth and mineralogy are important. In addition, the method of development and mining will be a major consideration so the operation will be profitable. And of course, the development must consider the safety of the miners. Although the basic decision to mine is always an economic question, the method determines the profitability of the venture.

There are three basic methods for underground mining. The first is typically used in stratified sedimentary rocks where distinct layers are removed. The second, more typical, for igneous rocks where the enriched ore veins (leads) must be followed by drifting and raising (stoping). The third is typically employed where the deposit is massive and horizontally broad enough, so caving can be used. The practice of actually cutting ore or fragmentation can occur by mechanical or chemical means, mechanical being the oldest and most common.

Conventional Coal Mining

Conventional coal mining methods are the oldest methods of mechanized mining and are cyclical with individual operations of cutting, drilling, blasting, loading and haulage. An opening is cut in the working face called a 'kerf' in order to provide free space for breakage. A cut seam requires less explosives for breakage and produces larger pieces of coal compared to blasting from a solid face. Cutting machines are used to cut above the undesirable bottom coal or below undesirable roof coal. It is then drilled and blasted. A loading machine picks up the coal and conveys it away from the work face. A roof-bolting operation immediately follows, which quickly installs roof bolts in the unsupported roof. The layout uses coal pillars for partial roof support and working rooms. The sequence is then repeated.

Room and Pillar Coal Mining

When the room-and-pillar (board-and-pillar) method is used, the coal seam is mined by cutting a network of 'rooms' or 'panels' and leaving behind 'pillars' of coal to help support the roof of the mine. Initially, coal recovery is only 50% – 60% of the coal. However, at a later stage of development, 'retreat mining' will remove the pillars. As a result, the mine roof collapses. This mining technique uses a continuous miner with a larger auger to cut the coal from the face and a shuttle car or conveyor to carry the coal away. Once the continuous miner removes enough coal, the miner operating the equipment is no longer under an artificially supported roof. The continuous miner backs out, so a roof bolter can place bolts up to the work face. When the bolter is finished, it backs out so the continuous miner can resume mining. Although a little over half of the coal can be remove, one third of a shift is spent mining, one third is spent bolting and one third is spent moving equipment.

Longwall Coal Mining

The longwall coal mining method uses mechanized shearers or plows to cut and a conveyor to remove coal from the face. The shearing face (panel) can be between 150 m – 300 m (500' – 1000') in width by 760 m – 3900 m (2500' – 13000') long. Self -advancing, hydraulically operated temporary supports (chocks) temporarily hold up the roof while the coal is extracted. Immediately behind the chocks, the roof is allowed to collapse (gob). Over 75% of the coal can be extracted using this method. Although initial set-up is costly and time consuming, an established long wall requires no equipment moving and is significantly more productive than other methods.

Shortwall Coal Mining

Shortwall coal mining is a cross between room-and-pillar and longwall mining. A shortwall panel is shorter than a longwall panel. Instead of using a shearer, a continuous miner is used. Since the chocks are self-advancing, the miner can work continuously without moving out from under the temporary roof support (chocks). This technique is not as popular as the longwall method, but it does mine smaller panels and is easier to control seams, which fluctuate in thickness.

Stoping Methods of Mining

When the geology indicates ore is found in veins or small deposits the method of stope mining is generally selected. Stratiform and horizontal deposits use open stoping methods. If the ore is found in steeply dipping veins, shrinkage stoping is employed. Ore bodies where the footwall is above the angle of repose, will use sublevel stoping. And, in special occasions four 'minor' methods may be used: top slicing, breast stoping, underhand stoping and overhand stoping. All of which have their advantages and purpose.

Open Stoping

Horizontal deposits, not greatly deformed by folding or metamorphism are typically mined by open stoping. Room-and-pillar mining methods used in coal mining are common in this mining method. Because the mining rooms may be larger than in coal mining, the equipment is much larger. Hard rock mining is always more aggressive on equipment due to the harder minerals and more aggressive chemical and thermal exposure.

Shrinkage Stoping

Shrinkage stoping uses a working platform of broken ore to remove overhand ore. Since broken ore has a higher bulk density and consequently a larger volume than solid ore, some of the 'muck' must be removed as the stope advances, hence the name 'shrinkage'. This method is used in steeply dipping vein-type deposits where the ore is strong enough to stand without added support. Rising mining costs and skilled miner shortages are gradually forcing this method out of existence. Once a stope nears completion, almost 60% of the broken ore reserve is left in place and must be removed. This is a long and arduous process. Certainly this step is necessary, but is considered a non-income-producing part of the investment.

Sublevel Stoping

Sublevel stoping is a large production combining the overhand and open stoping methods. This process is used in fairly regular ore bodies where the surrounding rock is sturdy enough to require little ground support. Extensive development is required before mining can begin, but once mining commences it is one of the lowest cost methods.

Minor Stoping Methods

Breast Stoping is found in low-dipping, extensive, thinly bedded deposits. Stoping is advanced on a breast or vertical face that has not been undercut. Longwall coal mining techniques can be used in this method. Concerns for the thickness if the deposit and strength of the ground. Usually these operations continually deal with poor roof conditions.

Underhand and Overhand Open Stoping methods are confined to narrow, steeply dipping ore bodies where both the country rock and the ore are strong and require little to no support. The ore body can range from vertical to dipping 50°. This method is only used in very rich ore deposits. The underhand method uses a series of benches 6 ft high and 4 ft. The slope approaches 60°. The overhand method also uses benches, but they are cut into the roof. Both methods require little ground control.

Top Slicing is a high-cost, low-tonnage mining technique, which is rarely used today. In the past it was used extensively in the copper mines, but the high manpower requirements have almost eliminated the practice. It works best in weak ground were open or filled stoping is impractical. It generally competes with sublevel caving, which is more economically favorable. The method extracts 90% – 95% of the ore with little dilution, but does not lend itself to mechanization. It uses a lot of timbering to maintain the stopes and is an extremely selective method of mining.

Caving Methods of Mining

Caving, when applicable, can provide the lowest mining cost per ton than any other underground mining method. It requires large up front development costs, but ultimately it is the best large-scale method. This method works best in moderately soft or moderately hard rock. Fracture patterns are usually the determining factor. The weight of the overburden is an important factor as it helps break the ore. Caving utilizes gravity to remove the ore. It is usually taken down in blocks or in sublevels.

Block Caving

Block caving usually requires dropping large blocks of ore. When the ore is soft or highly fractured, breaks fine and has a fairly high rate of drawdown, block caving is optimal. Flat beds greater than 100' in thickness can be mined if the cost to develop the deposit warrants it. Block caving is not a selective mining process, but definitely is inexpensive. It offers centralized production and good ventilation; however, development of the block takes time and money. The cost to maintain drifts are higher and recovery is sometimes low. The method is certainly inflexible.

Sublevel Caving

Whether an ore body is mined in blocks, panels or in mass depends on the competency of the rock. If the fracture pattern of the rock is more dispersed and the ore body has more strength as in steeply dipping veins, panels are more suitable. Sublevel caving works best in smaller ore bodies were less fracturing occurs. This method uses a main haulage level or collecting level some distance below the ore body surface. Sublevels are driven through the ore body so the large equipment can cave at different levels. The ore is collected and stored in a centralized area. Pillars are left for structural integrity.

Filled Stopes and Combination Methods

A filled stope is one, which uses waste material for ground control. It is called fill, backfill or gob. Progress in filled stopes is always upward. The ore-removal system varies with the properties of the fill, equipment available and overall economics. This method works well in steeply dipping ore bodies with restrictive dimensions and weak walls. The trend in this method is towards higher mechanization. In many cases, a mine may use more than one method to mine. As the ground rock changes, methods can vary.

Reference chart 5: Underground Mining – on page 35.

Underground Haulage

Ore from the production area is moved to the outside for processing via the haulage ways. In coal mining the haulage way is generally a conveyor system that follows the ventilation exhaust ways. Conveyor systems are one of the major areas of underground fire. Locating the conveyor system in the exhaust way will minimize the hazards associated with fire, thus protecting the miners. Longwall operations have a conveyance way called a 'tailgate', which is used to remove ore and exhaust air from the longwall face.

In other mines, ore can be removed by conveyor, cart, truck, trolley and train. Since an efficient haulage system is crucial for removing ore, preventative maintenance is a necessity. Loading areas are a point of congestion and high wear to the equipment.

Reference chart 6: Underground Haulage – on page 35.

MILLING – GENERAL SURFACE OPERATIONS

Ore can contain pieces of rock ranging from large boulders to dust. It can also contain unwanted mining debris such as wood, pieces of steel, tools, etc. The first order of processing is to remove the extraneous debris and begin the milling process. Most often, manual removal of debris is accomplished with pickers. The ore is then conveyed into the mill house.

The next step in milling is the reduction of particle size (comminution). If the ore from the mine is too large, it must be crushed or reduced in size. Once crushed, the ore is further reduced to a desired particle size for extracting the ore from the unwanted gangue rock. This is achieved by screening and classifying particles to a specified size. If size fractions are added to create a specific particle size range such as with coal then this is called 'beneficiation'. This is the end of the processing for most coal operations, since they are sold on size and degree of cleanliness.

However, if the ore is not to be sold by size, then processing continues to the next step-classification and concentration. Usually, this step involves the removal of the gangue or unwanted minerals, and concentrating the valued mineral. These processes are based on separating minerals by their physical properties. Separation techniques take advantage of differentials in density, magnetism, electrostatic charge, hardness, solubility, hydrophobicity, melt points or electromotive-potential between the gangue and the valued portion.

Once purity has been achieved, the mineral may have to be agglomerated into a saleable configuration. Sintering, pelletizing, briquetting, nodulizing or just molding into bullion bars may be the marketable shape. As part of any of these processes, there is always the need to de water and dry the mineral so that the final configuration can be met.

Because of variances in ore quality, a combination of mill operations may be required to produce a marketable product. In some cases, where multiple byproducts are possible, the mill process becomes even more complex. A mine that can produce sellable byproducts is a mine that is less vulnerable in a fluctuating market. Sometimes, the customer's product is mined, milled and refined at the same location. Oftentimes, mines contract with mills or refiners to offset costs and are able to pass that savings onto the customer.

