Society for Mining, Metallurgy, and Exploration, Inc.

SME

PREPRINT

00-140

RECENT DEVELOPMENTS OF RARE-EARTH MAGNETIC ROLL AND DRUM SEPARATORS

B.R. Arvidson

INPROSYS
Golden, CO

For presentation at the SME Annual Meeting
Salt Lake City, UT – February 28-March 1, 2000

ABSTRACT

Since the introduction of the first commercial rare-earth magnetic roll separator (REMRS) in 1982, the additional developments of this separator type and the rare-earth magnetic drum separator (REMDS) have progressed in several stages. This paper reviews the developments since 1992, when the first large capacity machines became available.

Greater magnetic strength machines are now available. The magnet temperature tolerance considerations are discussed in some detail. Comparative performances reported in the last few years are cited. Optimization of machine designs is discussed. Several examples of new installations and applications will be referenced.

INTRODUCTION

In 1981, when the first rare-earth magnetic separators were developed by the Bateman group in South Africa (1), the most suitable magnetic materials available were alloys of Samarium-Cobalt and various forms of "mischmetal". A few years later, Neodymium-Iron-Boron alloys became useable. Although the first commercial NdFeB qualities suffered from low temperature tolerance, by the late 1980's, better temperature-tolerant qualities were used in magnetic separators. The temperature tolerance is still an issue, which has been discussed in previous presentations (2). The main points are also reviewed in this paper.

The new generation of rare-earth (RE) magnets soon became more powerful than Sm-Co magnets. Lower costs contributed to accelerate the use of both roll and drum separators based on RE magnets. For various reasons, the machine unit capacity did not change much during the first 10 - 12 years of the RE magnetic separator existence. The magnetic roll diameter increased from 72 mm (2.8") in the original production separator (1982) to 75 (3") and then 100 mm (4"). The latter was first used for ultra-high purity quartz applications, but not much else until after 1990.

The roll separator process width was limited to 1 meter (39") or 1.2 meter (47") for two main reasons: The small diameter roll deflection and the methods used for separator belt tracking. Larger roll diameter enables reduced deflection and hence allows greater roll lengths. However, the belt tracking is still a constraint.

Drum separators became attractive with the advance of low-cost NdFeB magnets. The first common drum diameter was 300 mm (12") and the maximum process width has been limited to 1 meter for a considerable time. Eriez Magnetics was probably first in replacing ferrite magnets in a low-intensity magnetic drum separator (LIMS) and there are now many suppliers of such equipment.

Several hundred, probably close to 400, RE separator units had been delivered within the first 10 years after the first commercial use of a RE magnetic separator in South Africa in 1982. In the last 7 years, the population of RE roll and drum separators has increased to at least three times that number.

MAGNET MATERIALS

In the late 1970's, rare-earth magnets made of various cobalt alloys were in industrial use. For the first magnetic roll intended for mineral separations, it was found that $SmCo_5$ was the most suitable material. At the time, the strongest of commercially available magnets had an energy product rating of 24 MGOe, soon replaced by 26 MGOe. By 1985, several magnetic separator manufacturers had either copied the original design or had separators under development. Simultaneously, Neodymium-Iron-Boron magnetic materials became available, so the new machine suppliers could take advantage of lower-cost components while maintaining the magnetic strength, except for one important aspect: The new magnets could not tolerate high temperatures. Samarium-cobalt magnets could be used at extremely high temperatures (200+ °C, i.e.,400+ °F), while magnetic rolls made with the new magnets could tolerate about 60 °C (140 °F). This came as a surprise to many plant operators, who were processing materials that had been dried at higher temperature prior to magnetic separation. As the temperature of the separator feed material would not cool down to a tolerable level in the process chain, magnetic rolls, and also some drum separators lost magnetic strength. Sometimes, the loss was rapid; in some cases there was a gradual loss over several years. Evidently, the suppliers of such separators had not realized that when magnets are positioned opposing each other (north pole facing north pole, south to south), see Figure 1, this effectively changes the working point on the coercivity curve of the magnets.

