Physical separation methods, Part 1: A Review

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Abstract. Herein, the importance of physical separation methods of ores in mineral processing is widely acknowledged. Of interest is the magnetic separation, gravity concentration and sensor-based separation methods. The process of separating elements of value from gangue in ores depends on its chemical nature and mineralogical attributes hence the need for a profound characterization prior to physical separation. Some ores especially copper sulphides are readily available in nature in low grades usually less < 1% while some may appear relatively in small isolated deposits (Baba et al, 2012). Therefore, it is costly to extract a small portion of a purified metal from such ores. To circumvent high energy and costs when conducting relevant extraction operations, ores directly from mines can be processed physically before smelting, leaching, purifying or other recovery processes. Most physical separation plants and processes are adjunct to the mines to avoid transportation of a heavy ore with only a small portion of valuables. The aim of this review is to present an understanding on physical separation methods with emphasis on how they take advantage of ore physical properties to achieve separation. In addition, developments of these methods with growing technology is also presented.

1. Introduction
Extractive processes done on ores after mining activities are smelting, hydrometallurgy, floatation and electro-technologies. Due to diminution of high grade metal ores, extracting valuables directly from ores without physical separation practices first, consumes high energies and are costly processes. Therefore, physical separation techniques are important as they increase the metal grade and makes it easier to render valuables from gangue materials. The physical separation can be achieved by a few processes which includes; gravity concentration, dense medium separation, magnetic separation, sensor-based separation etc. These processes take advantages of the ore physical properties such as shape, size, density, color or light adsorption, magnetic susceptibility, and electrical conducting properties etc. For instance, particles of magnetite although they are minute, they are highly magnetic and if passed through poles of a magnet they will attach to that magnetic material, this magnetic property they exhibit allows them to be removed from gangue material with ease [2].

Physical separation follows crushing, a particle size reduction activity which liberates particles and increase surface areas. This is of benefit to separation processes and for drastic increase in chemical reaction rates during concentration. In physical separation of ores, a metal concentrate is attained without chemical decomposition since it does not occur at molecular level but rather it involves separation of aggregates [3]. The run of mine ores are readily available with non-uniform constituents and mostly available as low grades <1% to utilize for economic purposes or worst case scenario may
even be too coarse to process. Considering the structure of chalcopyrite, which is CuFeS$_2$ and according to atomic weight, 1 part of copper entails 3.46 parts of chalcopyrite. Taking account that the chemistry of chalcopyrite is not changed during physical processing, a Cu-concentrate with 29% (\[1/3.46\] *100) copper grade will be achieved. If copper was to be extracted from the very same chalcopyrite through smelting or dissolving chemically enormous heat will be required hence high cost. Physical separation can be considered dry or wet depending on the requirement of water (wet) as the processing medium. Most of physical separation process requires large volume except a few such as electrostatic methods (dry). In wet processing it is important to have water treatment plants connected in series with the physical separation plants so that water can be purified and recycled for the next batch of the physical separation process.

2. Physical separation methods

Valuable minerals can be separated from gangue materials by means of physical separation. Some physical separation techniques such as gravity concentration have been in practice as early as sixteenth century. Egyptians monuments from 3000 BC also depicts the use of film concentration used in the washing of gold. Evidence of further theoretical and experimentations on physical separation methods is believed to have been performed in nineteenth century (Aplan F, F, 2003)

Physical separation methods such as medium separation, magnetic separation, gravity concentration and sensor-based separation method can be applied to fresh ores from mines or tailings or even recycling plants for scavenging useful elements. Fig 1. Shows a typical scavenging flow sheet for a combination of processes from stockpiles of metallurgical wastes to physical separation techniques.

![Figure 1. Process flow for waste materials.](image)

