Optimizing the performance of wet drum magnetic separators

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Synopsis

The difference in the magnetic properties of minerals is the basis for magnetic separation. All minerals can be generally classified as ferromagnetic (strongly magnetic), paramagnetic (weakly magnetic) or diamagnetic (non-magnetic). Magnetic separation can be conducted dry or wet. The majority of the applications of wet magnetic separation in the mining industry are based on the wet drum magnetic separator. The wet drum magnetic separator has been in use for over 50 years and its design is based on a rotating drum installed inside a tank. Inside the drum are stationary, permanent magnets arranged in an arc to provide the magnetic field. These magnets can be of the ceramic ferrite type providing a low intensity magnetic field or of the rare earth type providing a high intensity magnetic field.

Wet drum magnetic separators are generally applied in three different ways, namely to recover and recycle the medium used in dense medium separation (DMS), to remove magnetic contaminants from ores and concentrates, and to recover valuable magnetic products. Wet drum magnetic separators are applied in the following commodity areas: coal, diamonds, iron ore, chrome, platinum, heavy mineral sands, industrial minerals, and base metals.

Whereas the design and operation of wet drum magnetic separators is relatively straightforward, it is very often found that the performance of wet drum magnetic separators is far from optimum. The reason for this is generally a lack of understanding of how the different design and operating variables interact and how they affect performance. This paper examines these variables, describing their importance and impact for all applications of wet drum magnetic separators. It also provides clear guidelines on how to adjust and control these variables so that optimum performance is achieved.

Keywords

Magnetic separation, ferrite and rare earth magnets, magnetite and ferrosilicon recovery, magnetic flocculation, demagnetization

Basic principles of magnetic separation

Classification of magnetic substances

Substances which can be magnetized, to a greater or lesser extent, by a magnetic field are called magnetic substances. From a beneficiation perspective substances can be magnetically classified as follows:

- Strongly magnetic or ferromagnetic such as ferrosilicon and magnetite
- Weakly magnetic or paramagnetic such as haematite
- Non-magnetic or diamagnetic such as quartz.

A ferromagnetic material when exposed to a magnetic field becomes magnetized but when it is removed from the magnetic field it remains magnetized and the degree of magnetization, or saturation magnetization, will vary according to the type of material. This magnetization is largely irreversible and is referred to as hysteresis. The only practical way to reverse this magnetization is by demagnetization.

A paramagnetic material when exposed to a magnetic field will become magnetized but, unlike ferromagnetic materials, will not retain the magnetization. The strength of the magnetic field required to attract paramagnetic materials will vary according to the type of material.

There is a misconception around the term 'non-magnetic'. Many people believe that if an ordinary magnet does not attract a material then that material is non-magnetic. An ordinary magnet will generate a magnetic field strength of 1000 to 2000 gauss. This will attract only ferromagnetic materials. For a material to be actually non-magnetic, the generation of a magnetic field, no matter how strong, will not attract the material.

Magnetic susceptibility

Magnetic susceptibility is a measure of the magnetic response of a material to an external magnetic field. The specific or mass susceptibility x, measured in units of m^3/kg, is defined as the ratio of the material magnetization J, (per unit mass) to the external magnetic field H:

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$$J = \times H \qquad [1]$$

All materials have magnetic susceptibility, which can be either positive (ferromagnetic and paramagnetic) or negative (diamagnetic). Ferromagnetic materials have large and positive susceptibilities and paramagnetic materials have small and positive susceptibilities. As an example, magnetite has a magnetic mass susceptibility range of 20 000 to 110 000 1 whereas for haematite it is 10 to 760[1]. Most materials have ranges of magnetic susceptibility because of variations in chemical composition (mainly iron) and physical properties (mainly crystalline structure).

The magnetic force *F* acting on a particle is proportional to the sum of mass susceptibility *x* and particle mass *m*, as shown below:

$$F \infty \times m^3 \qquad [2]$$

The significance of this is that for a particle with a positive mass susceptibility, the larger the mass of the particle, the smaller the magnetic field required for recovery. In other words, lower magnetic field strengths are required for recovering coarser particles. As an example, a particle with a magnetic susceptibility of 10 and a particle size of 1 mm will require the same magnetic field strength for recovery as a particle with a magnetic susceptibility of 10 000 and a particle size of 1 micron.

This is why very fine particles are often viewed as non-magnetic simply because they require very high magnetic field strengths for recovery.

Under a given set of conditions for magnetic separation to be applied, the recovery of the magnetic fraction will decrease with a decrease in particle size. Therefore, the conditions have to be modified to increase the probability of recovering finer particles. This is one of the most critical aspects of the application of wet drum magnetic separators and will be covered in more detail further on.

The magnetic susceptibility of all ferromagnetic and paramagnetic materials decreases with an increase in temperature—maximum magnetic susceptibility is taken at absolute zero.

Paramagnetic materials displa only a gradual decrease in magnetic susceptibility. For all ferromagnetic materials, they maintain their magnetic susceptibility with an increase in temperature until the Curie point is reached. At the Curie point the materials change from ferromagnetic to paramagnetic. As the temperature increases beyond the Curie point, the materials remain paramagnetic with a gradual decrease in magnetic susceptibility. However, from a beneficiation point of view, this has no impact since the Curie points for the materials of interest are at high temperatures (>300°C).

Magnetic field strength and gradient

In terms of wet drum magnetic separators, the permanent magnets installed inside the drum generate an external magnetic field of a strength that is dependent on the intensity of the magnets. Most wet drum magnetic separators are of the type with ceramic ferrite magnets generating a field strength between 1 500 and 2 500 gauss. Rare earth wet drum magnetic drum separators have rare earth based magnets generating a field strength between 3 000 and 10 000 gauss. The field strengths are measured at the surface of the drum.