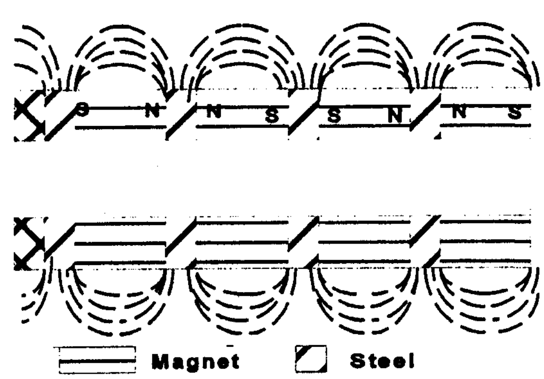

Figure 1, Rare-earth magnetic roll design principle.

In Figure 2 and 3, the typical coercivity curves for one medium-quality magnetic material and a high-quality magnetic material respectively are shown. At elevated temperatures, the coercivity curve changes, as shown in the two figures. The working point could then be on the steep vertical part, or perhaps at the "knee" of the curve, meaning that the magnetic induction is quickly reduced as the temperature rises. As can be seen, the material represented in Figure 2 (used in most separators), is less temperature tolerant compared to the magnets as shown in Figure 3 (used in most High-Force roll separators).

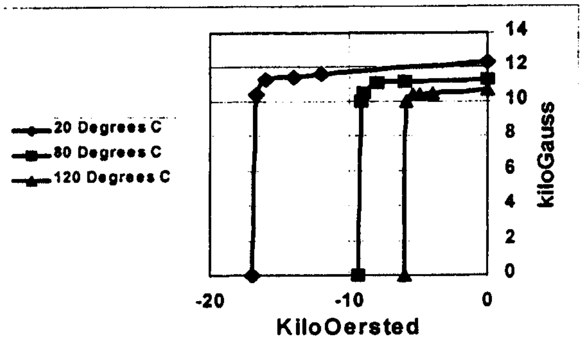

Figure 2. Demagnetization curves for various temperature levels for a common quality magnetic material

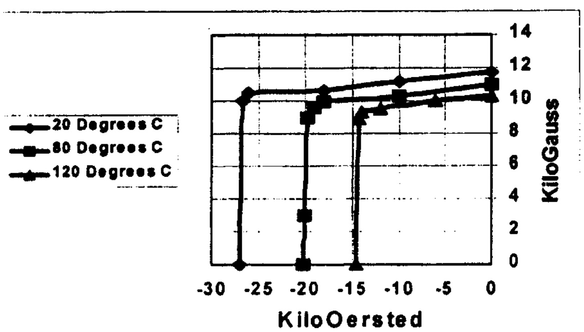

Figure 3. Demagnetization curves for various temperature levels for a high-quality magnetic material.

Another important factor that has escaped the awareness of some suppliers is that the magnet profile also has a profound effect on the working point position. These suppliers still do not allow for such factors in their design. Consequently, several users are now having unnecessary problems with reduced magnetic roll strength due to improperly selected magnetic materials. There is indeed no problem to construct rolls that tolerate continuous operation at 110-140 °C (230-284 °F). We have established that even higher temperature spikes can be tolerated if the time is limited to about 20 minutes in operation.

Currently, magnetic materials with energy product up to 40 MGOe are used in the most advanced roll and drum separators. The high-energy product magnets that are also high-temperature tolerant are more expensive than lower-temperature and slightly lower energy-product magnets, in some cases by a factor of 40%. It is then important to select the magnetic material best suited for each application, which will be discussed in the section on Optimized Magnetic Circuit Designs.