2.1. Gravity Concentration

This is a natural geological separation process that takes advantage of gravity or centrifugal force to separate mixed particles either in suspension or in dry condition. These particles are usually of different shapes, sizes and specific gravity being the latter. The property of density is paramount during separation, but size and shape of the components also plays a significant role in separation efficiency. If there is a wide variation on these properties, then separation is affected [5]. The most prominent advantage about this method is its low operational cost and reduction efficiencies. Literature has shown that more on gravity concentration is yet to be studied. Nonetheless, some countries like USA use roughly about 25% for degritting coal and most ores by this method more than its counterpart, which is flotation [3]. Other applications of gravity separation techniques are in industries for separating food grains, in paper pulp, toxic waste pipes, recycling solid waste etc. The principle of gravity concentration center around utilizing specific gravities of particles for success separation but to some extent can also take account of some physical properties such as size and shape.
[3, 5]. The best working range for gravity concentration is coarse particle size of 130 mm- 74µm. Fine particles (< 74 µm) are difficult to treat by gravity separation method. The settling kinetics of finer particles is quite slow [6]. Mineral processors use the concept of concentration criterion to determine the suitability of gravity concentration on particles below it can be applied. This criterion is defined as the CC equation 1. Given below.

\[
CC = \frac{SG(\text{heavy mineral}) - SG(\text{fluid})}{SG(\text{light mineral}) - SG(\text{fluid})} \quad \ldots \ldots (1)[8]
\]

And if CC is greater than 2.5, then the separator is suitable for working with particle size above 74 µm, for CC in the range 1.75 -2.5 the separator can work with particle size above 150 µm while any CC value between 150-1.75 the separator is suitable for degritting particles above 1.7 mm by size. For CC from 1.25-1.50 by value the working size for a separator is above 6.35 mm. If the value of CC is 1.25 then the separator is considered not suitable for any size [8].

Recent research and developments to focus more on invention of devices that accommodates for finer particles [6]. Physical properties of ore particles dictates their behavior when subjected various degritting devices. Some concentrating devices and corresponding size particles they work well with are given in table 1.

| Table 1. Concentrating devices and corresponding size ranges [3]. |
|-------------------------|------------------|------------------|
| Course                  | Intermediate     | Fine concentration |
| +6.4 mm                 | 6.4-100mm        | -0.150 mm        |
| Jigs, Heavy media, handheld device, Heavy media hydrocyclone, hindered-settling classifier, pneumatic jigs etc. | Jigs, heavy media hydrocyclone, water-only cyclone, Sluices, shaking tables, Humphreys-type spirals, cannon concentrator etc. | Kelsey Jigs, Round table, vanners, Cannon concentrator, Reichert cone, falcon concentrator, Mozley multigravity concentrator etc. |

2.1.1. Mechanics of gravity concentration. This method separates particles with different specific gravities. Specific gravity is simply the ratio of a particle’s density to some standard fluid usually with a unit equal to 1 [7]. According to Thomas, J (1978), the law of specific gravity was discovered by Archimedes in about 250 BC. The findings on this discovery were that if a floating particle is submerged in a liquid, the force that buoy the particle is equal to the to the weight of the liquid they displace. In mineral processing this principle is applied to separate components of differing gravities when lifted by a vacuum over a screen with vibrational effects. This leads to a lighter material being suspended in air while heavier impurities remain on the screen and are discarded out. Separation can be achieved in 2 main ways i) subjecting finely liberated particles in dry conditions under a gravitational or centrifugal force that enhances the settling kinetics of these particles, this is known as hydraulic separation and ii) subjecting particles to a wet media with a counter current flow which affect the fluid-particle interaction leading to a hindered settling phenomenon. The wet media is usually water, and this is known as pneumatic separation. Water has a high density which make separation in wet sharper than in dry conditions though it requires dehydration of the concentrate and tailings after separation [5, 8]. This problem is common during coal cleaning which results in the product with 10 % moisture. On the other hand, when using hydraulic separation, concentration can be achieved in a short period of time mainly because the centrifugal forces enhances gravity making particles to arrange and settle in the radial direction (Sarkar et al, 2018) . Particles can experience a free settling or hindered settling phenomenon. In hindered settling there is resistance due to a pull force from external sources while in free settling the particles to be separated falls freely without any opposing forces from other particles. Assuming spherical particles under separation, a Newtonian
relationship has been developed to calculate the terminal or free settling velocity of these free falling particles.