Comminution

Ore transported from the mine to mill is generally not in the optimal size and purity for the most efficient methods of extraction. Consequently, the size must be reduced so the ore can be treated, extracted, or beneficiated. The reduction of particle size is called comminution. If the ore is too large for the crushers additional breaking must take place. Once the boulders have been broken in size so that the ore will fit into the crusher, particle size becomes more manageable. Sometimes crushing is adequate as seen in quarries, which sell crush rock. On-the-other hand, metal bearing ores require substantial particle size reduction to gain efficiency in the flotation process, to be discussed later. An additional step in the reduction of particle size is called grinding. Once a specific particle size is met screening will take place, also know as beneficiation.

Breaking

Depending on the mining method or properties of the rock and ore body, ore can arrive at the mill in very large boulders or chunks. If too large for the crusher, then they must be blasted or broken into smaller pieces with a rock breaker or jack hammer. Careful selection of the mining method can alleviate the need for rock breaking, thus additional costs. In the breaking phase, wear and impact forces are substantial.

Crushing

Crushing is generally the first step in the milling process and takes place close to the mine site to keep transportation costs to a minimum. Crushing of ore is usually accomplished by a jaw or gyratory crusher. Single to multi-roll, sledging-roll, ring crusher and on occasion, hammer mills are used for crushing non-metallic ores. Jaw Crushers are the most common method of reducing blocky mined metallic ores. This crusher consists of a hinged plate, which opens and closes against a stationary plate. The crusher must have a large enough opening to handle the ore received from the mine and a discharge opening for dumping crushed ore. Heavy-duty frame construction is important for reducing extremely hard minerals. The wear faces also experience high compressive forces, while the discharge of the reduced ore causes sliding abrasion on the lower end of the jaw crusher.

Grinding

Grinding a particle for sizing or further processing utilizes the principals of milling. A mill, depending on the design can use any one or a combination of three forces to reduce particle size: impact, attrition and/or shear. Impact is when particles collide with one another or a hard surface and break into smaller sub particles. Attrition milling uses the rubbing between fine media at low speed to reduce particle size. Shear is a high-speed process where the shear created between particles moving at high-speed will rip large particles a part.

Grinding mill circuits are designed to reduce the size of the ore particles to the point where economic liberation of the valued mineral can take place. Usually grinding mills are arranged in sequence to further reduce particle size. These circuits can be wet or dry depending on the minerals present, although wet grinding affords many advantages. Both open and closed circuits are used. An open circuit passes material through once, while a closed system recirculates the ore through until the right size is achieved. Closed circuits reduce residence time. Where rod mills are open circuits, ball mills are closed.

Reference chart 9: Comminution – on page 37.

Beneficiation

Beneficiation is the process of cleaning, classifying or screening ground ore. For some minerals like coal, the end user requires a certain quality and size range of particles. Some minerals must be cleaned and some must be graded or beneficiated into a commercially desired size e.g., coal and gravel. Sometimes fines must removed from the crusher or mill feeds to increase plant efficiency by minimizing unnecessary reduction. And, sometimes feedstock must be sized for the concentration step.

Screening

Screens are used extensively to control particle sizes. They can be used in multi-deck configurations, in parallel arrangement or in long trains of screens in series. The mechanical method of forcing a certain particle size through a specified hole is called screening. The force used can be gravity, centrifugal, or pressure. There are two screen types: stationary or moving screens. Stationary screens are the simplest and oldest form of separating particles by size. For coal, the screens and classification machines are the heart of the process, where in metal processing they are less frequently used.

Reference chart 4: Beneficiation – on page 34.

Classification

Classification is the method of separating mixtures of minerals into two or more products on the basis of the velocity with which a particle falls through a fluid medium. This is accomplished using clarifiers. In mineral processing, the medium is usually water, and wet classification is generally applied to mineral particles, which are considered too fine to be sorted efficiently by screening. Classifiers can be grouped into three broad categories based on the direction of flow of the carrying current. Horizontal current classifiers (mechanical) are essentially the free-settling type and accentuate the sizing function. Vertical current or hydraulic classifiers are usually hindered-settling types and so increase the effect of density on the separation. A third group consists of devices that use centrifugal force to cause separation, the hydrocyclone.

Separation

The hydroclone unit consists of a conically shaped vessel, open at the apex, or underflow, joined to a cylindrical section, which has a tangential feed inlet. The top of the unit is fixed with a plate through which passes an axially mounted overflow pipe. This pipe extends into the body in a short section called the vortex finder, which prevents short-circuiting of feed directly into the overflow. In principle, the particles within the spiral flow pattern are subjected to an outward centrifugal force and an inwardly acting drag. The centrifugal force accelerates settling particles by size and specific gravity. Faster settling particles move to the wall where the velocity is the lowest and migrate to the apex opening. The drag force causes the slower settling particles to move toward the zone of low pressure along the axis and are carried upward through the vortex-finder to the overflow. Hydrocyclones work well for classifying 150 µm (100 mesh) to finer than 5 µm (400 mesh).

Reference chart 8: Classification – on page 36.

Concentration

The major objective of any milling operation is to concentrate the valued portion of the ore and discard the gangue or waste portion. Fortunately, minerals both valued or waste, have different physical properties which enable separation. The greater the difference in properties between the valued and gangue, the easier the separation. This section discusses methods and equipment that work on differentials in buoyancy, specific gravity, magnetic and electrostatic properties and chemical solubilities. All of these processes assume that the proper degree of comminution has been achieved beforehand to adequately facilitate separation.

Finely divided concentrates can be separated by gravity means using various chemical-processing aids. Flotation (buoyancy) and gravimetric (specific gravity) methods can be used in these cases. Minerals can be separated and concentrated by magnetic or electrostatic means. Minerals can also be extracted (refined) by chemical means using pyrometallurgy (melting point), hydrometallurgy (chemical solubility), or electrometallurgy (electrolysis).

Flotation

Flotation is a separation technique based on buoyancy. Some minerals when treated with the proper surface-active chemical will become more or less buoyant. Since 1906, flotation has become the most important and versatile mineral separation technique. It is very selective and can separate minerals from complex ores. Over one hundred different minerals are recovered by flotation alone.

Essentially, a series of flotation tanks or cells accumulate the valued mineral in a froth on the surface of the cell. Usually, some chemical is added to the mineral slurry (pulp) that enhances the separation and flotation of the valued mineral. Such basic factors as mineral structure, chemical reagents, pH, pulp density, temperature, operator skills as well as several other factors effect the efficiency of this process.

There are two types of flotation cells: the pneumatic and the mechanical cells. The Pneumatic Cells either use air entrained by turbulent pulp addition (Cascade Cells) or air blown in and sparged. The Davcra Cell employs a cyclonic nozzle that injects air into the tank. The pulp flows over the baffle and the valued minerals rise into the froth. These units work well for roughing or cleaning applications for a variety of minerals.

Gravity Separation

Gravity concentration is the method of separating solids of different specific gravities in a fluid medium, frequently water or air. This method works best when the specific gravity of the valued mineral is different than the waste or gangue mineral. For example, removing gold with a specific gravity of 15 to 19.3 from quartz of specific gravity 2.65 gangue sounds easy by gravity separation methods; however, if the medium is water both will sink. To separate both minerals by gravity, a medium with a specific gravity between the two would be better. That way one would sink (gold) and the other would float (quartz). Sounds good in principle, but actually the separation is much easier by froth flotation. When the medium is water, a specific gravity differential of at least 1.5 is desirable. Size of the feed stock is crucial, since with different size particles, the largest particles always sink faster. Consequently, a small particle of high specific gravity may settle at the same rate as a larger particle of lower specific gravity. Shape also effects settling rate, i.e. round particles settle faster than flat particles.

Gravity based separators are among the oldest mining machines. Although they declined in use at the turn of the century with the introduction of froth flotation, they remain today as main method of concentrating iron, tungsten, coal, tin, and other industrial ores. Gravity separators are classified according to feed size. Grinding is particularly important for adequate and efficient operation of gravity separators. They are extremely sensitive to the presence of slimes that increase viscosity of the slurry and reduce the sharpness of separation and obscure visual cut-points.

Magnetic High Tension Separations

Magnetic and high tension separators are used where there is a difference in magnetic attraction. Magnetic Separators can be low and high intensity separators, wet or dry, and control the rate of materials moving through the field. Two types of magnetics are used: Diamagnets are used to repel particles and are very small forces and Paramagnets produce attractive forces that can be concentrated.

Dense Medium Separations (DMS) or Heavy Medium Separation (HMS) or Sink-Float Process is applied to the pre-concentration of minerals after the rejection of the gangue, but prior to the grinding for final liberation. This process is also used for coal preparation to use commercial grade end-products. It is one of the simplest gravity processes, but uses high density liquids or thick suspensions (pulp) or some heavy solid in water to create the density differential. These mediums behave as heavy liquids and can make sharp separations at any required density. The principle works best if the valued mineral is coarsely aggregated in the host rock.

Dense Medium Liquids have high specific gravities and can be selected for use for separating valued from gangue minerals. If selected to be between the specific gravity of the two minerals, one will sink and the other will float. Examples are:

Fluid	Specific Gravity
Tetrabromoethane	2.96
Bromoform	2.89
Di Iodomethane	3.30
Sodium Polytungstate	3.10
Clerci Solution	4.20

The safety data sheets for the above chemicals should be reviewed to assess compatability with coatings used as well as worker exposure limits and proper protective equipment.

Dense Medium Suspensions of high-density solids in water can create a pseudo specific gravity as high as some of the solvents listed above. If the concentration of the dense medium is less than 30% by volume, the finely grained suspension behaves as a simple Newtonian liquid. If the concentration is above 30% by volume, the slurry is Non-Newtonian and creates a certain viscosity. Centrifugation is required to get the separation. Usually, the media must be hard and not slime or it will increase viscosity. It must easily wash out and resist chemical attack.