Magnet materials for *dry* drum separators have a wide range of criteria, depending on the particular magnet design. There will always be some temperature consideration because eddy-currents will develop in the rotating shell. The level of such currents depend on the magnetic flux density, the number of magnetic poles, the rotating speed, the shell thickness, and the shell material conductivity. Heat will develop roughly in proportion to the drive power that is needed to drive the shell to overcome the braking effect of the eddy-currents, just like the case for electromagnetic induced roll separators. If the separator feed temperature is high, the additionally generated heat in the shell will be added to the heat energy to levels that must be considered in the design. For example, in one case the feed material temperature was restricted to 60 degrees C (140 °F), based on operational experience. Previously, the same magnetic separator was specified for 80 °C (176 °F).

Cooling of the feed or the separator itself may also be options to evaluate. None of these are attractive to operators, especially in case of cooling the separator. Any dust that is drawn into the separator will eventually cause internal wear and may ultimately cause sudden destruction of the magnetic section. External cooling of the shell is not practical. A hollow shaft with water cooling has been suggested, but it is not generally acceptable. It is far better to design the system to tolerate the operation temperatures. For example, most of our dry drum separator designs are intended for either maximum 70 °C (158 °F), or 100 °C (212 °F) feed temperature. That is not the top limit, but so far there has not been a strong interest by the industry to go higher.

For *wet* drum separators the requirements are simple, since temperature is not an issue as long as the drums are operated with slurry or water. In a conventional design, the main portion of the magnets do not need to be of the high-coercivity kind and hence the cost is reasonable even for the highest strength type. Most suppliers use a "booster" or "bucking" magnetic feature, and these magnets have more strict requirements regarding coercivity.

High-strength drum separators using RE magnets were developed much later than roll separators. Nearly all current suppliers are, in principle, using simple replacement of ferrite magnets with blocks of Nd-Fe-B magnets to achieve higher magnetic strength. Two new magnetic circuit designs have been developed in order to take advantage of the rare-earth magnet unique properties. One of these is the design used by KHD in the Permos separators (3), the other was developed by the author (patented).

The drum separator magnetic force affecting small size (- 3 mm, - 1/8"), paramagnetic particles to be separated is moderate, typically about 5 to 10% of the highest-strength roll separators, in most situations. A major reason is that the magnetic field gradient cannot be brought to the same level as for roll separators. The magnetic field can be extended to a greater depth, which enhances the net force acting on coarse particles (e.g., 10 mm, 3/8", and larger). In practice, the roll separators are substantially stronger even for large particles if the magnetic design is done correctly. When the maximum strength is not required, or may even be detrimental, the magnetic rolls can be optimized for lower strength and enhanced capacity. In side-by-side comparisons, the High-Force roll separators have achieved more precise separations at lower cost per ton of product in a majority of tests compared to drum separators, even the most recently developed by the same supplier. A case in point is the installation by Westralian Sands Ltd. (now Iluka) of a large number of High-Force magnetic roll separators to process primary ilmenite. The decision to implement the new plant was taken after many years of using other rare-earth magnetic roll separators in trial operations. This company conducted extensive testing of similar units as well as a rare-earth magnetic drum separator. It is claimed that this roll separator plant offers greater operation flexibility compared to drum separators or even a combination of drum and roll separators. A more extensive discussion of the drum vs. roll separator applications will follow later in this paper.

To complete this discussion, it should be mentioned that there is another type of separator that uses RE magnets (4). It is called the Ferrous Wheel®, licensed to Eriez Magnetics. This author introduced the simple replacement of ferrite magnets by rare-earth magnets to effectively triple the magnetic strength of this separator. However, the magnetic force appears to be no greater than the strongest drum separator, developed in the last few years.