2.2. Magnetic separation (M-S)

Magnetic separation is applied in ore processing for separating magnetic materials, particularly Iron [4]. The advent of magnetic separation found favour in mineral processing for over 200 years ago. The knowledge and use of magnetic concepts can be traced back to Thales of Miletus, A Greek philosopher, mathematician and an astronomer who lived from c. 624 – 546 B.C [9]. In this approach, separation of particles is archived by passing finely liberated ore particles through a spectrum of a magnetic field preferably of sufficient magnitude. The resulting effect is the retention of magnetic particles (paramagnetic) to the vicinity of the separator’s magnetic component. On the other hand non-magnetic (diamagnetic) components deflects and falls off. At least one component of the particles should have magnetic susceptibility properties thereby responding to a magnetic field. Iron and magnetite are strongly magnetic materials therefore classified in a special group called ferromagnets. A reddish bronze ore pyrrhotite, hematite, Ilmenite, Ferberite, Franklineite and siderite etc. are paramagnetic materials. Diamagnetic materials includes Silica, bismuth, cobaltite, and skutterudite etc. The most common application of this method is in separation of Iron and iron bearing substances, ferrous and non-ferrous containing materials [10]. The recovery process of magnetite ore from blast furnaces is not 100% efficient since massive tailings are produced with substantial amount of iron losses. According to estimations, about 1 tonne of iron ore recovered from beneficiation produces 400 kg of tailings containing Iron grade equal or marginally more than iron grade found in other iron ores exploited. Also discard from gravity concentration of iron-bearing ores contains >39 wt. % of iron (Dauce, P.D, 2018). Recovery rates of iron can be increased by processing of tailings using magnetic separators. Such a practice is fast, efficient and can be of economic benefits and helps reduce the volume of tailings in landfills which is of interest to environment sustainability [12].

2.2.1. Separation mechanism

A real practical example which demonstrate the concept of magnetic separation is very common in scrap yards for sorting metals. A heavy magnetic metal is used to lift only magnetic materials and what remains behind is the non-magnetic components. The magnet is so strong such that it can withstand the gravitational forces of components. In mineral separation, besides force of gravity there are some external competing forces such as centrifugal, inertia, hydrodynamic forces etc. These forces can hinder separation therefore for successful separation of strong magnetic particles, the magnitude of magnetic force of the separator must be greater than that of competing forces summed together. Whereas, for weak magnetic particles the force of the separator must be smaller than the sum of external competing forces (Svoboda, J, 2005). However the two divergent forces should be of comparable magnitude such that the difference is too small. Otherwise if there is a large difference between the magnetic force of the separator and sum of competing forces i.e. \( F_{\text{separator}} \gg \Sigma F_{\text{opposing}} \), then separator cannot distinguish different magnetic components which respond differently to applied magnetic field. The attraction and deflection occurs along the line of a magnetic field until a point where the magnetic field intensity is large for paramagnets or small for diamagnetic components (Will, 2016). Another important factor in separation is the magnetic field gradient. Magnetic susceptible materials will mostly respond to a non-uniform field therefore the magnetic component of the separator should be capable of producing a significant field gradient (Wells, 1991).

2.2.2. Magnets for separators

The growing technology and research has led to development of more advanced tools for separation. Magnetic separators can be equipped with conventional magnets, permanent magnet and superconducting magnets depending on the physical attributes of components to be separated. The
efficiency of the separator depends on the type of magnet used (its strength, to be specific), as well as the volume and magnetic susceptibility of the component.

**Permanent magnets** were developed to address problems associated with conventional magnets during processing. These types are also called rare earth magnets, have a much higher intensity and are capable of producing high magnetic field gradient as compared to conventional magnets. This enable them to separate weakly paramagnetic components. Permanent magnets manufactured around the 1970’s were made of samarium and cobalt. With advancing manufacturing technology, engineers were able to design even high intensity rare earth magnets composed of neodymium, iron and boron. The two examples of the rare earth magnets are the rare-earth drum (RED) and the rare-earth roll (RER) magnets. RED is an NdFeB magnet with about 0.9 T strength that align uniquely to perpendicular to the drum surface. RED separates two or more weakly magnetic particles. RER has low operational capacity and effective in treatment of finer particles less than 1mm compared to its counterpart. This magnets on separators usually acts as pulley heads and as fines are fed on the pulley at higher velocities they experience a magnetic field which separates them according to their susceptibility (Dobbins et al, 2007). A typical separator installed with such magnets is the boxmag rapid mgnaroll magnetic separator. This separator was mostly commonly used for the removal of ash and sulphur containing components from coal (Wells, 1991). Another application is separation of iron bearing impurities from non-magnetic minerals. Permanent magnets can be applied separators for application in mining industries and solid state chemistry [15]. The latest permanent magnetic roll separator (permroll) is capable of producing field strength of up to 1.6 T.