Dense Medium	Specific Gravity	Uses
Galena	4.00	Viscosity
Ferrosilicon	6.7 – 6.9	82% Fe / 16% Si
Magnetite	5.1	Coal processes

Separating Vessels are either gravitational vessels or centrifugal in nature. In the gravitational units, the feed and the medium are mixed. Removal of the sinkers is the toughest part. Centrifugal separators rely on high centrifugal force and a low viscosity medium. This enables finer separations than gravity separators.

Reference chart 7: Concentration – on page 36.

Dewatering

In most mineral separations, water is the crucial carrying medium. It minimizes dust for worker health, lowers power consumption per ton, enables higher mill capacity, makes screening of fines possible, and provides for easier handling. But in order to produce the ultimate product, dewatering or solid-liquid separation is required. Partial dewatering is also performed at various stages in processing to concentrate the feed for better handling.

Dewatering is classified into three categories: Sedimentation, Filtration, and Thermal Drying. Sedimentation is advantageous when there is a large density differential between liquid and solid. Filtration is used where high-grade liquors, with densities close to that of the solid, are encountered. Thermal drying removes residual moisture, so the concentrate is dry for shipment. General dewatering can include all three in a process, i.e. most of the water is removed by sedimentation until the pulp is 55% – 65% by weight solid. Filtration is then used to make a filter cake of up to 80% – 90% by weight solids. Thermal drying maybe used to increase product to 95% solids by weight.

Gravity Sedimentation

The first step in dewatering is the rapid settling of solid particles in a liquid to produce a clarified liquid for decantation and thicker slurry for filtration. Settling rates are totally governed by Stokes or Newton's Laws, which is dependent on particle size. Very fine particles settle very slowly, while large particles settle rapidly. Centrifugation can accelerate settling as can chemicals be added to cause particles to agglomerate or flocculate into larger lumps (called flocs), and settle out. If the proper chemicals are added, then selective flocculation is possible. In this case, only the desired product will settle and the remainder can be re-treated or dumped.

Gravity sedimentation (thickening) is considered to be a relatively cheap, high capacity process with low shear forces, an ideal environment for flocculation. Thickeners may be batch or continuous units and usually have relatively shallow tanks from which clear liquid (supernatant) can be removed.

Clarifying capacity is determined by the thickener diameter. For a given or limited outside diameter, High Capacity Thickeners can be used. The thickener introduces the feed via a hollow shaft where flocculant is added and rapidly dispersed. The feed is then injected into a blanket of slurry where further flocculation takes place. The slurry slides down the inclined plates to the bottom. In the Tray Thickener trays are used to save space and create essentially a stack of clarifiers.

Filtration

This is the process of separating solids by means of a porous medium that retains the solids, but allows the liquid to pass. Whatever the type of equipment is used, a filter cake gradually builds up on the filter, and the resistance to flow decreases. Factors effecting the rate of filtration are: pressure drop between feed and other side of the filter, area of the filter surface, viscosity of filtrate, flow resistance of the filter cake, and the resistance of filter medium and initial layers of filter cake. Filter media can be cotton, wool, linen, jute, nylon, silk, glass fiber, porous carbon, metals, rayon, and other synthetics. Cotton fabrics are the most common and c an be as fine as 10 µm (0.5 mil).

The most common filter presses are the Plate and Frame Press. A hollow frame is separated from the plate by the filter cloth. A hydraulic piston or screw closes the unit and the slurry is introduced through holes in the plates and frame. The filtrate passes through the cloth and runs down the grooved surfaces of the plates and removed through a continuous channel. The cake remains in the frame for further washing or removal.

The Chamber or Recessed Plate Filter Press is similar to the plate and frame press except that the filter elements consist solely of the recessed filter plates. Filter chambers are formed between successive plates. All of the chambers are connected by a large hole in each plate. These types of filters are used for treating slurries with high solids contents. They afford easier cake discharge and are easier to mechanize. Coal preparation is a major use for these filters.

There are many types of Vacuum Filters, but they all incorporate filter media and a vacuum. Batch Vacuum Filters such as the Leaf Filter consists of a metal frame or a grooved plate over which a filter cloth is attached. Numerous holes in the framework enable the vacuum to draw a filter cake on the filter. A series of these leafs are immersed in a slurry, a vacuum drawn and a filter cake collected. Although simple to operate, the units require floor space.

Thermal Drying

Drying is the last process in a mineral processing plant. Unless a special form of end product must be made, this is the end of the line. Drying is aimed at reducing moisture to about 5% by weight. Drying reduces the cost of transport. Product loss can become a problem if moisture content is >5%.

Reference chart 10: Dewatering – on page 37.

Refining

Extractive Metallurgical Separations (Refining)

Refining is the final process for removing byproducts and impurities from the valued mineral. Refinement is accomplished by three methods: fire refining (Pyrometallurgy), chemical refining (Hydrometallurgy) and electrolytic refining (Electrometallurgy).

Extractive metallurgical processes have been used for approximately 6500 years. The earliest metals were gold, silver and copper found in their native form. Early civilizations learned to reduce oxide minerals to base metals with the discovery of charcoal based fire. Today, metallurgy has evolved to technologies other than fire. Metal separations have progressed to chemical, as well as electrolytical extraction.

Pyrometallurgy

This method of extraction utilizes heat to extract metals from the ore. Pyrometallurgy encompasses all processing operations using refractory lined furnaces and high temperature to dry, roast, sinter, distill, smelt or fire extract. Effective separation and recovery of extracted elements by this technique depends on the relative reactivity of the component minerals to fluxes, oxidants and reductants.

Fire refining is typically used with iron, copper and lead where they are purified by selective oxidation. In this process, oxygen or air is added to the impure liquid metal. The impurities oxidize before the metal value is removed as an oxide slag or a volatile oxide gas. Other fire-refining operations use fractional distillation. By this method, metals can be raised to very high purities by boiling off undesirable metals. The boiled off fraction can then be separated by further boil off. Other metals and metal oxides recovered and refined by fuming, volatilization and distillation techniques include minor tonnages of Arsenic, Antimony, Cadmium, and Lead. All of these methods use high temperature furnaces to produce the temperatures and atmospheres for purification.

Drying, roasting and sintering are subordinate operations that are used to prepare ores and concentrates at temperatures under the melting point. This prepares the ore and concentrates for smelting and leaching. Drying is a low-temperature process used to remove excess water and is described in detail in the dewatering section. Roasting uses gearth heat, fluid-bed flash and rotary-kiln-type furnaces to alter the chemical form of minerals. Toasting a compound can take place in oxidizing, reducing or neutral atmospheres. Sintering and a closely related nodularizing process differ from roasting. This process is referred to as agglomeration and uses higher temperatures to do so. Stationary and moving pallet berths, with up and down draft firing, are used when sintering. Counter current or concurrent rotary kilns are used for the nodularizing process. Fine particles, by incipient fusion, as well as by chemical charge are the end result.

Hydrometallurgy

Hydrometallurgy involves the selective extracting of leaching metallic compounds from a solution, where the metals can be precipitated or recovered. The leaching process is used as the simplest method with high-grade ore. When the ore is low-grade, a more expensive extractive process is typically used.

All too often, ores are not concentrated enough for a satisfactory leaching process. They must often be subjected to pretreatments, which alter the ore to a form acceptable for roasting, calcination, sulfatizing or oxidizing. During the leaching process, oxides are leached with sulfuric acid or sodium carbonate advert, while sulfates can be leached with water or sulfuric acid. Ammonium gydroxide is used with native ores, carbonates, and sulfides and sodium hydroxide is used for oxides. Cyanide solutions are solvents for precious metals, while sodium chloride solution dissolves some chlorides. In all cases where large volumes of leach solvent are used, it must be cheap, available, strong and preferentially selective for the values present.

The second phase of the chemical metallurgical process is the recovery of the valued minerals from the pregnant leach solutions. There are a variety of ways to precipitate the dissolved metal values and recover them in solid form. These methods can include chemical precipitation, transfer of metal ions, electrolytic deposition, solvent extraction in combination with electrolytic and chemical methods and carbon adsorption combined with electrolytic treatment.

Electrometallurgy

Electrolytic refining produces the highest purity metal product as well as the best recovery of valuable impurities. It is used to prepare high purity copper, nickel, lead, gold, and silver. The metal to be refined is cast into a slab, which becomes the anode of an electrolytic cell and another sheet of metal is the cathode. Both electrodes are immersed in an aqueous electrolyte capable of conducting an electric current. As a direct current is imposed on the cell, metal ions are dissolved from the anode and deposited at the cathode. The insoluble sludge left in the cell is treated to recover any valuable by-product metals.

Agglomeration

Some mineral consumer markets have certain requirements such as purity and cleanliness, while others need end products in a certain size and shape. Agglomeration is the formation of masses or clusters from fine particles. Most mineral products are agglomerated in four basic forms: sinters, pellets, briquettes, and nodules. Each of these forms will offer advantages to the consumer. Sintered product and pellets are the best form for feed in blast-furnaces, smelting and, therefore, are predominantly used to in these processes. Soft minerals are frequently briquetted to ensure uniformity. This uniformity is required for use in electric furnaces as raw material feed. Nodules are usually best suited for cement clinkers, which can be pulverized after fusion in the production of Portland cement.

Sintering

This method of agglomeration originated in the non-ferrous metal industry to roast sulfide concentrates prior to smelting. Thereafter, one process was adopted by the ferrous metal industry to agglomerate blast furnace flue dusts, mill scale and ion ore fines. Basically, the sintering process is one in which a bed of small ore particles is bonded into a clinker-like aggregate by high temperature for combustion processes. The burn-rate is controlled by drawing or blowing air through the bed. Temperature approaching 1400°C is used to soften and compress the particles into a sintered structure. Fluxes, gangue, or other metals can be added to aid in partial fusion during the sintering process.