MAGNETIC ROLL DIAMETER

The first prototype magnetic rolls were only 66 mm (2.6") in diameter and the first commercial machine used 71.5 mm diameter rolls. At the time of the manufacturing of these units, the diameter size was dictated by the largest diameter rings that a few magnetic component suppliers could make. By the time the first production separator was constructed in 1982, the available ring magnet diameter had increased to 72 mm (2.8"). It was realized that larger diameter rolls would enable higher capacity and improved magnetic strength, if the roll design was done correctly. However, when 101 mm diameter rings became available in 1984, the cost for these magnets was considered greater than the perceived benefit. Nevertheless, the application for cleaning high-purity quartz to highest possible levels provided the incentive to use the larger size roll diameters in order to maximize the magnetic strength without any cost consideration. Today, the cost situation has changed to frequently favor the larger diameter rolls, particularly when large capacities are required. For such applications, larger size machines are preferred, currently the High-Force 1.5 meter (60") process width, see Figure 4.

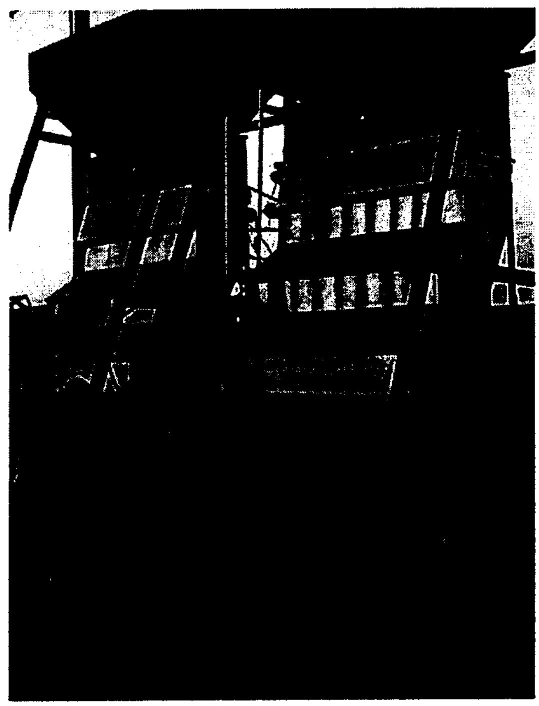

Figure 4. Quadruple-module INPROSYS High-Force magnetic roll separators.

If an identical magnetic force is assumed for different size diameter rolls and the particles are small (e.g., less than 3-4 mm), the capacity increase due to diameter size equals the square root of the diameter ratio ($\sqrt{D_2} / \sqrt{D_1}$). However, since the magnetic force can be enhanced with a larger diameter due to more space for a greater magnetic mass for the steel disk magnetization, it is possible to increase the capacity even further. Additionally, the greater arc where particles are affected by the magnetic force is a reason for enhanced capacity while maintaining a given performance

The first rare-earth magnetic drum separators (REMDS) were used for easy, dry garnet and ilmenite separations. There are several hematite iron ore applications. Wet drum separators have found use as high-powered scalper separators for removal of ferromagnetic material in the feed to wet high-intensity magnetic separators (WHIMS) of the matrix-type. Such separators tend to plug up due to inefficient release of ferromagnetic material, which is captured in the matrix even at low magnetization in the "zero-field" zones (3). One intermediate-strength wet drum separator is being used in a mineral sands application for removal of highly susceptible chromium-bearing ilmenite. Many other applications are being explored.

The largest RE drum diameter known at the time for this writing is just over one meter. It has a thick shell with tolerances resembling a LIMS design. At the present time, there are 610 mm (24") drum diameter separators available that have the tight tolerances necessary for maximizing the use of RE magnets. It is of course possible to make small test units of large diameter and tight tolerances, but currently available shell manufacturing methods limits production size equipment to 610 mm size. There are known recent cases when production machines by other manufacturers failed in plant trials to reproduce the performance of the same diameter, but smaller width test unit. The reason is likely to be that inadequate shell roundness and straightness tolerances reduced the effective magnetic force.