**Conventional magnets** are divided into 2 main groups, the ones used in High intensity magnetic separators and the other group used in low intensity separators. These are designed to remove deleterious tramp iron components in mineral processing equipment’s e.g. during production of silica, feldspar and zircon etc. it’s necessary to remove iron that occurs alongside these compounds to avoid damage to the equipment. These magnets are capable of separating components of different susceptibility. High intensity magnetic separators are used for either wet or dry applications for separation of weakly magnetic particles with low susceptibilities (Norrgran, 1988). Magnets with such high intensities are used in Induced-roll separators (IRM), Jones separators and Frantz Isodynamic separator. IRMs are for dry applications most commonly in sand circuits. But for better capacity the RERs are good replacement [14]. IRMS are used for cleaning of quarts, calcite and other non-magnetic particles by removing paramagnetic compounds with an attractive force of about 2.2 Tesla and high field gradient [17]. The Jones separator was designed for wet applications. In wet applications the main competing forces are the magnetic field force and the hydrodynamic drag forces (Shao et al, 1996). So for successful separation the field of the separator must be greater than the drag force. Jones separators have a plate-box like design with steel structure on the box edges mainly for support. The Jones separator is also grooved such that the magnetic field is concentrated on the tip of ridges and it can reach values above 2 Tesla. Addition to the list of conventional magnets for high intensity separators is the Frantz Isodynamic separator (FIS) which also separate mineral particles according to their magnetic susceptibility and how the individual particles in question behave towards applied field vs gravity. This process is effective but takes time and can only with particle size range of ~74 -700 µm. Otherwise very coarse will clog the separator. Conventional magnets can be applied in low intensity magnetic separators to produce flux densities around 0.2 T for mostly winning ferromagnetic particles such as magnetite, taconite and pyrrhotite etc. and other paramagnetic particles with high susceptibilities from non-magnetic materials. This low intensity separators can also be done in wet and dry applications. Examples of the low intensity are the protective (dry) (figure 3) and wet magnetic separators. The protective magnets are installed on conveyer heads mainly for removal of tramp magnetic materials from diamagnetic materials. To date most coal industries apply these technique to separate coal from magnetite in wet conditions. Traditionally low intensity wet separators have been used as the workhorse for winning iron from its ore magnetite.
Figure 2. Removal of tramp magnetic materials by protective magnets [4].

Though traditional permanent magnets are still widely applied in separators for mineral processing, they are limited to other applications e.g. separation of relatively weak magnetic components against hydrodynamic and opposing forces especially under liquid and gaseous streams has its own problems and complexity. This has made significant demands on the manufacturing industry to design more stronger and efficient magnets. Fortunately the magnet technology has expanded well enough to produce strong **superconducting magnets** that can produce more than twice the magnetic field of permanent magnets (up to 5 tesla). This permits for separation of small particles in liquid or gaseous streams [20]. Though some text dates the use of first conductor with strength of up to 20 T in 1950 in physics and research astronomy community [19], the first reported superconductor used in the USA was 1986 mainly for minerals and in 1986 they successfully installed a superconductor separator with twice the magnetic field as the previous. In the following years these separators started to get attention in Germany and Brazil [21]. The magnetic field of superconductors is produced by inducing an electrical current through resistive coil. They can also be generated by permanent magnets. The field strength is maxed by altering the geometry of magnets. However but both the solenoid coil and the permanent magnet have limits, for instance the magnetic field of the resistive coil is limited by windings which produce some form of intrinsic resistance (Vankatraman, 2004). In operation of superconductor separators, low power is required for cooling rather than to offset the ohmic losses from the magnet’s coil. So the use of these separators offers great economic efficiency which is proportional to the field strength. (Svoboda, 2005)

