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Advances in rare-earth magnetic drum separators for heavy mineral sands processing

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New magnetic materials in the neodymium-iron-boron class enable modifications of conventional magnetic circuits and a new magnetic circuit design (patented). Both dry and wet magnetic drum separators for heavy mineral sands processes have been developed. Testing on a large scale has resulted in dramatic improvements in performance over a prior generation of similar separators.

The development of the designs and the implications for various applications are reviewed. Additional developments will be discussed.

Introduction

By simply replacing all or some ferrite magnets in drum separators, conventional magnetic circuit designs could be used to achieve stronger magnetic forces than low-intensity magnetic drum separators (LIMS). The first available rare-earth magnets (various forms of samarium cobalt materials) for magnetic separator designs were both expensive and not as strong as the neodymium-iron-boron (NdFeB) magnetic materials that became commercially viable in the mid-1980s. Several LIMS manufacturers began to use the new magnets and soon found that some design modifications were required. These will be discussed in the next section.

At INPROSYS, we were first involved as consultants to develop a drum separator using NdFeB magnets in a modified LIMS-type separator. Some years later, we began our own drum separator development by studying the possibilities of using the new magnets from a different view point. Rather than basing new designs on prior ferrite magnet circuit designs, we looked at maximizing the use of the unique properties of NdFeB magnets. The objective was to optimize the effective magnetic force acting on different particle size fractions. This led to one new, unique magnetic design, which offers superior capabilities for separating minerals in fine sizes (below 3 mm) with similar magnetic susceptibilities (US patent, others pending). Of course, this design can be used for larger particles in dry process applications, probably up to 10 mm, but the main advantage for this system is for fine particles.

Improvements of more conventional designs were also made. One of these achieves a maximum force level at greater depth of field intensity for separation of particles in the range zero to 20 mm, usually at very high capacity. Another magnet design is intended for processing 20–80 mm. The designs for small particles are used for both dry and wet separator versions, while the design for large particles can be used for dry and top-fed wet or semi-dry separators.

Although measured field strengths up to one tesla have been recorded, the drum separators cannot match maximum strength High-Force magnetic roll separators with regards to the net magnetic force level. This is due to the fact that the roll separator magnetic field gradient multiplied by the magnetic flux density at the particle location reaches a higher level as compared to the possible highest-strength drum separator using permanent magnets. To categorize the new high-strength drum separators, we began to call them medium-intensity magnetic drum separators (MIMS), a designation that seems to be generally accepted.

Roll separators of a large diameter, 300 mm (12 inch) processing particles up to approximately 50 mm size are reported to surpass the performance of a superconducting drum separator of 1 metre diameter ('DESCOS'), operating at more than three tesla.

Rare-earth medium-intensity magnetic drum separator (MIMS) designs

The most common designs build on conventional low-intensity magnetic drum separator (LIMS) designs. There are two basic types: Axial magnet sections and radial—see illustrations in Figures 1 and 2. The first type may have magnets sandwiched between the poles to increase the magnetic field depth beyond the drum shell. These magnets may be called booster or interpole magnets. The radial type magnetic sections are usually of fairly large dimensions as the design is intended to provide a very deep magnetic field to maximize the magnetic force acting on large size particles (rock separation).

Various special forms of the axial type have been developed[1,2]. One was used in the 'Permos' separator, in which the particles being separated were supposed to be