Wet drum separators are open gradient separators. In other words, as the distance from the drum surface increases, so the magnetic field strength decreases. The rate of magnetic field decrease with the increase in distance from the drum surface is the magnetic gradient and this varies between different designs of wet drum magnetic separators. The gap between the drum surface and the bottom of the tank is on average about 25 mm. If the magnetic field strength is between 2 000 and 2 500 gauss at the drum surface then at 25 mm from the drum it will be between 1 000 and 1 500 gauss.

The combination of magnetic field strength and gradient will have the greatest influence on the recovery of a magnetic particle. The majority of applications of the wet drum magnetic separator are for the recovery of ferromagnetic materials. These materials have a high magnetic susceptibility, which means that the magnetic field strength and gradient generated by the separator will be adequate. For the recovery of paramagnetic materials, the application of wet drum separators will be effective only for coarser particles, generally over 100 microns.

Competing forces in magnetic separation

In wet magnetic separation when a particle with a positive magnetic susceptibility is being attracted by an external magnetic field, the force exerted by the magnetic field is mainly in competition with gravitational force and with drag force. In all types of physical beneficiation gravitational force is present and in some cases it is a process enabler (gravity concentration) or, as in the case of magnetic separation, it has to be overcome. However, in the application of wet drum separators the competition with drag force or hydrodynamic force is critical. In wet magnetic separation the impacts of hydrodynamic force are related to slurry velocity and slurry density. An increase in slurry velocity will increase the fluid drag force, which in turn will decrease the recovery of magnetic particles when the fluid drag force overcomes the magnetic force. An increase in slurry density will increase the slurry viscosity. An increase in slurry viscosity beyond a certain point (which varies between different feed materials) will result in excessive entrainment of non-magnetic particles within the magnetic concentrate. The effects of hydrodynamic force become more pronounced as the feed solids particle size decreases. The impacts of the competing forces are the same for ferromagnetic and paramagnetic materials.

Magnetic flocculation and demagnetization

Magnetic flocculation is essentially the agglomeration of ferromagnetic particles as a result of their magnetization in an external magnetic field. This is particularly important in the recovery of magnetite and ferrosilicon in dense media recovery circuits because of the very fine particle size of the media used. Without the mechanism of magnetic flocculation effective recovery of dense media would not be possible. When a suspension of ferromagnetic particles passes through an external magnetic field (between the drum and tank of a wet drum magnetic separator) the particles become magnetized.

Because of their relatively close proximity to each other they become attracted to each other and start forming aggregates of different sizes and shapes. These aggregates then start to attach themselves to the drum surface and, therefore, are removed for recovery to the magnetic concentrate. For these aggregates to form, the flocculation time must be less than the residence time in the wet drum magnetic separator[2]. The flocculation time can be reduced significantly by having a reasonably strong magnetic field. In practice this equates to a magnetic field strength of at least 2 000 gauss at the drum surface. The strength of the aggregates once formed must be sufficient to resist rupture due to hydrodynamic forces[3]. Finer particles have a higher coercive force than coarser particles and as a result finer particles will form magnetic aggregates of a higher tensile strength than those formed from coarser particles[4]. This is because finer particles have a higher residual magnetism than coarser particles after magnetization and magnetic flocculation takes place. This is another key aspect of the success of dense media recovery by magnetic separation.

Whereas magnetic flocculation promotes the recovery of fine ferromagnetic materials, the nature of the effect also promotes 'stubborn' entrainment of non-magnetic particles. As a result of this it becomes very difficult to obtain magnetic concentrates with a magnetics content in excess of 95%. Magnetic flocculation is restricted when either the magnetics content in the feed is very low or when the feed slurry density is very low. In these two cases, the number of magnetic particles will be small thus reducing significantly the probability of magnetic flocculation occurring.

After the removal of the magnetic concentrate in dense media recovery, the magnetic aggregates have to be broken down to allow the dense medium to be effectively mixed back into the correct medium stream. Magnetic flocculation can only be effectively reversed by demagnetization. Demagnetization can be achieved by heating the ferromagnetic material to above its Curie point but this is not practical when it comes to physical beneficiation. Instead, subjecting the magnetic concentrate slurry stream to a reversing and decreasing magnetic field will achieve demagnetization. Demagnetization basically returns the dipoles to a random orientation throughout all the particles—magnetization results in the dipoles all being orientated in one direction. A dipole is an object that has a magnetic pole on one end and a second, equal but opposite, magnetic pole on the other. In practice the magnetic concentrate slurry stream passes through a demagnetizing coil installed around a plastic pipe through which the slurry flows. Passing an AC current through the coil produces the required reversing and decreasing magnetic field.

Wet drum magnetic separator design

Introduction

Wet drum magnetic separators have been utilized in the mining industry for over 50 years and their fundamental design has not changed. The main developments over the years have been in magnet design and tank design. A wet drum magnetic separator consists of a drum housing a magnet assembly and the drum is installed in a tank. Figure 1 below presents a view of the main components of a wet drum magnetic separator. Generally the drum is manufactured from non-magnetic stainless steel and the tank can be mild steel or stainless steel depending on the application. In some applications the drum will have a rubber lining to ensure protection from excessive wear. The drum is supported by a shaft, which in turn enables the rotation of the drum by means of a geared motor coupled to the shaft. The drum rotates at a fixed speed and the speed will vary between applications.

Tank configuration

Figure 2 presents the two principal tank configurations, namely concurrent and counter-rotation. In both configurations the feed reports to a feed box ahead of the tank. There is a tramp screen installed in the feed box which is important because of the small gap between the drum and the tank, on average being 25 mm. The feed box must have a capacity to accommodate design feed slurry flow rates.