Pelletizing

This process begins by forming a green (wet) ball. A balling unit (drum, disk or cone) is fed moist ore or concentrate, which is aggregated into small spheres by rolling action. These small pellets grow as they roll over the feed particles. By controlling moisture and residence time, pellets can be produced in sizes form 1/8" – 1" in diameter. Sizing, if required, can be accomplished with screens in closed circuits with the balling unit.

Feed preparation is critical and particle size should be 60% > 375 mesh. Binders are blended into the mix to give the pellet adequate strength. Organic binder, such as starch, sugar, pitch or an inorganic substance such as clay, cement or sodium silicate, can be used to hold the pellets together. The moisture level is critical. Iron ore concentrates, fluorospar flotation concentrates and coal fines are common uses for pelletizing.

Briquetting

Briquetting offers a distinct advantage in the agglomeration of dusts and fumes, which are too fine or lack the proper size distribution for pelletizing. This process is different from sintering and pelletizing in that high pressures are used. Temperatures from ambient to the softening points of ore and concentrates can be used. Lubricants and binders are frequently used to improve briquetting conditions. Bonding in briquettes can be accomplished in several ways. Coal and charcoals use pitch to bond particles. Iron ore uses both high temperature and pressures to soften the grains. Briquettes are produced as flakes, pellets or pillows. Properly prepared, they are dust-free and uniform.

Nodulizing

The process takes place in a direct-fired rotary kiln, with raw materials fed as slurry or as a premix, sometimes as a balled solid. As the feed passes from the cool end of the kiln to the hot end, the particles soften. Rotating the kiln causes the sticky material to roll into lumps in sizes ranging from one inch to several feet in diameter. Material tends to build up on the sidewalls of the kiln for removal. Cement manufacture is one of the largest uses for nodularizing.

Phosphate rock is frequently nodularized with flux for phosphorous production in electric furnaces. Some iron ores have been nodularized, but are usually more costly than pelletizing. The resulting nodularized clinker is inferior to pellets when used as feed in a blast-furnace.

SUPPORT FUNCTIONS

In order for a mine and mill to produce valued minerals, it must have a series of support entities. And, because of the mine's need to be located next to the natural resource these operations are usually in remote locations. The most basic needs are to have power, water and wood. Many mines have their own power supply, usually coal fired power plants. All mines need water for processing and cooling. Frequently, they maintain their own reservoirs. Steam is also used to run equipment and heat buildings. This requires both a power plant and water. Other utilities such as compressed air require power to run the compressors. Wood from neighboring forests is a necessity for building and in some mines for underground roof support.

Once these basic necessities are present, then the mine needs material handling equipment. This can run from large earth moving surface trucks to conveyor belts, pump and pipelines. Moving rock from process to process is what ties the mining operation together.

The mining process requires elaborate waste support functions. Since most valued minerals are only available in rock form the greater portion of the ore mined is waste. The greater this dilution factor, the greater the cost to recover the valued mineral. Solid wastes leave the mine and mill, and end up as tailings. Water used for processing becomes waste at the dewatering step in final processing. Chemicals used for flocculation and extractive processes must be treated before entering the tailing stream. Most modern mines have chemical treatment plants for recovering water and making it possible to maintain tailing ponds. As heat is evolved in any process, there is the problem of gaseous wastes. This gas may have to be treated, precipitated, or scrubbed before releasing into the air. Mines must be responsible environmental operations or their neighbors can lobby to close them.

And finally, every operation has equipment that is subject to regular maintenance. Many underground mines use the third shift as maintenance time. Severe corrosion and abrasion will wear out machine parts and create down time. Down time is very expensive and mines treat it in different ways. Although a proactive maintenance program is the more successful approach, many mines are working on tight margins and must "only repair what is broke." Maintenance is a large percentage of a mine's overall operating cost, and for some mines, it can mean lost productivity or closure.

Material Handling

Transportation processes, storage, feeding and washing represent 30% – 60% of the cost to deliver the valued mineral to the end user. Most run-of-the mine ore contains potentially harmful mining debris, which can cause damage and shut down mill equipment or processes. Common debris can be iron, steel, drill; clays and slimes adhering to the ore; large pieces of wood used as temporary roof support in an underground mine; and dust. Dust is the finest contaminant and probably the most expensive to remove.

Ore transportation can include moving ore by conveyor belts for loose bulk materials; feed chutes designed to deliver ore at the right rate to coincide with belt rate. The ore should never strike the belt vertically, hence the use of bucket elevators to move ore vertically. Most transport from the mine to the mill is dry transport. The dry transport produces environments of high impact and severe abrasion to chutes. Once the ore reaches the crushers, the ore is wetted for processing.

Hydraulic transport replaces dry transport to hold down dust and provide greater transport efficiencies. Pipeline use with centrifugal pumps is common. Although pipelines are used underground, they are designed for mobility as the mine environment continually changes. Generally, these pipelines contain process water, not ore slurries.

On the surface and in the mills, pipelines are fixed and require continual maintenance. In order for slurries to be moved in pipelines, centrifugal pumps are used. The main disadvantage of using these pumps is the high velocity produced within the pump casing, which results in serious wear of the impeller and volute. This is especially true as the particle size, loading, irregularity and hardness of the ore is increased. Most mills maintain a back-up inventory of pumps for rapid change-out to keep the mill running on schedule. Mills cannot afford downtime.

Ore Storage

Different mill processes function at different rates, some intermittent and some continuous. In addition, frequent interruptions for repair require immediate storage. The mine hoists ore part of the day. This allots time for maintenance and other mill functions to keep the pace. However, grinding and concentration run best when they are continuous. Coarse breaking and chute jams create more downtime than fine crushing and grinding.

Dry storage is easier, but it has its shortcomings with the presence of dust, explosive hazards and abrasive conditions. Wet storage is a more common way to store wet ore pulp. The major shortcoming of wet storage is that salts in the ore dissolve and create a corrosive, as well as, an erosive environment. The hazards associated with dry storage are eliminated with wet storage, but the need to continually maintain concrete or steel storage containers can be costly.

Waste Management

Because of the dilution factor, most of what comes out of the ground is waste. The grinding and concentrate processes, which prepare valued minerals for market, create solid, liquid, and gaseous waste. Proper disposal of these wastes are common consideration by all mines. In some cases, the environmental expectations for these wastes are beyond the financial capabilities of the mine operation. The costs to comply with all environmental regulations frequently cause operations to close.

Solid Wastes

Solid wastes become more of an issue as the higher quality ore bodies are consumed and necessitate development of the lower grade deposits. These deposits have more gangue by nature. As these ore bodies move from the mine to the mill, every aspect of processing requires more work, greater water and power consumption. They may cause more fines and more complex mineral byproducts to encumber the process. And, as a result, the tailings that result will be greater.

Apart from the visual effects on the landscape associated with tailings disposal, there could be a major ecological impact in the form of water pollution. This pollution occurs when natural water runoff filters through contaminated solids, which could include heavy metals, mill reagents, sulfur compounds and so on. The nature of tailings varies widely in that they are usually transported and disposed of as slurry. It may contain course, dry material such as the float fraction from dense medium plants. Open pits, for example, typically generate lower grade ores, which result in the production of very fine tailings.

The tailings make-up will vary from one mine to another. Its granular size, concentration and chemical make up will be dictated by the mineral being mined and the process required to concentrate the mineral for market.

Liquid Wastes

Since most mines use wet processing, the transport media is water. Contaminants in the ore can create acid or basic process waters. If the product necessitates gravitation, separation or flotation, high pH chemicals must be added for stability and to promulgate flociculation. During the concentration process, if hydromettalurgy is used, pulps can contain acids, gases, and other organic moieties to enhance separation and concentration. And finally, this water can pick up contamination from other process streams. As a result, waters entering the waterways are extremely deterious to the environment.

Most mines try to reclaim solutions, especially the high-density liquids where it cannot be dumped into the same waste environment. Chemical treatment plants are more and more common to recover these materials. Those operations, like the power plant are areas detailed in the appropriate manual on how to deal with these products. Frequently, these operations have neutralization tanks, flocculation and dewatering tanks.

Gaseous Wastes

These waste gases come from power generation, pyromettalurgic extractive processes, agglomeration methods and dewatering/drying processes. These gases must be treated much like a power plant or a chemical plant. Scrubbers, precipitators, bog houses and all of these associated subjects require Industrial coatings and linings.

Reference chart 11: Material and Waste Handling – on page 38.

Utilities

The remote locations of most ore bodies necessitate mines and mills to be self-sufficient. This means that many mines must have their own power supply, access to water and a vast supply of wood. Whatever is not available must be brought in at a cost to the operation.

Power is one of the most critical needs of a mine. Without electricity, equipment will not run, thermal drying or pyrometallurgic processes are not feasible. Remote mines and mills must frequently generate their own power, bringing in the nearest energy source to deliver it. Coal fired power plants are common in all the aspects of coal handling, transport and power generation. These plants are no different then the power plant that supplies energy to cities and towns near you.

In many instances, the plants produce steam as well as electricity. Steam is still used in some mines for heating, but most mines rely on the electric power to run compressors. A significant amount of underground equipment relies on compressed air and electricity to power roof bolters, continuous miners and rock drills. Above ground process equipment will need electricity to run compressed air for the flotation process. All of these support utilities require pumps, pipes and adaptation to equipment. Each area will represent an opportunity to improve efficiency and overall productivity.

Mining Equipment Glossary

Breaking/Crushing

Gyratory Crushers use the rotation of a tapered mantle inside of an opposing concave area. Large pieces of ore are dumped into the top and as the main shaft rotates, the ore is crushed between the opposing tapers. The reduced ore is discharged at the base of the unit. Gyratory crushers offer the ability to handle slab materials and offer the possibility of larger reduction ratios i.e., inlet size to discharge size. Although the wear faces within the gyratory crusher require hardened alloys to survive, the inlet and discharge outlets do not. Sliding abrasion is a key factor. Low surface energy surfaces for handling sticky or dirty feeds is desirable.