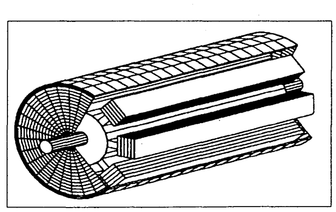

Figure 1. Axial Drum Magnet Design

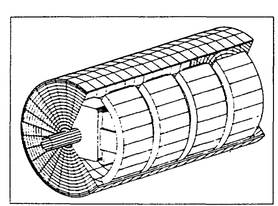

Figure 2. Radial Drum Magnet Design

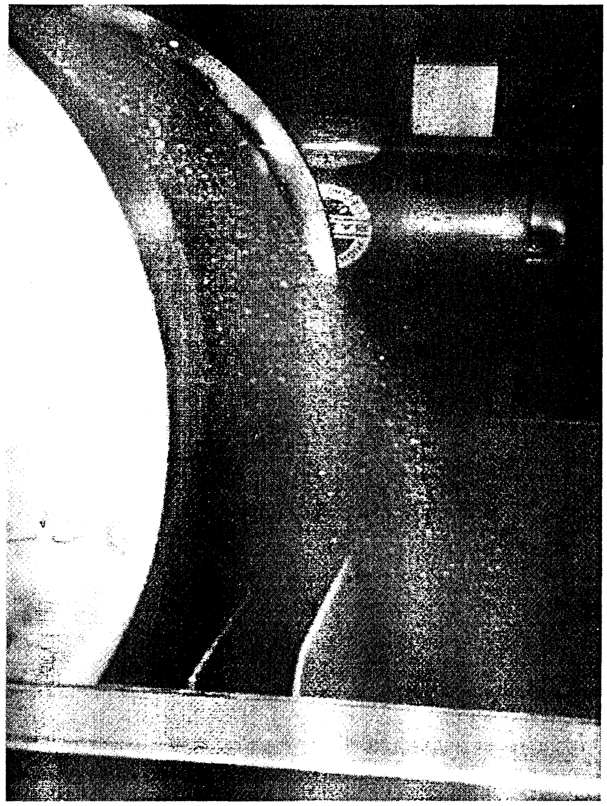

Figure 3. Multiple splitters producing multiple products

exposed to a changing magnetic field direction. The purpose was to achieve an effect where nonmagnetic particles would be easily released and be removed under the influence of centrifugal or hydrodynamic drag forces. Such a design is rather costly to manufacture.

Another patented design uses magnetization of highly susceptible steel to achieve a multiple pole system while maximizing the use of the magnetic mass, analogous to the basic principle behind the typical roll design. The magnet poles are now steel magnetized to a high level. These poles are shaped to hold the magnets in precise positions. Booster magnets can be used for this design as well, which enhances the rather short range magnetic field while retaining a high level of field gradient.

As several of the MIMS magnet designs provide short-range magnetic forces when compared to LIMS designs, it is critically important that these shells are operating close to the magnet poles and that they are as thin as is practical and economically feasible. Hence, the MIMS drum shells should have much tighter tolerances regarding roundness and thickness across the drum separator width when compared to LIMS shells. Typically, the shell thickness is half, or less than half, compared to the LIMS. The tolerance between the shell and the poles can be almost one order of magnitude smaller compared to LIMS. One version of a moderately strong MIMS model (for removal of a little less magnetic material than magnetite), is using the basic LIMS shell design criteria. All other MIMS, which are intended for much less magnetic materials (such as ilmenite, hematite, or garnet) have the tighter tolerances to various degrees.

Another important aspect in the MIMS design is the greater eddy-current development due to a higher magnetic field, in some designs a larger number of poles, and yet for some; a higher rotational speed compared to a typical LIMS. The strong electric current acts as an electromagnetic brake, which necessitates a high drive torque. The energy is converted to heat, which must be considered in the magnet design of dry process drum separators. If the feed material is hot, as is the case after thermal drying, the additional contribution to the temperature level may require magnets that can tolerate elevated temperatures. This has been discussed previously in regards to roll separators and similar aspects are valid in the drum separator designs. Of course, it may be possible to apply cooling of the feed material and even to the drum separator itself, but this may be an unwanted complication (and cost).

MIMS applications

There are numerous uses for MIMS, e.g., in iron ore, ilmenite, garnet, tantalite-columbite and diamond ore processing. In the following, we will discuss heavy minerals processing (ilmenite, garnet, tantalite-columbite), although much of the most interesting data are not available for publishing.

The first MIMS were used for several dry garnet applications. As a drum has a large separation zone by comparison to a small diameter magnetic roll separator, it is often feasible to extract more than two products from a single pass separator. The particle streams have sufficient retention time under the influence of magnetic forces, so that the separated particle streams may be easily recognized and kept separate by splitters (see Figure 3). In the case of garnet, more susceptible material such as ilmenite can be removed as a highly magnetic fraction, while clean garnet is usually less magnetic and would fall into a middle fraction—quartz is nonmagnetic (actually diamagnetic) and can be removed in a stream further away from the shell. Our first production drum separator does exactly that at relatively high capacity when processing fine particle size fractions. As a matter of interest, these fractions are rejects from another supplier's MIMS. The question may be asked: 'can Rare-Earth Magnetic Roll Separators (REMS) be used to achieve the same separation?'. The answer is *yes*. Basic criteria for choosing one over the other will be discussed in the next section.