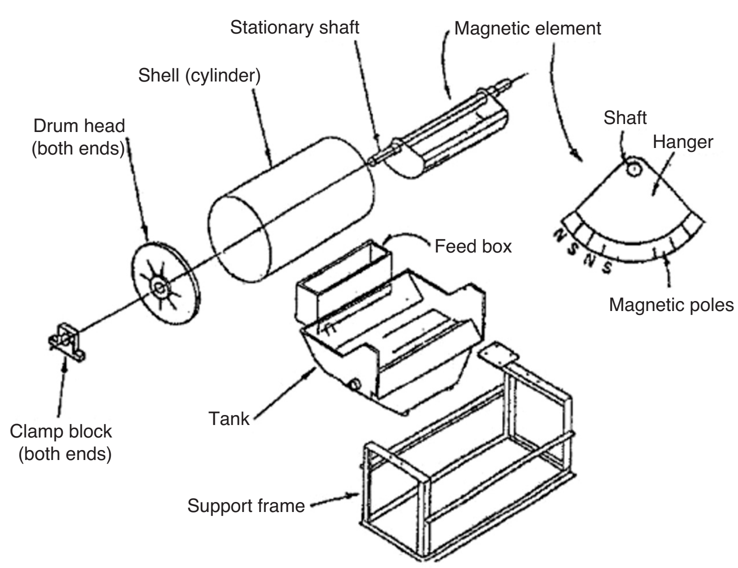

Figure 1—A view of the main components of a wet drum magnetic separator

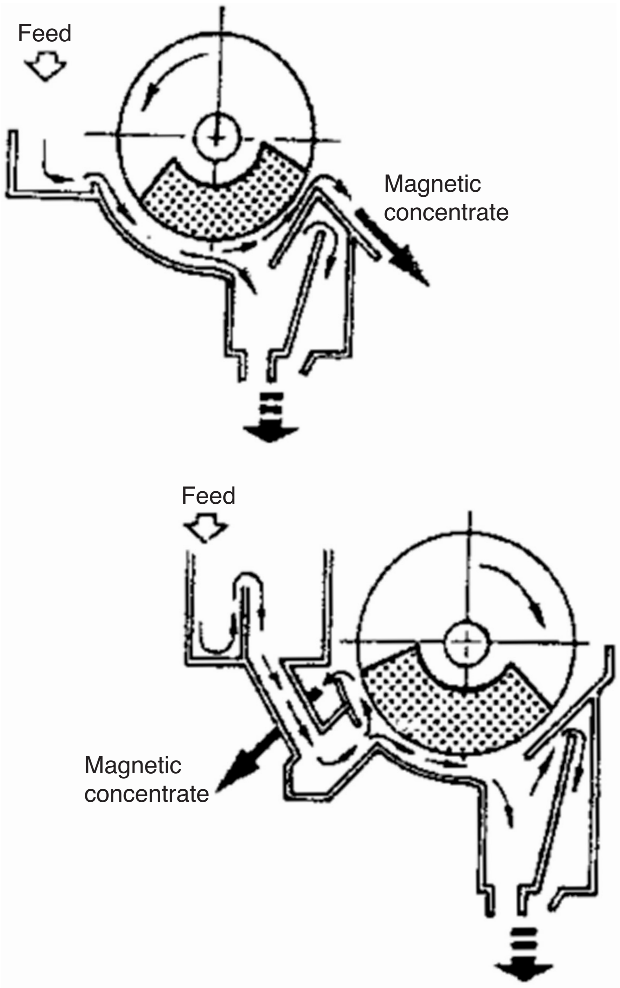

Figure 2—Concurrent tank configuration at the top and counter-rotation tank configuration at the bottom (taken from *Magnetic techniques for the treatment of materials* by J. Svoboda)

In the concurrent configuration, the slurry flows into the tank and makes contact with the drum rotating in an anti-clockwise direction, thus achieving concurrent engagement. The effect of this is to capture and transport the magnetic particles to the other side of the tank for discharge at the concentrate lip. This also has the effect of increasing the residence time of the captured magnetics in the tank, thus promoting grade. Therefore, generally the concurrent tank configuration is applied to the cleaning stages in magnetic separation circuits.

In the counter-rotation configuration, the slurry flows into the tank and makes contact with the drum rotating in a clockwise direction, thus achieving counter-rotation engagement. The effect of this is to capture and transport the magnetic particles close to the feed side of the tank for discharge at the concentrate lip. This also has the effect of minimizing the residence time of the captured magnetics in the tank, thus promoting recovery. Therefore, generally the counter-rotation tank configuration is applied to the rougher and scavenger stages in magnetic separation circuits.

For both tank configurations slurry level is controlled by adjusting underflow valves located underneath the tank. There is also an overflow launder which accommodates the non-magnetics slurry stream not passing through the underflow valves. There are also tank designs that incorporate self-adjusting slurry level which eliminates the need of operator intervention for slurry level control.

Magnets

It is probably true to say that the magnets are the heart of the wet drum magnetic separator. Up until recently wet drum magnetic separators could be applied only to the recovery of ferromagnetic materials as the magnetic field strength at the drum surface did not exceed 2 000 gauss. Modern ceramic ferrite magnets allow a magnetic field strength of up to 2 500 gauss at the drum surface. However, it has been the development of permanent rare earth magnets that has expanded the applications of wet drum magnetic separators. These magnets are primarily centred on the neodymium-iron-boron (NdFeB) magnetic composition and these can provide magnetic field strengths between 3 000 and 10 000 gauss at the drum surface.