ROLL SEPARATOR BELT TRACKING METHODS

The pioneer roll separator model was equipped with Kevlar® fabric belts with riveted studs at the edge. Although the stud material has evolved and the shape developed to enhance wear characteristics, the basic system has proven in parallel performance tests to be better than crowned or flared rolls. With the patented INPROSYS High-Force system, better belt life due to superior tracking has been achieved even when compared to one automatic tracking system, see Table 1 (6).

Such systems are using adjustments of the support idler roll position guided by belt edge sensing. If the adjustments are limited, a contamination of the rolls, such as a slight increase of dust often causes the belt to go off track. We have further enhanced the automatic belt tracking to a new level, that provides better belt life than prior systems. However, for the separators using 100 mm (4") diameter rolls (or smaller), the cost for the new system does not justify the additional advantage over our mechanical tracking method.

Table 1. **Comparable Belt Life Data for Various Separator Makes**

Glass Sand Application, 0.25 mm (0.010") Average Belt Life in Months						
A	B	C	D	E	F	G
6	2	2	2	2.5	(2.5)	10-12
Similar Data for 0.13 mm (0.005") Belt						
2	0.5	N/A	N/A	N/A	N/A	3-6

N/A = Not known to be available with this separator

A - F = Various magnetic roll separators. Minimum belt thickness for machine F is 0.35 mm

G = HIGH-FORCE Magnetic Separator

Crowned rolls have been used in other belted equipment for many decades. This system works well if there is large distance between the rolls and high tension is applied. With short roll center distance and limited tensioning, the crowned roll is system is very sensitive to any variations - and cannot be used for very thin belts.

The flared rolls use an angled profile on the idler roll, either as removable flanges as used in some High-Force separators, or the idler roll ends are machined with an angle. The belt edge climbing onto the flange will be highly stressed, which forces the belt to move toward the center until the belt edge cracks (in the case of thin, brittle belts) or is stretched (in the case of thicker, elastic belts), or until the edge climbs so high that it may fold over. High temperature may accelerate the failure.

When the large diameter (300 mm - 12") roll separators were first developed, the belt length was large in relation to the width. Consequently, crowned idler rolls were adequate for tracking the thick belts used for such separators. However, as the processing width was enlarged, a new system was needed to avoid increasing the belt length. A new method based on a segmented, pivoting idler roll was developed and patented (US Patent No. 5,458,229), see Figure 7. It was tested to 1.7 meter width with good results. At this time, larger widths have not been tried. One such machine and several smaller units have been in operation. Although this system works adequately in some operations, there were situations when another way of tracking the belt became necessary. For this reason, our version of an electronic tracking system first used in 1990 was further improved and implemented.

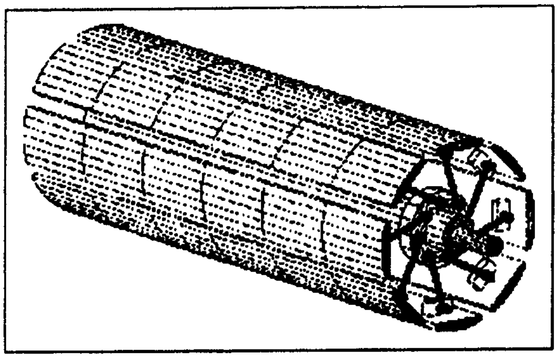

Figure 6. Automated Mechanical Belt Tracking System

OPTIMIZED MAGNETIC CIRCUIT DESIGNS

Roll Separators

When very weakly magnetic particles need to be removed (or recovered), it is very important that the net magnetic force is maximized relative to the particle size range to be processed. This can be done with proper selection of magnetic material and magnetic circuitry. Figures 7 and 8 illustrate the magnetic material removal performance when a given roll geometry is applied, but different magnetic materials are used.