Hammer Mills are used as primary crushers in the reduction of quarry rock less than 2.5 cm (1") in size. Typically, the hammer mill is preferred for softer minerals such as phosphate, gypsum, cement rock and bituminous coal. Although there are several designs for hammer mills, all use a freely hanging hammer that strikes free falling ore against a stationary breaking plate. Feed and discharge openings see impact and sliding abrasion. The actual breaking plates are generally hardened metal faces and see heavy impact and sliding abrasion. Since the preferred ore is usually soft, friable and slippery materials, the wear surfaces of these mills do not require the tenacity needed on jaw or gyratory crushers.

Cone Crushers are a modified version of a gyratory crusher. The primary difference between the two is that the cone crusher has a shorter spindle and “bowl”, which flares outward and allows for higher capacity. The head has a replaceable mantle, which is backed with a epoxy cement. The Gyradisc™ Crusher is a specialized form of cone crusher used by the quarrying industry for producing fine sand at low cost.

Impact Mills along with hammer mills are frequently used for intermediate crushing. Metal wear is substantially reduced in impact mills, because crushing is achieved by rock-to-rock impact against a stationary breaking plate. Impact crushers are generally selected for non-abrasive minerals.

Rotary Coal Breakers are used were large amounts of coal is to be broken. They are massively constructed with perforated walls. The size of the openings being the size of the coal desired. Coal is fed into the rotating cylinder at speeds of up to 1500 tons/hour. Differential breakage is used to reduce the coal and shale fines enough to fall through the holes. Shale, which does not break as easy, is discharged on the end of the breaker.

Grinding

Rod Mills use rods rolling along the bottom of the mill to reduce ore size. Several methods of discharge are used: center peripheral, end peripheral and overflow or open-end discharge. These mills can handle a wide variety of feed size and produce a discharge with minimal fines. Rod mills grind by the rolling of the rods and the impact created between the rods. They normally run 50% – 65% of critical speed to cascade the product rather than create a cataract. They produce grinds with a narrow size range. Rod mills typically run wet in open circuits.

Center Peripheral Discharge Mills are fed at both ends through the trunnions. The ground product is discharged through a port along the center periphery. The mill can be used wet or dry and is used mostly for specification sands.

End Peripheral Discharge Mills are fed at one end. The ground ore is discharged at the end through a peripheral port.

Over Flow Discharge Mills are the most widely used roll mills. The feed is introduced at one end through the trunnion and discharges through the other end. These mills are wet grinders and usually feed ball mills.

Ball and Pebble Mills are the most common method of grinding particles. They are the final step in comminution. Ball mills contain forged or cast-steel balls, whereas pebble mills use pebbles, rocks, ore or ceramic materials as grinding media. Pebble mills are used extensively in South African gold mining. Since balls have a greater surface area per unit weight than rods, they are better qualified for fine grinding. Two types of discharge are used: grate or overflow. Typically they operate in a closed circuit with a classifier.

Grate Discharge Ball Mills are fitted with grates between the mill body and the discharge trunnion. The pulp flows freely through the openings. These mills have a lower pulp level than over flow mills, reducing the dwell time within the mill. Little over grinding will take place and the product will contain a large fraction of coarse particles.

Trunnion Over Flow Designs are the simplest to operate and most common. Energy consumption is less, while it produces about the same efficiency as the grate discharge.

Autogeneous Grinding (AG) and Semi Autogeneous Grinding (SAG) were developed to reduce grinding-media consumption. Autogeneous mills use tumbling to achieve comminution. Semi autogeneous mills use a combination of ore tumbling and a reduced load of steel balls. In these mills, large pieces of ore, 15 cm (6") is used to reduce grinding costs. Some of these mills also use large media balls with large pieces of ore. These mills are operated "semi-autogeneously" using "as-crushed" ore.

Benefication

Grizzly Screens are used to screen the coarsest particles. Some use heavy parallel bars or chains to remove oversize boulders. Some are shaken or vibrated to facilitate sizing and remove the oversize particles. Feed flows down the Grizzly to prevent clogging, which can be a major issue in the process.

Sieve Bend Screens are used to wet screen very fine particle sizes. The feed slurry enters the top surface and flows down the screen. Sieve Bends are typically used in closed-circuit grinding of heavy mineral ores.

Hukki Screen uses both classification and screening. The open stationary vessel with a cylindrical top section and a conical base, allows the feed to enter at the top. The wash water enters through the bottom. Over-sized particles exit through the base and the undersized pass through the screen mesh.

Vibrating Screens are the most common method for classification. They offer large surface area, simple installation and low cost per ton screened. Although screens as fine as 45 µm (325 mesh) are used, the practical limit is 150 µm (100 mesh). Vibrating screens consist of a vibrating inclined-plane screen. There are two modes of vibration: rectilinear path or circular to elliptical path. Screens can be wire cloth, bars or punched metal. They can be metal or plastic (urethanes). Screen vibration is imparted by hammers, cams, eccentric motors, electro-magnetic mechanisms or other means.

Trommels are one of the oldest screening devices. Generally they are an inclined, rotating cylindrical screen and can be used wet or dry. Material is fed in one end of the screen cylinder and the oversized flows out the other end. A major problem with this screen is rapid wear.

Compound Trommel overcomes this wear problem with the use of concentric cylinders. The particles are coarse at the center and get progressively finer as they move outward.

Shaking Screens use a reciprocating movement to mechanically drive material in the horizontal direction. They are mounted in a horizontal to slight incline. They strike at 60 to 800 per minute and find use for grading large size feed. They are used dry for grading coal, but seldom used with abrasive metallic ores.

Reciprocating Screens use a horizontal gyratory motion to the end of a rectangular screen. The motion at the feed end slowly diminishes to the opposite end. However, this motion spreads the slurry at the feed end and concentrates it by the terminal end. This reduced action aids in the screening out of the "near mesh" particles and are used for fine separations down to 45 µm (325 mesh).

Gyratory Screens imparts gyratory motion throughout the whole screen cloth. Used wet or dry, they are used for screening down to 45 µm (325 mesh).

Vibrating Screens are the most important screening machine for mineral processing. They handle ore from 25 cm (10") – 250 µm (60 mesh) in size. Vibration is induced vertically and can operate at low slopes. Coarse screening machines are known as "full-floating screens".

Mogensen Sizer® operates on the principle that a definite and quantifiable probability that a particle will pass through an aperture larger than the maximum diameter of that particle.

Rotating Probability Screen was developed to extract fines from lump raw coal. A horizontal circular screen is rotated, which avoids the problem of deck blinding and clogging fine mesh apertures.

Classification

Hydraulic Classifiers use water flowing counter-current to the feed pulp to accelerate settling. Commonly called elutriators, the feed pulp flows into a vertical column where water moving up from the base is rising and the denser particles settle out. The higher the velocity, the longer the particles take to settle. Typically these units are placed in succession to more and more particle sizes. Although some of these classifiers are unhindered, most are of the hindered-settling type.

Horizontal Classifiers come in several forms. They are the hindered settling cones, mechanical classifiers, and spiral classifiers. Settling cones are the simplest form of horizontal classifier. More common in the aggregate industry to deslime coarse sand products, they also find use in upgrading coal and mica.

Mechanical Classifiers take several forms, but essentially take material of lower settling velocity to an overflow and the faster settling velocity is deposited on the bottom.

Rake Classifiers utilize rakes actuated by an eccentric motion, which slowly moves material up the incline to the discharge.

Hydrocyclones use centrifugal force to accelerate the settling particles. It has become one of the most important devices in the mineral industry to classify fine particles efficiently. It is widely used in close circuit grinding operations, but has also shown success in desliming, degritting and thickening operations.

Magnetic and High Tension Separators are used where there is a difference in magnetic attraction. Magnetic Separators can be low and high intensity separators, wet or dry, and control the rate of materials moving through the field. Two types of magnetics are used: Diamagnets are used to repell particles and are very small forces and Paramagnets produce attractive forces that can be concentrated.

Dense Medium Separations (DMS) or Heavy Medium Separation (HMS) or Sink-Float Process is applied to the preconcentration of minerals after the rejection of the gangue, but prior to the grinding for final liberation. This process is also used for coal preparation to use commercial grade end products. It is one of the simplest gravity processes, but uses harmful high density liquids or thick suspensions (pulp) or some heavy solid in water to create the density differential. These mediums behave as heavy liquids and can make sharp separations at any required density. The principle works best if the valued mineral is coarsely aggregated in the host rock.

Wemco® Cone Separators are large [up to 6 m (20') in diameter]. The feed is fed onto the surface where the float fraction overflows a weir. The sinkers are removed by pump.

Drum Separators can be up to 4.3 m (14') in diameter. The medium is fed into the drum, where it sinks to the bottom, the valued mineral remains in the riffles along the bottom, lifted and conveyed to a sink launder and out. The float passes through the lower area.

The Two Compartment Drum Separator uses two rotating drums. The first compartment produces a pure float product and the sink is lifted and conveyed to a second compartment to separate middlings and true sinks. Drum separators have huge sink capacities. They work best for metallic ores where sinks are 60% – 80% of the feed.

Drew Boy Baths are used in the United Kingdom to take raw coal in one end and the float comes out the other end. The sinks collect in the lower end.

Norwalt Washers were developed in South Africa to handle raw coal which is fed into the center of an annular separation vessel with stirring arms. The floats are carried around by stirrers and discharged over a weir. The sinks collect in the bottom and are dragged out by scrapers attached to the bottom of the stirring arms.

DSM Cyclones are a centrifugal separator used with very fine ferrosilicon or magnetite media which is introduced to the cyclone under pressure (gravity head). The sinkers leave via the central vortex finder.

Vorsyl Separators are used to treat coal up to 50 mm (2") and rates up to 120 tons per hour. The feed is deslimed raw coal and the media is usually magnetite introduced tangentially or by involute entry. The heavier shale particles move to the wall and down the throat. The vortex tractor retains the medium.

Larcoderms (Large Coal Dense Medium Separator) treats coal up to 10 mm (4"). The cylinder is inclined 30 degrees to the horizontal and feed the media is injected by pump or static head. Clean coal is removed in the vortex.