The magnets are mounted in a stationary position inside the drum in an arc spanning between 90 and 135 degrees. The magnet assembly is in blocks of alternating polarity, the number and size of blocks varying according to the size of the drum separator. The magnet assembly can be in a radial or an axial configuration inside the drum. In the radial configuration the polarity of the magnets alternates across the width of the drum and is the same along the drum circumference. This type of configuration promotes recovery and improves the volumetric capacity of the drum separator. It is the preferred configuration for dense media recovery. In the axial configuration the polarity of the magnets alternates along the circumference of the drum and is uniform across the width of the drum. This type of configuration promotes improved grade but at the expense of a lower volumetric capacity. Figure 3 below illustrates the difference between

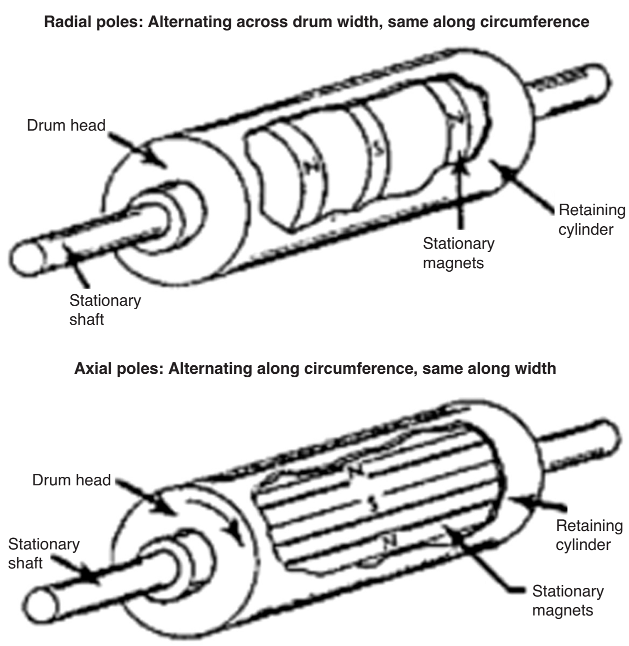

Figure 3—The difference between radial and axial configurations of magnet assemblies (taken from *Magnetic techniques for the treatment of materials* by J. Svoboda)

radial and axial configuration. The materials of construction of the magnets make them very heavy and as such this large mass of the magnets restricts the size of wet drum magnetic separators. Currently the common limit to drum diameter is 1 200 mm and the limit to drum width is 3 000 mm.

Wet drum magnetic separator feed preparation and characterization

Introduction

Wet drum magnetic separator feed preparation and characterization is critical to their optimal operation. It is the author's experience that this aspect of operating wet drum magnetic separators is the least understood. When considering feed preparation and characterization, the following parameters have the greatest impact:

- ➤ Feed slurry density
- ➤ Feed particle size distribution
- ➤ The proportion of magnetic material in the feed solids
- ➤ The distribution of the feed slurry to the magnetic separator.

Feed preparation and characterization has a significant impact on dense media recovery configuration in terms of single stage versus two stage. This will be detailed below.

Feed slurry density

The impacts of feed slurry density are on volumetric capacity, viscosity and magnetic flocculation. If the feed slurry density is too low then the volumetric capacity of the wet drum magnetic separator is likely to be exceeded. Enough separator capacity can be installed to cater for a low feed slurry density but then the associated capital and operating costs increase. Best practice is to design for the lowest practical feed slurry density such that magnetic separator performance is maintained but without excessive volumetric capacity requirements. Another impact of low slurry density is on magnetic flocculation. Low density means fewer particles present in the slurry, which in turn reduces the probability of magnetic flocculation for ferromagnetic particles. This is critical for dense media recovery which relies on magnetic flocculation for the recovery of the very fine magnetite and ferrosilicon particles.

A high feed slurry density increases slurry viscosity. The impact of increased viscosity is an increase in entrainment of non-magnetic particles in the magnetic concentrate. Therefore, if a clean magnetic concentrate is required then lower feed slurry densities will be required. In dense media recovery the magnetite and ferrosilicon slurries have a high viscosity, which is why the maximum allowable density is relatively low. Table I presents feed slurry density guidelines for different applications.

Feed particle size distribution

Successful magnetic separation in ore concentration will initially depend on adequate liberation being achieved. In dense media recovery you are treating a liberated material for recycle purposes. There are two aspects of the feed particle size distribution that influence the performance of wet drum magnetic separators. Firstly, the topsize is generally not greater than 1 mm. This is mainly a function of liberation but also the small gap between the drum and the tank, usually not more than 25 mm, presents a physical restriction on top size to prevent choking of the gap and excessive wear on the drum. Secondly, a decrease in particle size results in a decrease in magnetic susceptibility. The impact of this is a reduced magnetics recovery. In the case of dense media recovery, with magnetite and ferrosilicon being ferromagnetic, the high magnetics content in the feed ensures a high probability of magnetic flocculation, which in turn ensures high recovery. However, when treating lower concentrations of magnetite in iron ore recovery circuits, a decrease in particle size will have a negative impact on recovery and this can to a point be countered by increasing magnetic separator capacity. In the case of treating paramagnetic materials, a decrease in particle size will have an even greater negative impact and this can again to a point be countered by increasing magnetic separator capacity but increasing magnetic field strength will also be required.

The proportion of magnetic material in the feed solids

The proportion of magnetic material in the feed solids has a number of impacts on wet drum magnetic separator performance. The capacity to remove the magnetic concentrate is directly related to the magnetics content in the feed and this needs to be balanced to prevent loss of magnetics. This is particularly critical for dense media recovery and for ore concentration cleaning applications. If the maximum feed slurry densities are not exceeded, as indicated in Table II, then magnetics removal will not be a problem provided the overall solids and volumetric capacities are not exceeded.

In ore concentration circuits the capacity of the rougher stage is dependent on the overall solids throughput because the magnetics content is generally well below 50%. If there are instances when the magnetics content does exceed 50% then the rougher feed slurry density would have to be controlled to the lower end of the range, as indicated in Table II. This would be needed to ensure adequate magnetics removal. The capacity of ore concentration cleaning stages is directly related to the proportion of magnetic material in the feed since the rougher concentrate will contain well over 50% magnetics.