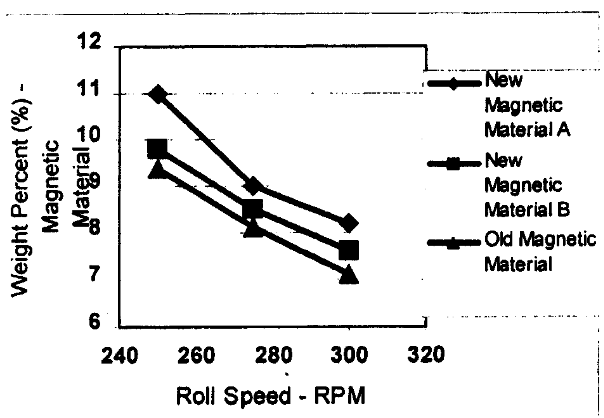

Figure 7. Comparisons tests for a 75 mm (3 inch) diameter magnetic separator: Feldspar A

Both of the "new" magnet materials (A and B) have higher energy product (BH_{MAX}) than the "old" magnet material, but the magnetic properties are otherwise quite different. As can be observed, one of the "new" magnetic materials (A) outperforms both the prior ("old") magnet quality and another "new" magnet material (B). In the case of feldspar B testing, there is virtually no difference between the "old" magnets and the "new" magnet B, while there is a substantial difference when processing feldspar A. This is

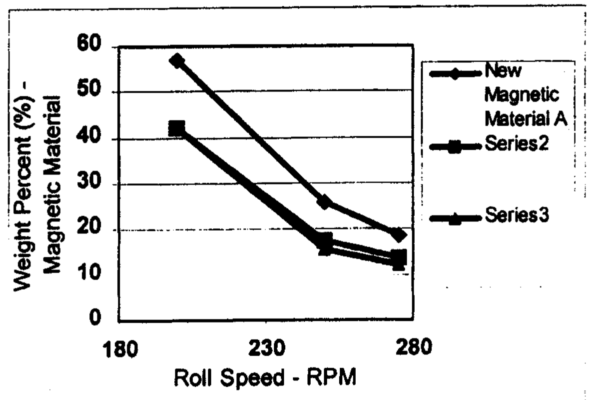

Figure 8. Comparisons tests for a 75 mm (3 inch) diameter magnetic separator: Feldspar B

due to the difference in the magnetic product being removed from the two different feldspars. Feldspar A has more of very weakly magnetic particles (muscovite) than feldspar B (biotite and another mineral). Consequently, to make a difference in performance, the superior magnet A must be used, enabling stronger magnetic force to begin removal of less magnetic material in feldspars A and B than the other two types of magnets. Magnet quality B is used extensively by several separator suppliers.

If extremely high temperature is encountered, magnet B will lose magnetization rather quickly, see Figure 2. Magnet A has better tolerance than B. The "old" magnet will have the best tolerance, see Figure 3. As most feldspar applications involve high feed material temperature after drying, the "old" magnet quality is still the best choice for most feldspar separators. Magnet A may be used if temperature is not an issue, and maximum feldspar product quality is wanted. The cost for these two magnetic materials ("old" and magnet A) is nearly identical.

Why would magnet quality B be used at all? It is less expensive than the other two. In applications where removal of a moderately magnetic fraction is adequate and high temperature is not a factor, the lower quality magnets may be used as the cost of a separator will be lower. However, magnet quality B has never been used in High-Force separators as it is possible that separators intended for one application may be shifted to new duties in the future with potentially drastic change in magnetization, even total loss. Today, the cost difference is very small for magnets that we have determined to tolerate up to 120 degrees C (248 °F). Hence, there is no reason why a better quality magnet should not be used unless a few dollars difference really makes a difference.

Once the best magnet quality has been selected for an intended application, the optimum roll geometry should be determined. Figures 9 and 10 show the importance of roll geometry designs. With the most powerful magnets available today, it is important that the magnet working point is established with care. It has been found by the author that the optimized roll configuration is different for the best Nd magnets than lower-quality Nd and $SmCo_5$ magnet materials. Evidently, this aspect has been overlooked by nearly all separator suppliers. The original roll geometry developed by the author, based on $SmCo_5$ magnets, is still being used by other manufacturers. Especially for delicate separations of extremely weakly magnetic material such as the one illustrated in Figures 8 and 9, the performance difference can be substantial.