Dyna Whirlpool Separator is similar to the *Larcoderm* and used for coal, diamonds, fluorospar, tin, lead, and zinc. It can handle ore from 30 mm (1.25") to 0.5 mm (20 mil). The cylinder is inclined to 30°, the media is pumped in and creates a vortex. Float passes down the vortex and does not contact the outer wall (reducing wear). The float leaves out the lower vortex outlet tube.

Tri-Flow Separator consists of two Dyna Whirlpool Separators in series. Although primarily used for coal, it can be used in metals and non-metals. Two different density media can be used to produce two sinks. In coal, the second stage cleans the float to produce a higher grade coal. In metals, the second stage can be used to scavenge the sinks for dense minerals. Two stages increase the sharpness of separation.

DMS Separators are used in DMS circuits. Magnetite or ferrosilicons are removed by a drum lined with magnets. The concurrent rotation unit removes the water and clean magnetic particles. In the counter current rotation unit, the feed flows opposite to the rotation of the drum. The tailings travel in the opposite direction.

Cross-Belt Separators are used with mineral sands to recover Ilmenite. Essentially, the ground ore passes beneath a magnet, which picks up the magnetic particles and brushes them off to the side. The non-magnetic particles continue down the conveyor and are dumped at the end. It is one of the oldest magnetic separators.

Disc Separators are a modified version of the belt separator, but uses a closer air gap than the belt design with a greater degree of selectivity. A series of magnetized disks with concentrating grooves revolves above a conveyor belt. This unit is substantially more selective than the cross-belt separator, but the particle size must be finer.

Induced Roll Separators use high intensity magnetic rolls to retrieve particles from a dry, fine <75 µm (< 3 mil) feed dropped between them. They find application in beach sands, tungsten, tin, glass sands, and phosphates.

Continuous High Intensity Wet Separators such as the Jones Separator use a continuous feed dumped onto plate boxes and collected in a launder. Non-magnetics are washed out and the magnetics are retained. This device is especially popular with low grade, iron ores.

High Gradient Separators are used for minerals with low magnetic susceptibility and require magnets with great forces. These large iron devices are used with very fine particles and work well to remove pyrite from pulverized coal.

Super Conducting Separators rely on a current to establish magnetism. A super conductor induces the magnetic field. Periodically, the power is shut down to clean the retain paramagnetics.

Concentration

Froth Flotation utilizes the physico-chemical surface properties of particles in conjunction with reagent treatment, and then by air bubble attachment will lift the particles out of the pulp. It is very efficient for fine particle separations. There are two flotation techniques: Direct Flotation where the desired mineral attaches to the air bubble and goes to the froth for removal leaving the gangue in the pulp or tailings and the second is Reverse Flotation where the gangue is taken into the froth and the valued mineral resides in the pulp.

Froth Flotation Circuits are groups of tanks or cells arranged to handle grinding volumes, changes in flow rates, and easily maintainable. The larger the cell, the lower the maintenance costs. Most mills use between 8 and 14 cells and produce up to 15000 tons per day.

Flotation Columns were developed in recent years and improve separation performance on the finer materials, lower capital and operational costs, and reduce plant space demand. Feed pulp enters the top of the column and treated particles contact the air rising from a sparger at the bottom of the unit. As the air attaches to the particles, they rise to the working area at the top. Wash water rinses free undesired particles, which fall through the column and are removed with the tailings at the base.

Jameson Cells have a mixing device at the top of a vertical downcomer. The air-liquid mixture flows downward into a shallow pool of pulp where bubbles disengage and rise to the top of the column to overflow into a concentrate launder. Tailings leave out the base.

Froth Separators allow the treated pulp to enter from the top onto a froth bed. The hydrophobic particles are retained, while the hydrophilic particles pass through and out the bottom with the tailings. These units enable feed rates up to ten times the rate of other mechanical machines. They typically separate 75 µm (200 mesh) – 2 mm (10 mesh) particles with up to a 3 mm (6 mesh) upper size limit.

Mechanical Flotation Machines are the most widely used flotation cells. A typical cell, the Denver Sub-Aeration Cell has a mechanically driven impeller, which agitates the slurry and disperses incoming air into small bubbles. Cell to cell banks are separated by weirs and can be "open-flow" or "free-flow". The current trend is toward larger units, where most use "open-flow" to give higher throughput. Another cell, the Denver D-R Flotation Machine, consists of a series of square cells separated by a weir. The shaft draws air down the shaft standpipe and is sheared into fine bubbles. Pulp flows over the weir and the process is repeated in the next cell. Tanks can be large, flotation efficiencies are high, operation is simple and used in the "open-flow" design.

Wemco® Fagergren Cell is one of the most used mechanical flotation machines. Pulp flows throw each cell and is drawn up into the rotor by the suction created by rotation. Air is also drawn down the standpipe and thoroughly mixed with the pulp before the bubbles are broke down by the disperser. These units can be very large reaching 85 m^3.

Agitair Machines use a straight-line flow of pulp through the cell. Flow is produced by gravity and the agitator produces a great froth. These units are best for ores with poor floatability.

Sala Flotation Mechanism minimizes vertical circulation. The float disk diffuser, with vertical radial blades, will diffuse air from the upper blade and expel slurry from the lower blades. Aerated slurry is expelled through the conventional circular stator. These versatile blades are used to treat everything.

Electro Flotation was developed to deal with ultrafine particles. An electric current is used to produce a stream of hydrogen and oxygen bubbles in the 10 µm – 60 µm range. Industrial flotation is not used for particles under 10 µm because of the inability to contol air-bubble size. This equipment is most popular in sewage treatment.

Agglomeration Skin Flotation uses special chemicals to agglomerate the air-particles into a denser medium. These agglomerates are denser than the un agglomerated particles and less dense than water.

Table Flotation uses reagents to coat particles that are fed onto a wet shaking table. Hydrophobic particles form aggregates with air bubbles and float.

Magnetic and High Tension Separators are used where there is a difference in magnetic attraction. Magnetic Separators can be low and high intensity separators, wet or dry, and control the rate of materials moving through the field. Two types of magnetics are used: diamagnets are used to repell particles and are very small forces and paramagnets produce attractive forces that can be concentrated.

Jigs are mechanized concentrating devices that consist of a submerged screen that supports a feed of ore. Two currents of water, one moving upward and alternated with a down-current keeps the ore stratified. Particles collect by size and specific quantities. Jigs are used extensively in coal cleaning. They are economical and easy to operate, but use vast quantities of water. The trend is to replace jigs with shaking tables for treating minus 2 mm (10 mesh) ore and "sink/float" for larger sizes.

Harz Jigs are one of the oldest jigs and uses a plunger moving vertically up and down in a separate compartment. The high-grade concentrate is produced in the first compartment, with successively lower grades being produced in subsequent compartments.

Denver Mineral Jig is primarily used to remove heavy minerals from closed grinding circuits, thus preventing over grinding. A rotary water valve can be adjusted to give any variation, from complete suction to complete pulsion. Although jigs come in square and round tanks, circular tanks have the largest capacity.

Circular and Radial Jigs offer large capacity and are used to treat gold, diamonds, and iron as fine as 60 µm (2.2 mil). They can be made with up to twelve modules. Another radial jig, the IHC® Modular Radial Jig offers a rapid upward stroke and a slow downward stroke to accelerate separation.

Coal Jigs show two types of air pulsated jigs. The Baum Jig is over 100 years old, and works by air forced through to cause pulsations. This stratifies the coal enabling separations of a wide range of sizes. The Batac® Jig has no single air chamber, but a series of multiple air chambers (two per cell), and works well for washing coarse and fine coals. No feed preparation is required.

Sluices and Cones are among the most elementary methods of separation. Water carrying a slurry of crushed fine minerals will tend to settle out the heavier minerals in depressions (riffles) in the sluice. Constructed on an incline, a light stream of water will carry lighter minerals down stream, while heavier minerals collect in the riffles.

Pinch Sluices use the same principal as the simple sluice, except that the width decreases by a factor of 10 from the start to the finish. This narrowing creates stratification and separation. Splitters are used to enhance the separation.

Reichert Cone is a wet gravity concentrator device designed for high-capacity applications. It functions like the Pinched Sluice, but the pulp is not influenced by side-wall effects. Several fiberglass cones are stacked vertically.

Humphrey Spiral is a helical sluice. The flow is accelerated by centrifugal action. The coarsest and densest particles collect on the inside, while the lighter material washes over the outside. A series of splitters arranged along the outside curvature enhances separation.

Shaking Tables utilize a film of flowing water down an inclined table. The film velocity profile is higher at the surface of the liquid and lowest at the table surface. Small particles will not move as rapidly as larger particles and will submerge to the slower-moving film near the table. Particles of high specific gravity will move more slowly than lighter particles, so a lateral displacement will take place. The process essentially separates coarse light particles from small dense particles, which is the most metallurgically efficient form of gravity concentrator. Some shaking tables can have multiple decks.

Pneumatic Tables blow air up through a porous bed. It is used primarily for heavy mineral sand deposits. Density and particle size decrease from top down. Coarsest particles collect in the middling bands. The technique is similar to hydraulic classification.

Duplex Concentrators are used for tin, tungsten, tantalum, gold, chromite, and platinum fine feeds. A feed slurry is fed onto a deck where lower density particles runoff and heavy minerals stay on the first deck. After time, gangue washes off the upper deck with water, then the table is tipped to a higher angle and heavy minerals are washed off. One table is always concentrating, while the other is always being washed off or discharging concentrates.

Centrifugal Concentrators have been designed to treat ultra-fine particles. The Knelson® Concentrator has an active fluidized bed to capture heavy minerals. A force roughly 50 times gravity, centrifugally traps heavy particles on a collecting ring. The gangue is flushed away. The Mozley™ Multigravity Separator (MGS) uses two slightly tapered open-ended drums mounted back to back. The drums rotate at 90 rpm – 150 rpm to produce 5 – 15 times the force of gravity with a sinusoidal shake to separate particles.

Simple Leaching and Pressure Leaching are the two primary methods used. Simple leaching occurs at ambient temperature and atmospheric pressure. Pressure leaching is accomplished when pressure and temperature is increased to accelerate the operation. The method chosen depends on the grade of the feed material.