In dense media recovery the proportion of magnetic material in the feed solids is critical to achieving high recovery of magnetite or ferrosilicon. There must be more

Table I

Feed slurry density guidelines for wet drum magnetic separators

Application	Feed slurry density range % solids by mass
Dense media recovery Magnetite and ferrosilicon	5–20
Ore concentration Rougher duty	30–45
Ore concentration Cleaner duty	20–30

Table II

Drum width vs minimum number of feed distribution points

Drum width, mm	Minimum number of distribution points	Drum width, mm	Minimum number of distribution points
300	1	1800	3
600	1	2100	4
900	2	2400	4
1200	2	2700	5
1500	3	3000	5

than 50% magnetics in the feed otherwise there will be insufficient magnetic flocculation which is responsible for the high magnetics recovery required, greater than 98%, in dense media circuits. Figure 4 below shows the relationship between magnetite content in the feed and magnetite recovery in a typical coal washing plant dense media recovery circuit.

The distribution of the feed slurry to the magnetic separator

The capacity of a wet drum magnetic separator is fundamentally a function of drum diameter and drum width. Once a suitable drum diameter and width have been selected, full capacity utilization then depends on distributing the feed across the full width of the drum. This means that if the full drum width is not utilized then magnetic separator performance will suffer because the part of the drum that is being utilized will be overloaded. For a drum width of 600 mm a single feed point into the magnetic separator feed box is adequate but this also assumes that the feed box is cleaned on a regular basis to prevent solids build-up which prevents feed reaching the full width of the drum. For drum widths of over 600 mm two or more distribution points are required for adequate feed distribution. Table II presents the minimum number of distribution points as a function of drum width.

When feed distribution across two or more points is required then a reasonably accurate splitting of the feed is required. The simplest way to achieve this is to install a manifold located above the magnetic separator feed box and having a length equivalent to the drum width. Figure 5 shows a typical feed manifold arrangement for a wet drum magnetic separator.

The concept is simple but a manifold design that works would have to ensure that the feed is evenly distributed along the full length of the manifold and ensure that the slurry velocity inside the manifold is sufficient to prevent settling out of solids, which is particularly critical for magnetite and ferrosilicon.

Dense media recovery single stage versus two stage

In dense media recovery circuit design there is often a debate around a single stage versus a two stage configuration. A two stage configuration means treating the non-magnetics stream from a primary magnetic separator in a secondary magnetic separator to maximize media recovery, whether magnetite or ferrosilicon. It has already been stated that high dense media recovery is dependent on ensuring maximum probability of magnetic flocculation. This in turn is brought about by having the correct feed conditions in terms of slurry density and the proportion of magnetics in the feed solids.

Assuming that the primary magnetic separator is operating optimally, then the secondary magnetic separator will not receive the required feed. The feed slurry density will be too low and the proportion of magnetics in the feed solids will be too low because of the magnetics recovery in the primary stage. Therefore, the magnetics recovery in the secondary stage will be low. One can argue that the purpose of the secondary stage is to provide insurance against poor primary separator performance. However, the correct focus on optimizing wet drum magnetic separator performance will make secondary separator insurance unnecessary.

Where two stage circuits are installed it would make more sense to split the feed to the primary separator between primary and secondary. In this way both separators would

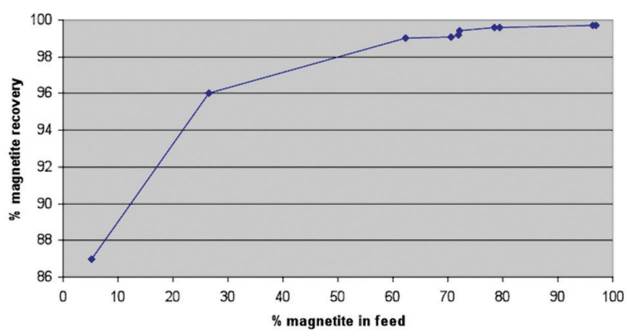

Figure 4—Magnetite content in feed vs. magnetite recovery for a typical coal washing plant dense media recovery circuit

Figure 5—Typical feed manifold arrangement for wet drum magnetic separators

contribute to media recovery effectively and there would be a degree of insurance as well because the volumetric feed flow rate to both separators has been essentially halved. This means that both separators will have increased volumetric capacity, which in turn means more flexibility to cope with feed volume fluctuations.

The case for single stage dense media recovery circuits is further supported by using wet drum magnetic separators with a counter-rotation tank configuration together with a radial magnet assembly configuration in the drum. These two aspects further maximize recovery of the magnetics.

Wet drum magnetic separator capacity considerations

Introduction

The capacity of a wet drum magnetic separator essentially revolves around drum diameter and drum width. For the same drum diameter and drum width different equipment suppliers will quote different capacities. This is primarily as a result of differences in magnet assembly design and tank design.

Capacity is based on solids feed rate and slurry volumetric feed rate. The size of wet drum magnetic separators has to be selected on the basis of satisfying BOTH capacity requirements. If the solids or slurry volumetric capacity exceeds the recommended maximum then the separator will become overloaded, which in turn will result in a decrease in magnetics recovery. If the solids feed rate falls below the recommended minimum then it means that the feed slurry density is too low, which in turn will result in a decrease in magnetics recovery. If the feed slurry flow rate falls below the recommended minimum then it will be difficult to maintain slurry level in the tank, which in turn will result in a decrease in magnetics recovery.

For a given drum diameter the capacity is generally quoted on the basis of tph solids per m drum width and m^3/h slurry per m drum width. The capacities are generally quoted as ranges, the numbers representing recommended minimums and maximums. The ranges are derived as a function of magnet assembly design, tank design, feed solids type and feed solids particle size. For ore concentration there will be differences between rougher and cleaner applications.

Drum diameter and width variations

Commercially available, production scale, wet drum magnetic separators for low intensity applications, such as magnetite and ferrosilicon recovery, have drum diameters of 900 or 1200 mm. Rare earth wet drum magnetic separators are generally available only with 600 mm diameter drums. For any given drum diameter, drum width generally varies between 600 and 3000 mm, the widths being available in 300 mm intervals. Table III presents a capacity comparison between the different drum diameters.