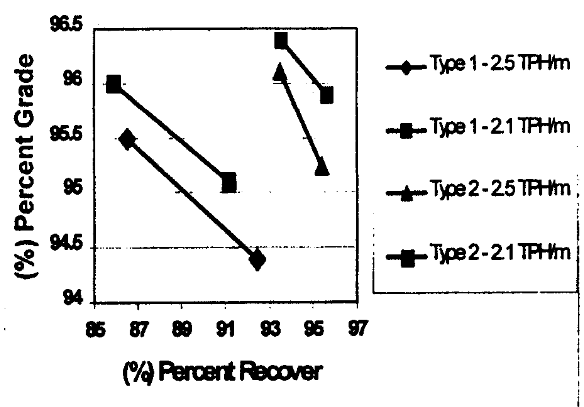

Figure 9. Removal of magnetic contaminants with two different magnetic separator rolls at two different process capacities. Size fraction 1.

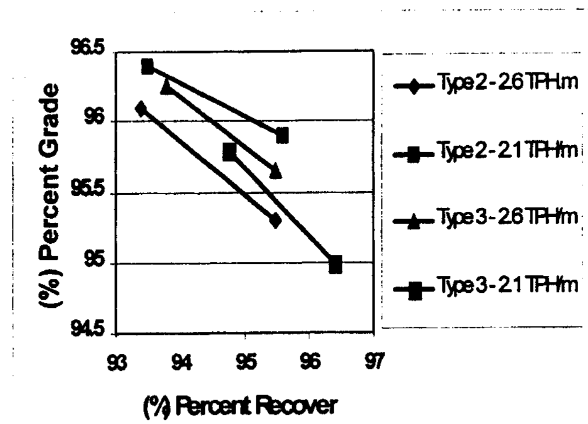

Figure 10. Removal of magnetic contaminants with two different magnetic separator rolls at two different process capacities. Size fraction 2.

Even in cases of separation of highly magnetic material such as ilmenite and hematite iron ores from material with very small difference in magnetic susceptibility, a remarkable sharpness in separation can be achieved when a optimized roll configuration is used compared to the more traditional designs. In a case of lump iron ore, better separation was achieved than what the relationship between measured susceptibility and iron grade would give reason to believe. Similarly, in several ilmenite - garnet and garnet - biotite separations, the product quality far exceeded the result obtained with all other roll and drum separators used in the test programs. In one such case, the yield of desired quality was at least four times greater by using a new, optimized High-Force roll system.

Table 1 shows some comparisons between the prior level of REMS technology and the more recently developed.

Table 1. **Comparative Performance on Feldspar**

DESCRIPTION	OTHER REMS TPH/M	HIGH-FORCE TPH/M	COST RATIO: HIGH-FORCE/ OTHER REMS
1. Finnish	3.0	4.5	0.58
2. Italian	3.0	7.5*	0.43
3. Swedish	1.5	3.0	0.61

* In full production, the feed rate averages 12 TPH/m.

Drum Separators

There are two basic magnetic design types: Axial and Radial. Within both categories, many variations exist. We shall discuss some that appear to be the most common. 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 are developed (5,6). One was used in the "Permos" separator (2), in which the particles being separated were supposed to be 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 design (patented) 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 a 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 MIMDS 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 technically 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 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 (approximately 3,500 gauss on the shell surface) MIMS model, is using the basic LIMS shell design criteria. It is intended for removal of material a little less magnetic than magnetite. All other MIMDS, which are intended for processing weakly magnetic materials (such as ilmenite, hematite, or garnet) have the tighter tolerances to various degrees.

Another important aspect in the MIMDS design is the greater eddy-current development due to 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 in 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 the drum separator itself, but this may be an unwanted complication (and cost).