In-Situ Leaching or **Leaching In-Place**, are used with ores, which are too far underground or too low a grade for surface treatment. A leach solution is circulated down through a fractured ore body to dissolve the values and then pumped to the surface. The metallic compounds are precipitated.

Heap Leaching is used for semi-low ore grades, which are high enough in concentration to be brought to the surface. Heap leaching is increasing in popularity as tonnages of more semi-low grade ores are mined. The ore is piled on plastic or elastomeric liners and sprayed with leach solution, which trickles down through the heaps while dissolving the values. The leachate or pregnant solution is drained away and collected in precipitation tanks.

Tank Leaching is used with higher-grade ores, which can be carried out in two ways. One method uses very large-scale concrete tanks, which hold several thousand tons of ore and a circulating solution. The second method uses small amounts of finely ground high-grade ore, which is agitated in tanks by air or mechanical impellers. In both methods, the leachate is passed to a precipitation process after leaching.

Pressure Leaching shortens the treatment time by improving the solubility of solids, which otherwise dissolve very slow at atmospheric pressure. Autoclaves are used for these processes. Both horizontal and vertical styles are used.

Dewatering

Clarifiers are similar in design, but less robust handling suspensions of lower solids content than the thickener. The Continuous Thickener consists of a cylindrical tank, ranging from 2 m (6.5') to 200 m (650') in diameter, and from 1 m (3.3') to 7 m (22.5') high. Pulp is fed into the center of the tank by a feed-well about 1 m (3.3') below the surface. This creates little disturbance as possible. The clarified liquid overflows a peripheral launder and the solids settle to the bottom. Within the tank, there are one or more radial arms and blades to rake the settled solids toward a central outlet. In most modern thickeners, these arms rise automatically as the torque starts to rise to prevent overloading. Tanks are constructed of steel and/or concrete. As the tank diameter increases, a superstructure maybe required to support the rake mechanism, which is referred to as a bridge or beam thickener.

Traction Thickeners use a single long arm mounted on one end of the central support and the other end is a fixed traction wheel that runs on a rail along the periphery. Cable Thickeners have a hinged rake arm fastened to the bottom of the drive cage or center shaft. The hinge provides simultaneous vertical and horizontal movement of the rake arm. The rake arm is pulled by cables. A Caisson Thickener is large enough that the center column can house a control room.

Lamella Thickeners use a nest of inclined plates, which reduce the settling distance and increase the effective area. As the solids accumulate, they slide down the plates for collection. The entire lamella pack can be vibrated intermittently or contiuously for handling sticky sludge.

Centrifugal Sedimentation is an extension of gravity separation. As settling rate is accelerated due to centrifugal force, emulsions which are normally stable under gravity can be separated by centrifuge. Centrifugal sedimentation can be performed either by hydrocyclone or centrifuges. The hydrocyclone is simple, but limited to the solids concentration and the relative proportions of overflow and underflow. Even a small diameter cyclone falls off rapidly as particle sizes drop below 10 µm (0.5 mil). The cyclone is better suited to classification than thickening.

The **Continuous Solid Bowl Scroll Centrifuge** sees the widest usage. The unit has a horizontal revolving shell or bowl, cylindro-conical in shape. Inside of this, a screw conveyor rotates at a speed slightly higher or lower. Through the center tube of the screw conveyor and out into the bowl, the solids pass into where centrifugal action deposits the solids on the inner surface of the bowl. The solids are then transported through the outlet. Solids are continuously dewatered. The final moisture content of the product can be 5% – 20%

Continuous Vacuum Filters fall into three categories- drums, disks, and horizontal filters. The **Rotary-Drum Filter** is the most common type in industry and can be used to filter or cake washing. A drum is mounted horizontally and partially immersed in a filter trough containing feed slurry. The periphery of the drum is divided into compartments which when the drum is rotated, can be internally evacuated to build filter cake on the filter. As the drum rotates, the cake is removed by a reverse blast of air, which lifts the cake for easy removal.

Hyperbaric Filters have been developed to deal with the need for continuous pressure filtration. Some of these are simply drum filters inside a large pressure vessel, while Rotary Disc Filters - rotate they collect cake on both sides of the disc and lift the cake above the slurry in the trough where the cake is sucked dry. A pulsating air-flow blows the cake with the help of a scraper onto a collection area.

Horizontal Belt Filters consist of an endless perforated rubber drainage deck supporting a separate belt made from a suitable filter cloth. During the horizontal belt travel, slurry flows by gravity on to the belt, filtration begins and the filter cake forms. The filter cake is then dried by air passing over the belt. Applications for these filters are increasing in hydrometallurgical circuits where metal values are dissolved in alkali or acid.

Tube Presses use hydraulic pressure at 100 bars (1500 psig) to squeeze water from the slurry. The slurry enters an annular space between a filter tube and an outer tube. The outer tuber contains the filtration pressure. The filtrate, which collects in the central well is discharged at the far end of the press. Tube presses can save up to 80% of the energy consumed by a thermal dryer.

Rotary Thermal Dryers are common in the mineral processing industry. There are two designs, direct fired and indirect fired, direct fired being the most common. Indirect fired is used when the gases cannot come in contact with the product. The dryer consists of a long cylindrical shell mounted on rollers at a slight incline. Product feed is delivered at one end of the shell while the dried product discharges at the opposite end under gravity. Dryer units have the capability of drying product to less than 1% moisture content.

Chart 1: Shafts, Shaft Ventilation, and Hoists

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Hoists	601 Chain Drive and Pin Bushing Lubricant/715 Spraflex® Gold, 615 HTG #2-460, 787 Sliding Paste	ARC S1PW ARC S1HB	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Bearing Housings and Gearboxes	615 HTG #2-460, 783 ACR	ARC 858	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Motors	635 SXC, Lubri-Cup™, 860 Moldable Polymer Gasketing	ARC S1PW, ARC S1HB	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Structural Steel	740 Heavy Duty Rust Guard	ARC S1HB, ARC S4	N/A	N/A	N/A
Ductwork	N/A	N/A	N/A	N/A	N/A
Fans and Housings	635 SXC, Lubri-Cup	ARC BX1, ARC BX2, ARC SD4i, ARC S2	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Concrete Floors	415(E) Concrete Sealer	ARC 791, ARC CS2, ARC CS4	N/A	N/A	N/A
Cages	752 Cold Galvanizing Compound	ARC S2	N/A	N/A	N/A
Shaft Liners (Concrete)	415(E) Concrete Sealer	ARC 791, ARC 988	N/A	N/A	N/A
Shaft Liners (Steel)	N/A	ARC S2	N/A	N/A	N/A
Shaft Bottom Pump	615 HTG #2-460, Lubri-Cup	ARC S2, ARC SD4i	N/A	1810/2810, Split Seals	1730SC, DualPac® 2211, DualPac 2212

(E) IL/MRO products available for EMEA region only.

Chart 2: Roof and Ground Control

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Drainage Channels and Concrete Floors	415(E) Concrete Sealer	ARC 791, ARC 988, ARC CS2, ARC CS4	N/A	N/A	N/A
Structural Steel	N/A	ARC S1HB	N/A	N/A	N/A
Roof Support, Cylinders: Leg, Canopy, Base Lift, Ram, and Chock	787 Sliding Paste, 800 GoldEnd® Tape	ARC S2	W21K, 22KE Rod and Piston Seals, Piston Cap Seals, Wear Bands	N/A	N/A
Dewatering Pumps	615 HTG #2-460, Lubri-Cup	ARC S2, ARC SD4i	N/A	1810/2810, Split Seals	1730, 1730SC, DualPac 2211, DualPac 2212
Motors	273 Electric Motor Cleaner, 635 SCX, Lubri-Cup, 740 Heavy Duty Rust Guard, 775 Moisture Shield	ARC S1PW. ARC S1HB, ARC S2	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A

(E) IL/MRO products available for EMEA region only.

Application conditions may differ. Speak with a Chesterton representative or other experienced professional before selecting a product.

Chart 3: Underground Ventilation

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Fans and Housings	635 SCX, Lubri-Cup™	ARC S2, ARC SD4i	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Structural Steel	N/A	ARC S1HB	N/A	N/A	N/A
Baring Housing and Gearboxes	635 SCX, Lubri-Cup	ARC 858	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Motors	635 SCX, Lubri-Cup	ARC S2/ ARC S1PW	30K Bearing Protection	N/A	N/A
Heat Exchangers	783 ACR, 860 Moldable Polymer Gasketing	ARC S2/ARC SD4i	N/A	N/A	N/A
Coolant Pumps	615 HTG #2-460, Lubri-Cup, 783 ACR	ARC SD4i	N/A	1810/2810, Split Seals	1400R, 1730, 1730SC, DualPac® 2211, DualPac 2212
Compressors	783 ACR, 860 Moldable Polymer Gasketing	ARC S2, ARC SD4i	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	S20, 225	890 Moldable Polymer Gasketing
Vacuum Pump	346 Descaler and Chemical Cleaner, 615 HTG #2-460, 783 ACR, 860 Moldable Polumer Gasketing	ARC S2, ARC SD4i	N/A	891, 1810, S10	890 Moldable Polymer Gasketing

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Chart 4: Beneficiation

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Screen Decks	615HTG #2-460, Lubri-Cup	ARC BX1, ARC BX2/ARC BX5, ARC MX1	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Screen Table/Frames	763 Rust Transformer®/ 740 Heavy Duty Rust Guard	ARC SD4i	N/A	N/A	N/A
Motors	635 SCX, Lubri-Cup	ARC S2	N/A	N/A	1730, 1730SC, DualPac 2211, DualPac 2212, SpiralTrac™ (optional)
Slurry Pumps (Bayer Process)	See Chart 9: Comminution	See Chart 9: Comminution	N/A	1810	1830 SSP, 477-1T with 1400R, DualPac 2211, DualPac 2212
Liquid Pumps (Bayer Process)	See Chart 9: Comminution	N/A	N/A	2810	1830 SSP, 477-1T with 1400R, DualPac 2211, DualPac 2212

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Application conditions may differ. Speak with a Chesterton representative or other experienced professional before selecting a product.