Table III shows that for each increase in drum diameter there is a doubling of capacity. Therefore, when selecting the most appropriate size of wet drum magnetic separator for a particular application, there needs to be a balance between drum diameter and drum width such that capacity minimums and maximums are adhered to while minimizing the total number of separators.

Drum speed

The drum speed for wet drum magnetic separators is fixed and will generally be set at a speed in the range of 10 to 20 rpm. Higher speeds are generally required for feed solids with a high magnetics content. This is to ensure adequate magnetics removal capacity. However, no firm relationship has been established between drum speed and magnetics removal and thus in turn there is no firm relationship with magnetics recovery. Most separators utilize drum speeds below 15 rpm because higher speeds will increase drum wear.

Capacity guidelines

Table IV below presents capacity guidelines for ore concentration applications utilizing 900 and 1200 mm diameter drum separators.

Table III

Comparison of capacities of different drum diameters

Drum diameter, mm	Maximum feed solids tph per m drum width	Maximum feed slurry flow rate m^3/h per m drum width
600	30	50
900	60	100
1200	120	200

Table IV

Capacity guidelines for ore concentration applications utilizing 900 and 1200 mm diameter drum separators

Feed particle size, microns	Feed solids tph per m drum width 900 mm diameter	Feed slurry flow rate m^3/h per m drum width 900 mm diameter	Feed solids tph per m drum width 1200 mm diameter	Feed slurry flow rate m^3/h per m drum width 1200 mm diameter
-1000	40–60	70–100	80–120	140–200
-300	30–50	50–80	60–100	100–160
-75	20–40	30–60	40–80	60–120

Table V below presents capacity guidelines for dense media recovery (magnetite and ferrosilicon) applications utilizing 900 and 1200 mm diameter drum separators.

The guidelines in Table V have been based on various equipment supplier specifications and a review of literature[2,5,6] and as such will give a reasonable indication of capacity variations as a starting point. Capacity limitations should be benchmarked via equipment suppliers based on their experience with similar applications. Ultimately the best estimate of capacity will be obtained from pilot-scale testwork. Using 600 mm diameter by 300 mm wide wet drum magnetic separators in pilot plant circuits is recommended for obtaining reliable process design data for magnetic separation circuit design.

Wet drum magnetic separator operating parameters

Introduction

Once a wet drum magnetic separator has been correctly sized and the feed to the separator has been optimally delivered then the maximizing of the magnetic product recovery and grade will depend on optimal operation. There are four operating parameters which are crucial to optimal operation:

- ➤ Level control
- ➤ Drum/tank clearances
- ➤ Magnet position
- ➤ Magnetic concentrate removal.

Demagnetization of magnetic concentrates will also be covered in terms of when it is required and the methodology employed.

Level control

Feed slurry reporting to a wet drum magnetic separator is distributed evenly across the full width of the feed box and then flows underneath the full width of the drum and into the tank beneath the drum. The level control of the slurry in the tank must be maintained such that the bottom of the drum is submerged constantly. Most wet drum separators have a slurry level indicator on the side of the separator which shows that the optimum level is being maintained. The bottom of the magnet assembly arc is positioned at the bottom of the drum so that maximum magnetic field strength at the drum surface is obtained. The area of the drum that covers the majority of the magnet assembly arc must be submerged in the feed slurry so that the recovery of magnetics can be maximized constantly. As soon as there is an air gap between the feed slurry and the drum, recovery of magnetics will decrease substantially.

The control of slurry level in most wet drum magnetic separators is by means of spigots or valves located beneath the tank. The spigots or valves are opened until the level indicator shows the required drum submergence is in place. There will always be variations in the feed volumetric flow rate, which means that operators will need to check the level indicator on a regular basis and adjust the spigots or valves if required. A decrease in flow rate will drop the slurry level and create an air gap between slurry and drum, leading to a drop in magnetics recovery. An increase in flow rate will result in a rise in slurry level to the point when some of the non-magnetics stream will report to the magnetic concentrate, leading to a drop in magnetics grade. Most wet drum magnetic separators do have an overflow launder positioned next to the underflow box and this will generally absorb excess feed slurry flow rate. However, the overflow launder will not cope with excess feed slurry flow rate if any of the underflow spigots or valves are choked. Therefore, it is essential that the underflow spigots or valves are regularly checked for choking. It is also important that when in operation all the underflow spigots or valves are opened and level control is maintained with all the spigots or valves, thus reducing the probability of choking. Very often, however, the accessibility of the underflow spigots or valves is a real problem and this discourages regular adjustment and checking. Therefore, it is important that during plant design adequate accessibility to the underflow spigots or valves is provided. The problems associated with level control are largely eliminated in those wet drum magnetic separators that have a 'self-levelling' tank design. These separators do not have underflow spigots or valves and the level adjusts with fluctuations in feed flow rate without operator intervention.

Drum/tank clearances

There are two drum/tank clearances that are critical to wet drum magnetic separator operation, namely the gap between the drum and the bottom of the tank (feed pan gap) and the gap between the drum and the concentrate lip (squeeze pan gap). Figure 6 presents an illustration of these gaps.