One distinct feature of the superconducting separators it the solenoid coil. Examples of the superconducting magnets includes the high gradient wet magnetic separator (HGMS) and the Open gradient dry separator (OGMS). OG separators offers deep strong magnetic field which renders for large volume for separation. The magnet can be inclined such that feed material falls over and as they reach the neighbourhood of the magnetic zones deflection of the magnetisable species in an inhomogeneous manner according to their size and magnetic susceptibilities. So with this separators the geometry of the magnet makes it easy to generate the required field gradient for rather than incorporating a matrix (Svoboda). The HGMS offers a higher magnetic intensity mainly form the superconductor coil instead of a solenoid coil used for open gradient separators. Contrary to a read by Vankatraman, (2004) the coil has no resistance so much lower power is required to charge the magnet. This coil is also capable of storing energy which enables a once off charge. The trapped particles are removed using a ram, so step determines the separation efficiency of the magnet. The magnet also allows for charge and discharge incase for demagnetization purposes at the end of the separation cycle (Svoboda, 2005).
2.2.3. Magnetic separation equipment.
Magnetic separation equipment has been classified accordingly as 3 main groups namely; equipment for tramp iron removal, magnetic separation equipment for purification or concentration and lastly equipment designed for product cleaning. Tramp iron separators act as protection to handling and processing devices such as screens, crushers, pulverizing machines etc. in mineral processing mainly to avoid abrasion wear, discoloration or contamination by tramp iron. These should be applied on materials which are dry or with surface moisture. The separators for tramp iron removal includes rare earth magnets applied in pulleys of conveyor belts, plates magnets found in chutes, grate magnets incorporated and various magnetic drums that are installed as separate units in separators [23]. Concentration equipment such as magnetic pulley separator, magnetic drums, induced roll magnets, wet intensity magnetic separators and high gradient magnetic separator (HGMS). HGMS can be used for purifying limestone and other minerals such as kaolinite. Concentration separators can also be used as cleaning separators and have been used for recovering elements that are lost along gangue materials. Some research conducted in mid-90s shows that Boliden Mineral AB had a high gradient magnetic separation installed adjunct to the flotation tank to recover zinc lost along lead concentrate after flotation of their main target product copper.

2.3. Sensor based separation method
Sensor based separation commonly known as sensor based sorting is a dry separation technology for separation of coal, diamonds and various minerals according to physical properties calibrated on the sensor. These properties include reflectance, color, magnetism, atomic density, visual fluorescence brightness etc. (Wills, 2016). The principle of the particle detection technology is simply the actuation of impulses of the detector by identification of sample particles which report back “yes/no” ejection decisions [25]. First, individual particles are eminently identified by a sensor followed by rejection mechanisms of an amplified mechanical or pneumatic processes [26] Hand sorting in some extent can be considered as a conventional technique for sensor based separation. Hand sorting involves the sorting on mineral particles based on visual examination while sensor based it the automation counterpart. Hand sorting has been years ago in mining separation but due to the demand of processing of extremely low grade ores and fine particles its application has declined with time and growing technology. However hand sorting can still be applied as a preliminary separation technique e.g the removal of timber components from tramp iron. It is also still applied in countries with low pay rates (Wills mineral processing, 2016). According to research there is evidence of patents from late 1920s that proves the application of optical based sorting (a technology along the lines of sensor based sorting) to have a long history in mineral processing. Application of sensor based separation techniques in mineral processing without any doubts offer a wide range of advantages. The use of such a technique addresses certain challenges by other separation methods. The use of this method results in improvement of critical areas i.e. consumes less energy, solves ore dilution problems, reduced water usage and environmental impacts (Mahlangu et al, 2016). From processing of fines point of view traditional sensor based methods have lost popularity since the development of more advanced sensor based separators. Modern separators solves limitations associated with previous techniques such as inability to separate a media with both coarse and fine particles, Impreciseness resulting from fluctuating particle movements and conventional sensors are limited to separation by color variations [26]. The diamond industry profit from using this technique to separate diamond from its ore Kimberlite. This method on separation of diamonds enables the removal of waste rocks embedded in its ore which deems difficult with other separation techniques [27]. Sensor based sorters are divided in accordance to the work they form. Use of conventional techniques poses significant challenges hence the ideology of development of efficient and sustainable techniques to address challenges in question while maximizing profit e.g. Development of high temperature sensors to increase durability in high temperature applications, introduction of sensors for processing fines and many more to reduce energy usage and improves life of mine in a challenging landscape. The two main sorter are the chute-type and belt type figure 3a and 3b respectively. Other types include
the channel-type, bucket-wheel type and the cone-type sorter. In the chute-type sensor the ore particles are introduced to the sensor system through an inclined chute of some angle sufficient enough to allow for free fall. Before the particles reach the reject or accept chambers they encounter an optical beam of the sensor mounted on both sides to allow detection of properties on both sides. The belt system consists of a moving belt in a fixed point like a pulley system. Particles are introduced into the belt on one end and allowed to settle prior to detection on the other end by a sensor fixed on a location above the belt. Because there is enough settling time this gives a better resolution as compared to the chute-type system [28].