Likewise, for ilmenite processing, both MIMS and REMS can be used for dry processing; sometimes both types of separators can be used in the same machine unit. A dry mill feed will usually have a large portion of magnetic material, having been preconcentrated by gravity and sometimes also by WHIMS. When a great amount of magnetic material is present, it may be necessary to use multiple stages of separation, as discussed in a paper presented at a previous conference[3]. If the separation is done in one stage, either the feed rate must be adjusted to a low level, which is usually not the optimum, or another process must be added, either additional magnetic separation of a different kind, or high-tension separation (electrostatic separation). If too much magnetic material is removed, there will be a large amount of inclusions due to clustering of magnetic particles as illustrated in Figures 4 and 5, showing the case for a roll separator. Figure 6 shows the importance of using multiple separation stages to achieve a clean magnetic product.

In an ilmenite recovery from a tailings test programme, it was clearly demonstrated that the new High-Force high-

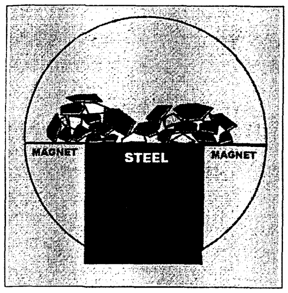

Figure 4. Overloaded collection sites

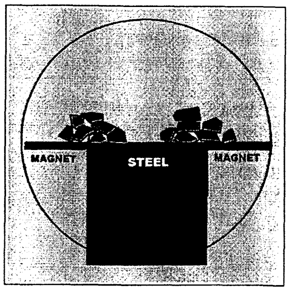

Figure 5. Optimum loading of collection sites

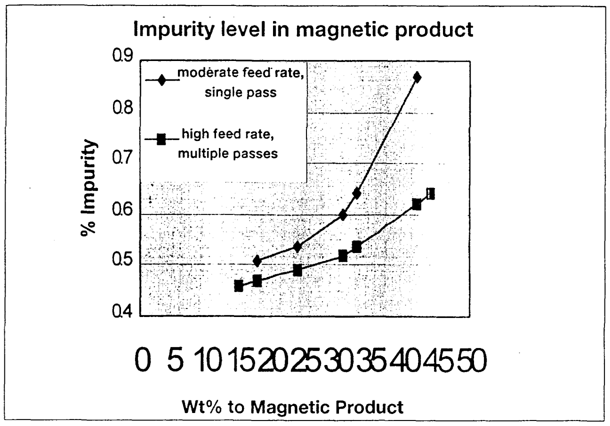

Figure 6. Advantages in Multiple Pass Separation

gradient magnet design is superior to more conventional designs.

Dry MIMS can also be used in iron ore applications, even for a relatively weak magnetic iron mineral such as siderite. In one full-scale trial installation, three similar size MIMS from different suppliers are being compared at the time of writing. The one provided by the current largest maker of MIMS has been removed due to inadequate performance. There is a wealth of data for iron ore applications that shows the many advantages of the new High-Force magnetic designs, but this is beyond the scope of this paper.

Due to the recent successes in a variety of heavy minerals applications, intensive work is under way to evaluate new ways of applying the High-Force separators, e.g., primary dry mill processing before high-tension/electrostatic separation, chromite-bearing mineral removal from ilmenite in a dry process rather than the current wet process, tantalite/columbite recovery from tailings—to name a few.

Wet MIMS with a low-strength magnet design (and a thick shell with wear liner) is used for relatively highly magnetic chromite-bearing minerals removal from ilmenite immediately following magnetite removal. Similar types separators can be used as scalper units before WHIMS to more effectively remove highly magnetic materials, which often become trapped in a WHIMS matrix.

Higher-strength High-Force MIMS have been used in pilot plant settings with successful results in the recovery of fine ilmenite. In one case the recovery was on the same level as a WHIMS, with a higher concentrate grade. More testing is presently being planned. All work so far has been done by contract research facilities with our first prototype wet MIMS, temporarily preventing release of actual data. One of the projects reported will proceed shortly with a full-scale installation of our separators.

Selection of MIMS vs REMS

Until the market entry of High-Force REMS, the industry's general impression of belted roll separators was that the use of separator belts was difficult, due to short belt life and high maintenance effort in replacing such belts. Hence, the industry welcomed MIMS for applications where the relatively low magnetic strength was adequate. However, the new generation of REMS did not suffer from the problem with belt life and high-cost maintenance. For applications requiring relatively low magnetic strength, an *optimized* High-Force roll separator offers both sharper separation and higher capacity compared with prior generations of REMS while employing a *thick* (long-lasting) belt.

At a large installation of REMS (30 machines) processing ilmenite, the average belt life is reported to be better than 12 months, often reaching 18 months. In the process development stage, the customer considered both REMS and MIMS for this plant, and selected REMS for several reasons, one being greater flowsheet flexibility. Extensive evaluation of High-Force REMS proved that long belt life could be projected, now confirmed in full scale operation.