The gap between the drum and the bottom of the tank basically determines magnetic gradient. A larger gap will decrease gradient and thus promote grade, and a smaller gap will increase gradient and thus promote recovery. However, there is a fine balance with this gap adjustment. When reducing the gap there will be an increase in feed slurry

Table V

Capacity guidelines for dense media recovery (magnetite and ferrosilicon) applications utilizing 900 and 1200 mm diameter drum separators

Feed solids tph per m drum width 900 mm diameter	Feed slurry flow rate m^3/h per m drum width 900 mm diameter	Feed solids tph per m drum width 1200 mm diameter	Feed slurry flow rate m^3/h per m drum width 1200 mm diameter
10–20	50–100	20–40	100–200

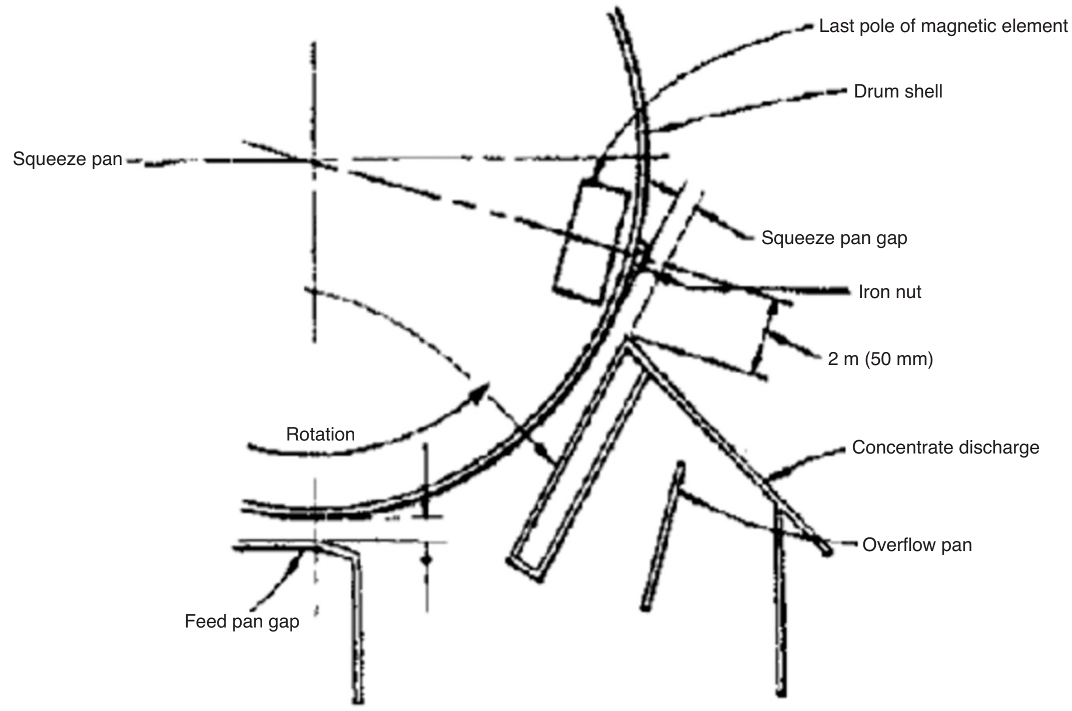

Figure 6—An illustration of the two critical drum/tank clearances and magnet position

velocity if the feed flow rate is not reduced. The increase in velocity will increase hydrodynamic drag, thus reducing magnetics recovery. Therefore, if there is a need to maximize magnetics recovery through a further increase in magnetic gradient then there will have to be a reduction in feed flow rate and thus separator capacity. Best practice is to start with a 25 mm gap and then decrease the gap in stages until an acceptable recovery-grade balance is achieved at the required feed flow rate. Generally the optimum gap is not greater than 25 mm and not smaller than 10 mm. The gap is adjusted by adding or removing shims beneath the shaft and frame.

The gap between the drum and the concentrate lip is the point where the magnetic concentrate leaves the drum and reports to the concentrate lip for discharge into the concentrate launder or chute. The gap enables dewatering of the magnetic concentrate and its magnitude is mainly a function of the magnetics content of the feed solids. If the gap is too large then the magnetic concentrate will have a higher moisture content, and if the gap is too small then some of the magnetic concentrate will be forced into the non-magnetics stream, thus reducing magnetics recovery. As a guideline the magnetic concentrate target slurry density is 60 to 70% solids by mass. Best practice is to start with a 15 mm gap and adjust until reasonable dewatering is achieved without magnetics recovery loss. Slotted shaft clamp mounting holes provide room for gap adjustment.

Magnet position

The magnet position in wet drum magnetic separators refers to the position of the magnet assembly arc in relation to the tank. The arc must cover the area of the drum that is submerged in slurry in the tank and at the magnetic concentrate discharge side of the tank the last pole of the magnet assembly should be approximately 50 mm above the concentrate lip. Figure 6 illustrates this requirement. If the magnet position is too high then magnetic concentrate discharge will be impeded and this will result in build-up of the magnetic concentrate. Eventually some will be forced back into the non-magnetics stream, thus reducing magnetics recovery. A visual inspection of the magnetic separator operation will show magnetic concentrate 'climbing' up the drum. If the magnet position is too low then some of the magnetic concentrate will discharge from the drum before reaching the concentrate lip. This will result in this magnetic concentrate reporting to the non-magnetics stream, thus reducing magnetics recovery. A visual inspection of the magnetic separator operation will show magnetic concentrate struggling to reach the concentrate lip. The position of the last pole of the magnet assembly can be checked with a small steel object such as a nut or a nail. If the steel object is less than or more than 50 mm from the concentrate lip then the magnet position will need to be adjusted at the non-drive end of the drum shaft. Figure 6 illustrates this requirement.

Magnetic concentrate removal

If level control, drum/tank clearances and magnet position are all optimized then magnetic concentrate removal should not be a problem. However, having said that, the passage of the magnetic concentrate from the concentrate lip into the concentrate launder or chute will require some assistance. In the case of the recovery of ferromagnetic materials the assistance is in the form of water sprays. Water sprays can be effective in moving ferromagnetic concentrates providing the following criteria are satisfied:

- Sufficient pressure in the spray water supply, a minimum of 2 bar
- A clean water supply to minimize spray nozzle blockages
- Spray water coverage along the full width of the drum
- The position of the water sprays should be such that the spray is directed onto the concentrate lip
- Excessive volumes of spray water should be avoided as this could hamper the further processing of the concentrate—adequate spray pressure with low spray volume is the optimum
- Effective maintenance of the spray water system and spray water nozzles in particular so that efficiency is not compromised.