SELECTION OF MIMDS vs. REMRS

Until the market entry of High-Force REMRS, 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 MIMDS for applications where the relatively low magnetic strength was adequate. However, the new generation of REMRS 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 to prior generations of REMRS while employing a *thick* (long-lasting) belt.

At a large installation of REMRS (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 REMRS for several reasons, one being greater flowsheet flexibility. Extensive evaluation of High-Force REMRS 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 the first case, the first intention was to use drum separators only, until the client learned about the vast difference in ilmenite recovery (88% vs. 99%). Because of better recovery, the roll separator option was then favored, 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 separators equipped with belts, the roll separator option may have been a better option for both technical and economic reasons. An example is shown in the table below (table 2).

Table 2. Ilmenite Gravity Concentrate @ 30 tph, 0.1 - 0.9 mm Fraction, 70 °C

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

The comparison charts in table 3 summarize the technical and economic reasons for selecting one machine type over another (6). If there is no particular bias one way or the other, it can be said that an optimized REMRS usually provides greater selectivity and flexibility than a MIMDS 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 enable new uses of both REMRS and MIMDS in many mineral processing plants. It is anticipated that a new magnetic roll design will be used in full-scale in early year 2000 (order is being processed at the time of this writing). New magnetic drum separators are currently being evaluated in full-scale. The trials are proving that the enhanced magnetic designs provide the projected superior performances in several dry process applications. Additionally, wet MIMDS of the most powerful designs yet may be tried in large scale in the near future. The potential for replacing WHIMS for ilmenite processing is great, as well as in other applications. The ultimate goal is to process iron ores, at least in the more magnetic forms such as specular hematite and martite.

The greatest impediment for the implementation of full-scale use of these newly developed separators has been the lack of finances. It is likely that this situation will change soon.

Table 3. 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. Combination with a drum module for primary separation may be adequate.	High-strength, release bar required, high feed rate, less separation sharpness than roll. Combination with roll modules may be optimum, enhancing overall efficiency.	May replace multiple passes of WHIMS, or some WHIMS all together, 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.
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 about 80 °C, some 100 °C	One manufacture tolerates up to 100 °C, others up to about 75 °C	Not Applicable
Process control	Wide range of adjustability	Small adjustments only	Small adjustments only

CONCLUSIONS

Rare-earth magnetic separators are now widely accepted by mineral 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. A higher product yield obviously increases the revenue without substantial investments. The developments can be greatly accelerated if additional, rather modest, financial resources become available.

REFERENCES

1. Arvidson, B.R., Barnea, E., "Recent Advances in Dry High-Intensity Permanent-Magnet Separator Technology." Paper presented at XIVth International Mineral Processing Congress, Toronto, Canada, October, 1982.

2. Arvidson, B.R., Henderson, D., "Rare-Earth Magnetic Separation Equipment and Applications Developments." Paper presented at Minerals Engineering '96 Conference, Brisbane, Queensland, Australia, August 26-28, 1996. Minerals Engineering, Vol. 10, No. 2, pp. 127-137, 1997.

3. Wasmuth, H.D.: "The New Medium Intensity Drum Type Permanent Magnetic Separator PERMOS and its Practical Application for Processing of Industrial Minerals in Dry and Wet Mode." Paper Presented at 1st International Industrial Mineral Processing Conference "Processing for Profit", Amsterdam, 1995.

4. Arvidson, B.R., "Two New Magnetic Separators Improving Industrial Minerals Cleaning." Paper presented at 1985 SME-AIME Annual Meeting, New York, N.Y., February, 1985.

5. Arvidson, B.R., Rademeyer, L. "Rare-Earth Magnetic Separators for Mineral Sands Applications," Heavy Minerals 97 Conference, SAIMM Journal, October, 1997.

6. Arvidson, B.R., "Rare-Earth Magnetic Separation of Heavy Minerals." Paper presented at 1998 SME Annual Meeting, Orlando, Florida USA, March, 1998.