In a couple of plants the 'combo' separators (drum followed by roll stages) were selected. In one case, the first intention was to use drum separators only, until the client learned about the vast difference in ilmenite recovery with roll separators (88% vs. 99%). Because of better recovery, the roll separator option was then favoured, but the client finally settled for the'combo' machines as a compromise. If there had been sufficient space available and there had been no bias against separator belts, the roll separator option may have been a better option for both technical and economic reasons. An example is shown in Table I.

The comparison charts in Table II summarize the technical and economic reasons for selecting one machine type over another. If there is no particular bias one way or the other, it can be said that an optimized REMS usually provides greater selectivity and flexibility than a MIMS for dry processing of highly, and moderately, paramagnetic minerals. In situations where floor area is at a premium, drum separators, or combination drum and roll separators may provide the most attractive solution for economic reasons.

Future developments

Recent advances in magnet circuit designs encourage new uses of both REMS and MIMS in heavy mineral sands processing plants. It is anticipated that a new magnetic roll design will be in full-scale use in early 2000 (order is being processed at the time of this writing). New magnetic drum

Table I
Ilmenite gravity concentrate @ 30 tph, 0.1– 0.9 mm fraction, 70 °C

Equipment	Stages required	Capacity	Qty	Price each US $	Total price US $
Drum/Roll Combo	1 drum 2 rolls	7 tph/m	3	114,000	342,000
Roll Separator	3 stages	4 tph/m	5	65,000	325,000

Table II
Selection of REM Roll vs. Drum separators

Criteria	Roll separator	Dry drum separator	Wet drum separator
Ferro-magnetic material (magnetite, abrasion iron, tramp iron)	Scalper model (low-strength, low-cost) with long-lasting, thick belt Any amount tolerated	Small amount tolerated, using release bar/wiper or take-off roller. High-wear risk	Small amount tolerated, using a take-off roller
Highly paramagnetic material (ilmenite, garnet)	Moderate-strength with high capacity, thick long-lasting belt	High-strength, release bar required, high feed rate, less separation sharpness than roll	May replace multiple passes of WHIMS, or some WHIMS altogether, or scalper before WHIMS
Operator attendance	Very low attendance. Belt change very easy	Replacing drum shell requires qualified shop work	Replacing drum shell requires qualified shop work (scalper has liner)
High capacity	Large diameter available (300 mm and provides 4–5 times capacity of 100 mm diameter	Large diameter provides very high capacity. (Currently 610 mm —future up to 980 mm)	Large diameter provides very high capacity
Moderately paramagnetic (biotite, leucoxene, monazite)	High efficiency, higher grade and recovery compared to electromagnetic induced roll (IMR)	No use	Scalper before WHIMS
Weakly paramagnetic material (muscovite, amphiboles, pyrite), cleaning of quartz, feldspar, zircon, rutile, etc.	High efficiency, higher grade and recovery compared to IMR	No use	Scalper before WHIMS
High temperature	One manufacture tolerates up to 140 °C, others 80 °C	One manufacture tolerates up to 100 °C, others up to 75 °C	N/A
Process control	Wide range of adjustability	Small adjustments only	Small adjustments only

separators are currently being evaluated in full-scale. These are proving that the enhanced magnetic designs provide projected superior performances in several dry process applications. Additionally, wet MIMS of the most powerful designs to date will be tried on a large scale in the near future. The potential for replacing WHIMS for ilmenite processing is great, as well as in other applications.

The greatest impediment to the implementation of full-scale use of these newly developed separators is the lack of finance. Despite the unsurpassed acceptance of our High-Force magnetic roll separators (more than 600 production units sold in the last few years-many of the largest size available) and undisputable small scale superior performance when using prototype units, the full scale deployment of several new advanced separators have not progressed as fast. A major reason is that small business support in our country is geared to businesses in different fields. One possible solution would be a partnership with the industry in the form of sponsors (with adequate rewards for the participants, of course). We have had a couple of these types of partnerships.

Conclusions

Rare-earth magnetic separators are now widely accepted by heavy minerals processors in developed countries. Additional developments in progress will make such equipment more common both in the up-front processing, intermediate and final stages, including current and prior operation tailings scavenging. The advances in the application of new magnetic systems will benefit the industry in providing products of higher grades and at significantly higher yields. The higher grade effectively reduces concerns about radioactive content. A higher product yield obviously increases the revenue without substantial investments. The developments can be greatly accelerated if additional, relatively modest, financial resources would become available.

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