Figure 7 shows a spray water installation satisfying the above criteria.

In the case of the recovery of paramagnetic materials using wet rare earth drum separators, the removal of the magnetic concentrate was a significant problem because of the high magnetic field strength of these separators. Spray water alone enabled very little removal of concentrate. A solution to this problem is the installation of a rotary vane scraper on the concentrate lip which rotates in unison with the drum, i.e. a separate drive is not required. The scraper is manufactured from steel and its close proximity to the drum when facing it results in its magnetization from the high magnetic field strength. The consequence of this is that the concentrate in effect 'jumps' from the drum to the scraper. When the scraper turns away from the drum, the degree of magnetization decreases and the concentrate discharges from the scraper with the aid of spray water. Figure 8 shows an installation of this concentrate removal system.

Demagnetization of magnetic concentrates

As mentioned in the introduction to this paper, ferromagnetic materials when exposed to an external magnetic field become magnetized and this then leads to magnetic flocculation during the recovery of ferromagnetic materials using wet drum magnetic separators. A consequence of magnetic flocculation is that the magnetic concentrate produced consists of magnetic agglomerates. These magnetic agglomerates are very strongly bound such that it is difficult to de-agglomerate them. Even using high energy agitation or milling has little effect. The only effective way to de-agglomerate is to demagnetize these magnetic concentrates. Demagnetization is in effect a reversal of the original magnetization. In practice the magnetic concentrate slurry stream passes through a demagnetizing coil installed around a plastic pipe through which the slurry flows. Passing an AC current through the coil produces the required reversing and decreasing magnetic field. Demagnetization of paramagnetic concentrates is not required because paramagnetic materials do not retain their magnetization and, therefore, do not form magnetic agglomerates. Figure 9 shows a demagnetizing coil.

In dense media recovery circuits the recovered media (magnetite or ferrosilicon) has to be demagnetized to allow effective mixing when producing the correct medium stream. When a magnetic concentrate requires regrinding for further liberation then it must be demagnetized to allow effective milling. When a magnetic concentrate undergoes cleaning through two or more wet drum magnetic separators in series, demagnetization in between the magnetic separators is not practised. This is because there is no significant benefit in demagnetizing. Why this should be is not understood and has been the subject of debate over many years. However, if the magnetic concentrate requires cleaning with, for example, a hindered settling classifier then demagnetization will be essential.

Conclusions

The wet drum magnetic separator is a well established and well proven piece of equipment in the global mining industry. It is key to the success of dense media recovery in the overall DMS process, whether for magnetite or ferrosilicon. It is also key in magnetite recovery whether for iron ore production or for producing a concentrate for vanadium extraction.

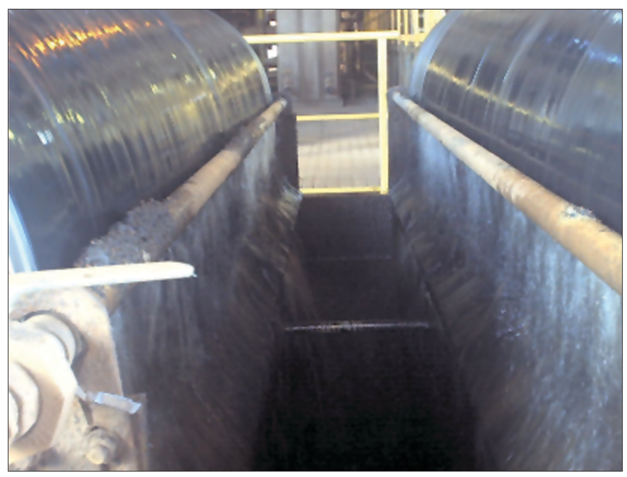

Figure 7—A spray water installation for the removal of magnetite concentrate

Figure 8—Rotary vane scraper system for magnetic concentrate removal (courtesy of Eriez Magnetics)

Figure 9—Demagnetizing coil

Developments in wet drum magnetic separator design have led to a wider use of rare earth wet drum magnetic separators for the recovery of paramagnetic materials. This is already well established in the Brazilian iron ore industry and further applications are likely in other iron ore sectors and in the mineral sands industry.

Although the wet drum magnetic separator is of a relatively simple design and its operation is relatively straightforward, obtaining optimal performance from wet drum magnetic separators still remains a significant problem. This paper has presented a basic background to the principles of magnetic separation that govern the design and operation of a wet drum magnetic separator. A knowledge of these principles is helpful in understanding how the performance of wet drum magnetic separators can be optimized.

The design aspects of wet drum magnetic separators that have the most influence on performance relate to the tank configuration, whether concurrent or counter-rotation, and to the magnet assembly configuration, whether axial or radial.

Wet drum magnetic separator feed preparation and characterization is critical to their optimal operation and the following parameters have the greatest impact:

- Feed slurry density
- Feed particle size distribution
- The proportion of magnetic material in the feed solids
- The distribution of the feed slurry to the magnetic separator.

The capacity of a wet drum magnetic separator essentially revolves around drum diameter and drum width. Capacity is based on solids feed rate and slurry volumetric feed rate. The size of wet drum magnetic separators has to be selected on the basis of satisfying BOTH capacity requirements.

Once a wet drum magnetic separator has been correctly sized and the feed to the separator has been optimally delivered, then the maximizing of the magnetic product recovery and grade will depend upon optimal operation. There are four operating parameters which are crucial to optimal operation:

- Level control
- Drum/tank clearances
- Magnet position
- Magnetic concentrate removal.

In summary, optimal performance of wet drum magnetic separators is based on the following:

- Selection of the most appropriate design in terms of tank and magnet assembly configuration
- Correct feed preparation, characterization and distribution
- Capacity estimation based on satisfying both feed solids feed rate and feed slurry volumetric flow rate, followed by appropriate drum diameter and width selection
- Optimal setting of level control, drum/tank clearances, magnet position and magnetic concentrate removal.

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