These types can be further classified according to two groups which are transmitting and reflecting technologies. The reflection system is composed of the optical camera which captures particles according to surface features while the X-ray of the transmission system identifies particles in accordance to the difference in density. ‘’Yes or no’’ decision causes the individual particles to be removed from the mainstream through the mechanism of air jets [25]. The transmitting technology analyses the inner constituent’s features of individual particles while the reflecting scans and interprets surface information. So with reflecting technology the sample particles need to be free from contaminants as much as possible for accurate interpretation of information. The main disadvantages of reflecting types the inability to achieve 100% probability of detecting all components of the
particle. Examples of transmitting technologies include but are not limited to X-ray transmission (XRT), electromagnetic sensor (EM). X-ray luminescence is a reflecting sorter.

2.3.1. XRT
It is a dry separation process that identifies materials based on particle properties such as specific atomic density, regardless of its size, moisture content or pollution level. XRT is capable of sorting high atomic mass particles and also provides high quality data of both the internal structure and information on contaminants (Kolacz, 2012). It is used in sorting or separation of diamonds, gold, coal and sulphide ores. It upgrades the grade of gold especially in gold bearing sulphide. Crushed ore particles are fed into screens prior to introduction onto a conveyor belt (belt-type sorter). The XRT for identification is equipped with an x-ray source such as an electrical tube which creates a broad-band radiation that penetrates the material and provides absorption data. This data which records on the x-ray camera as a digital dense image. The material is scanned at a rate of about 3m/s. The sensor system consists of 2 distinct channels which records the image depending on energy levels i.e. one captures images of low density while the other captures high density images so thickness and atomic weight of particles plays a major role in quantification in this process. Density is usually measured as shades of grey. The commands instructions of the system then allows the valves to open and close for the identified particles to exit the system. The individual identified material is pulled from the rest of the material by jets or compressed air. Materials separates in two different chambers the “reject” and “accepted”. An example of the XRT such as the dual energy x-ray transmission (DE-XRT) is very useful in separation of coal from torbanite which often results in contamination of coal. This separation also removes pyrite sulphur (Ketelhodt et al, 2010, tombra ref). Another application of this automatic sorting technique is in classification of base metals according to respective atomic densities of the constituents (Mesina et al 2006).

2.3.2. Near-infrared (NIR)
It is a recent technology in the world of mineral processing and mining industry (mahlangu). It analyses materials based on particle behavior under reflected light in the near infrared spectrum of the sensor. NIR spectroscopy of the sorter analyzes information such as chemical compositions as well as the context of associations and occurrence. The belt moving at 3m/s usually accommodates a throughput of up to 300tonn/hr with particles sizes not greater than 300mm due to mechanical constraints. The working principle of the NIR is simply the emittance of radiation from the NIR source above the belt. The radiation then penetrates the material and a polygon mirrors mounted perpendicular to the belt axes reflects point signals to the spectrometer of the detector unit. The mirror is mounted such that it allows for rotation so that the point scanner covers the whole belt width. the data is interpreted by the spectrometer as a hypercube with 3 point coordinate x, y and λ (spectral response) (Robben 2012).There are well known advantages associated with the use of NIR such as low operational cost, non-destructive, offers reduced processing time in mineral processing and provides higher resolution and extended frequency ranges [36]. It can be applied to discriminate between kimberlite and waste materials.

3. Summary
Physical processing of ores is important in mineral processing. Physical processes offers a wide range of advantages when rendering elements of values from low grades ores such as energy efficiency, reduced processing time, ability to separate finer particles etc. This enables mines to up its economic reserves. Some ores naturally occurs as low grades and extraction of minerals of interest from these ores with smelting, hydrometallurgy and electrorifing processes is very costly. Separation of the ore physically prior to these activities helps reduce the operational cost and ease up extraction processes. Physical sorting is important as a start-up activity. From the listed physical separation methods, a choice of sorting technique to use is selected based on the nature of ore, its size particles after crushing and surface properties and other physical properties.
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