Chart 5: Underground Mining

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Process Pumps	235 SSC, 615 High-Temperature Grease, 610 Plus Lubricant Synthetic Fluid, 690 FG Lubricant, 783 ACR	ARC BX2, ARC MX2, ARC S2, ARC SD4i	N/A	1810/2810, Split Seals	1730
Shearers	601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 787 Sliding Paste	ARC BX1, ARC BX2, ARC BX5, ARC MX1	Custom Seal Kits	N/A	N/A
Plows	601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 787 Sliding Paste	ARC BX1, ARC BX2, ARC BX5, ARC MX1	Custom Seal Kits	N/A	N/A
Drills (Pneumatic)	652 Pneumatic Lubricant and Conditioner, 740 Heavy Duty Rust Guard, 783 ACR	ARC S2	N/A	N/A	N/A
Drills (Wet)	740 Heavy Duty Rust Guard, 783 ACR	ARC S2	N/A	N/A	N/A
Loaders	601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 787 Sliding Paste	N/A	Custom Seal Kits	N/A	N/A
Continuous Miner	601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 787 Sliding Paste	N/A	W21K, 22KE Rod Seal, 22K Rod Seal	N/A	N/A
Shuttle Car	601 Chain Drive Pin and Bushing Lubricant, 725 Nickel Anti-Seize Compound, 740 Heavy Duty Rust Guard, 787 Sliding Paste	ARC S1HB, ARC S1PW, ARC S2	N/A	N/A	N/A
Fork Truck	601 Chain Drive Pin and Bushing Lubricant, 783 ACR	N/A	Custom Seal Kits	N/A	N/A
Roof Bolter	652 Pneumatic Lubricant and Conditioner	N/A	Custom Seal Kits	N/A	N/A
Rotating Drum Miner	601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 783 ACR, 787 Sliding Paste	N/A	Custom Seal Kits	N/A	N/A
Ripper Miner	601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 783 ACR, 787 Sliding Paste	N/A	Custom Seal Kits	N/A	N/A
Structural Steel	740 Heavy Duty Rust Guard/763 Rust Transformer®	ARC S1HB	N/A	N/A	N/A
Concrete Floors	415(E) Concrete Sealer	ARC CS2	N/A	N/A	N/A

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Chart 6: Underground Haulage

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Conveyor	615 HTG #2-460, Lubri-Cup™, 783 ACR	N/A	N/A	N/A	N/A
Carts	615 HTG #2-460, Lubri-Cup, 783 ACR, 787 Sliding Paste	N/A	N/A	N/A	N/A
Trolleys	615 HTG #2-460, Lubri-Cup, 783 ACR, 787 Sliding Paste	N/A	N/A	N/A	N/A
Trucks	615 HTG #2-460, Lubri-Cup, 740 Heavy Duty Rust Guard, 783 ACR, 787 Sliding Paste	N/A	W21K, 22KE Rod and Piston Seals, Piston Cap Seals, Wear Bands	N/A	N/A
Trains	615 HTG #2-460, Lubri-Cup, 740 Heavy Duty Rust Guard, 783 ACR	N/A	N/A	N/A	N/A

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Chart 7: Concentration

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Tanks (Concrete)	N/A	ARC CS2, ARC CS4	N/A	N/A	N/A
Tanks (Steel)	N/A	ARC S2, ARC S4+, ARC S1HB	N/A	N/A	N/A
Structural Steel	740 Heavy Duty Rust Guard	ARC S2, ARC S1HB, ARC S1PW	N/A	N/A	N/A
Pumps	615 HTG #2-460, Lubri-Cup, 860 Moldable Polymer Gasketing	ARC BX1, ARC BX2, ARC MX1, ARC MX2	N/A	1810/2810, Split Seals	1400R* with 477-1T End Rings or 1830 SSP, 1730SC, DualPac® 2211, DualPac 2212
Tables	783 ACR	ARC S2, ARC SD4i	N/A	N/A	N/A
Concentrators	235 SSC, 783 ACR	ARC S2, ARC SD4i	N/A	N/A	N/A
Jigs	235 SSC, 783 ACR	N/A	N/A	N/A	N/A
Coner	235 SSC, 783 ACR	ARC BX1, ARC BX2, ARC MX1, ARC MX2	N/A	N/A	N/A
Flotation Cells	615 High-Temperature Grease, Lubri-Cup, 235 SSC	ARC S2, ARC SD4i	N/A	N/A	N/A
Separators	235 SSC, 783 ACR	ARC S2, ARC SD4i	N/A	N/A	N/A

* Includes Bayer Process

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Application conditions may differ. Speak with a Chesterton representative or other experienced professional before selecting a product.

Chart 8: Classification

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Classifiers	235 SSC, 783 ACR	ARC BX1, ARC MX1	N/A	N/A	N/A
Feed Pulp Pump	15 High-Temperature Grease, Lubri-Cup™	ARC MX1	N/A	1810/2810, Split Seals, SpiralTrac	1730, DualPac® 2211, DualPac 2212, SpiralTrac (optional)
Water Pump	635 SXC, Lubri-Cup, 783 ACR	ARC S2, ARC S1PW	N/A	1810/2810, Split Seals, S10/S20	1730
Hydroclone	783 ACR	ARC MX1	N/A	N/A	N/A
Cenfrifugal Seperator	783 ACR	ARC BX1, ARC BX2, ARC MX1, ARC MX5	N/A	N/A	N/A
Gravity Separator	783 ACR	ARC S1, ARC SD4i	N/A	N/A	N/A
Slurry Pumps	615 HTG #2-460, Lubri-Cup, 783 ACR	ARC BX1, ARC BX2, ARC MX1	N/A	1810/2810, 170, Split Seals	1730, 1730SC, DualPac 2211, DualPac 2212, SpiralTrac (optional)

* Includes Bayer Process

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Chart 9: Communution

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Chutes, Screen Decks, Discharge Lips, and Fumes	740 Heavy Duty Rust Guard, 763 Rust Transformer®, 783 ACR	ARC BX1, ARC BX2, ARC S2	N/A	N/A	N/A
Motors	635 SXC, Lubri-Cup, 860 Moldable Polymer Gasketing	ARC S1PW	30K Seal, 33K Seal, Polymer Labyrinth Seal, Matrix Seal	N/A	N/A
Structural Steel	740 Heavy Duty Rust Guard, 763 Rust Transformer	ARC S1HB, ARC S2	N/A	N/A	N/A
Slurry Pumps	615 HTG #2-460, Lubri-Cup, 783 ACR	ARC BX1, ARC BX2, ARC MX1, ARC MX2	N/A	1810, 170, SpiralTrac	1730, 1730SC, DualPac 2211, DualPac 2212, SpiralTrac (optional)
Clarifier	615 High-Temperature Grease, Lubri-Cup, 783 ACR	ARC S1PW, ARC S1HB	N/A	N/A	N/A
Wash Water Tanks	783 ACR	ARC S1PW, ARC S1HB	N/A	N/A	N/A
Grinding Mills	615 HTG #2-460, Lubri-Cup, 715 Spraflex® Gold	N/A	N/A	N/A	N/A
Jack Hammers	652 Pneumatic Lubricant and Conditioner	N/A	N/A	N/A	N/A
Crushers	613 Moly Grease, 615 HTG #2-460, 783 ACR	N/A	N/A	N/A	N/A

* Includes Bayer Process

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Chart 10: Dewatering

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Gravity Thickener	274 Industrial Degreaser, 601 Chain Drive Pin and Bushing Lubricant, 740 Heavy Duty Rust Guard, 783 ACR	ARC S2, ARC SD4i	N/A	N/A	N/A
Structural Steel	N/A	ARC S1HB	N/A	N/A	N/A
Dryers	615 HTG #2-460, 740 Heavy Duty Rust Guard/763 Rust Transformer®, 783 ACR	ARC BX1, ARC BX2, ARC MX1	N/A	N/A	1730, 1730SC, DualPac® 2211, DualPac 2212
Filters	235 SSC, 615 HTG #2-460, Lubri-Cup™, 740 Heavy Duty Rust Guard/763 Rust Transformer	ARC S4, ARC SD4i	W21K, 22KE Rod and Piston Seals, Piston Cap Seals, Wear Bands	N/A	N/A
Filter Press Pump	615 HTG #2-460, Lubri-Cup, 860 Moldable Polymer Gasketing	ARC S2, ARC SD4i	N/A	2810	1400R, 1730, 1730SC, DualPac 2211, DualPac 2212

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Chart 11: Material and Waste Handling

Application	Industrial Lubricant/ MRO Products	ARC Industrial Coating Products	Polymer Seal Products	Mechanical Seal Products	Packing & Gasket Products
Tanks (Concrete)	N/A	ARC S2, ARC S4+, ARC S1PW, ARC S1HB	N/A	N/A	N/A
Tanks (Steel)	N/A	ARC CS2, ARC CS4	N/A	N/A	N/A
Chutes	N/A	ARC BX1, ARC BX2, ARC S2	N/A	N/A	N/A
Conveyors	615 High-Temperature Grease, Lubri-Cup	ARC BX1, ARC BX2, ARC MX1	N/A	N/A	N/A
Tailings Pumps	615 High-Temperature Grease, Lubri-Cup, 860 Moldable Polymer Gasketing	ARC MX1	N/A	1810/2810, 170, Split Seals, SprialTrac™	1730, 1730SC, DualPac 2211, DualPac 2212, SpiralTrac (optional)
Concrete Pipe	N/A	ARC 791, ARC 988	N/A	N/A	N/A
Steel Pipe	N/A	ARC S2	N/A	N/A	N/A
Tailing Valve Bodies	783 ACR	ARC BX1, ARC BX2	N/A	N/A	N/A

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A.W. Chesterton Company
860 Salem Street
Groveland, MA 01834 USA

Telephone: 781-438-7000
Fax: 978-469-6528
chesterton.com

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