The Many Uses of Rare-Earth Magnetic Separators for Heavy Mineral Sands Processing

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ABSTRACT

In the time since the first trials in the mid-1980s, the Rare-Earth Magnetic Separators (REMS) are presently (year 2001) found in many heavy mineral sands plants around the world. Both the roll and the drum type are used from ilmenite concentration to cleaning high-purity zircon products. Chromium-bearing materials are removed from ilmenite more selectively than with electromagnetic separators. Greater flexibility and higher grades in ilmenite circuits are achieved. Cleaner rutile and zircon products, even with respect to levels of radioactive materials, are the result of superior magnetic force optimisation. Tailings from roaster plants can be reprocessed effectively, which is encouraging some operators to look at replacing old equipment in order to process roasted material plant feed or implement use of the new generation drum separators in new plants.

Wet separation of ilmenite by using powerful wet REMS drum separators is now a possibility. This may be an alternative to at least a portion of the Wet High-Intensity Magnetic Separators (WHIMS) process for ilmenite preconcentration.

A dry plant process flowsheet can often be modified by displacing a portion of high-tension separators with new high-temperature tolerant REMS.

INTRODUCTION

High-Intensity Magnetic Separation (HIMS) has been a standard beneficiation method for heavy mineral sands along with gravity and electrostatic separation methods, for a long time. A great variety of HIMS equipment has been used, such as different Induced Roll Magnetic (IRM) separators, cross-belt and disk magnets, lift IRM and wet HIMS of various rotor types.

The rare-earth magnet separation technology was introduced to the minerals industry in the early-1980s. After a few years, the first large-scale trials in the heavy mineral sands area occurred and the efforts soon resulted in a few small installations. In the early-1990s, the technology became generally accepted by the industry. Design improvements helped to make the separators more reliable and more economical (Arvidson, 1997). Rare-Earth Roll Magnetic Separators (RERMS) and Rare-Earth Drum Magnetic Separators (REDMS) (Arvidson and Rademeyer, 1997; Arvidson, 1999), have replaced primarily cross-belt and disk magnetic separators, and in some cases displaced IRMs. In other industrial mineral processing applications, the most advanced RERMS have also replaced IRMs, (Arvidson, 2001). Due to the enhanced efficiencies, lower costs and further design improvements, new flowsheet options were implemented. These we will discuss in more detail.

A later development is the wet REDMS, which comes in a range of strengths and configurations. Some of these are used as improved strength Low-Intensity Magnetic Separators (sometimes called Medium-Intensity Magnetic Separators, or MIMS) to remove Chromium-bearing components (Arvidson, 1999). The more recently developed higher-strength wet REDMS has the potential to replace a portion of the electromagnetic WHIMS processing.

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TECHNICAL FEATURES OF RERMS

A rare-earth magnetic roll is composed of magnet rings interleaved with steel rings (see Figure 1).

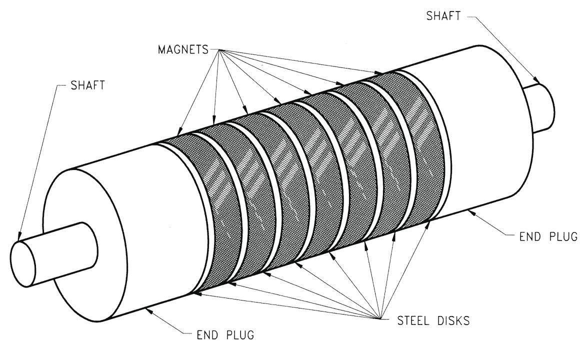

FIG 1 - Rare-earth magnetic roll design principle.

Many different magnet qualities are used today, and the selection criteria for such magnets have been discussed in another paper by the author, (Arvidson, 1997). The most common roll diameter is 100 mm. For large capacity applications, a 300 mm diameter roll is available, (Arvidson, 1999). The maximum process width offered is 1.5 m.

For mineral sands, there are essentially two categories of roll configurations used, depending on the application:

1. Maximum selectivity roll for highly magnetic materials (eg ilmenite, removal of Cr-bearing components).
2. Highest strength roll for cleaning nonmagnetic products (eg zircon, rutile).

Roll A is typically used at a very high speed while employing a relatively thick (0.65 mm), long-lasting belt. In one large ilmenite application the average belt life is more 18 months (Arvidson, 2001), while the roll speed can be as high as 530 rpm for the first stage separation. In another plant, the maximum roll speed was 550 rpm.

Roll B is used extensively for zircon cleaning and also rutile. Thin (0.13 mm) belts are commonly used, which makes it even more important that the operating life is extended to the highest levels possible. Depending on the separator model, the life can average six months or as little as two to four weeks. In a multiple-stage process, a thicker belt (0.25 mm) may be used in the first stage(s), which of course extends the belt life further (there are examples of better than 12 months average life). Roll speeds may range from around 250 rpm to below 100 rpm, depending on the product quality requirements. One new installation has six stages of separation to produce a new, high-purity material quality. It is more common to use three stages, though.

The ability to operate roll A at very high speeds provides one of the conditions for more selective separation than with previous HIMS machines. Although the magnetic force level is reduced compared to roll B (approximately 75 per cent of the maximum strength), it is still on such a high level, that both thick belts, (which reduces the effective magnetic force further) and very high centrifugal forces can be applied. Compared to an IRM, for example, the competing centrifugal force is one order of magnitude higher at the speeds reported above. The IRM has a relatively low level of maximum roll speed due to particle stream flow constraints.

Another contributing factor to the sharp separation is the conveying of particles over a reasonable distance (see Figure 2), which enables all of them to be accelerated to an exact horizontal velocity. Hence, there is no bouncing or scattering of particles as they enter the magnetic zone. Therefore, the particle inertia forces are precisely defined.

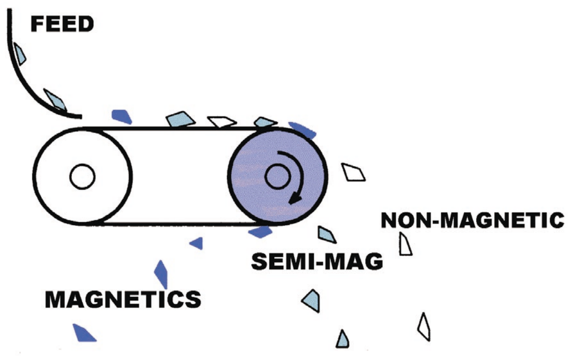

FIG 2 - Rare-earth magnetic roll operating principle.

A consequence of the possibility of adjusting the roll speed over a very wide range is that product qualities can be easily 'dialled in'. This is practiced in the largest roll separator installation in the world for ilmenite production.

Even in the high-strength roll applications, plant operators report greater yields of the high-value products compared to IRMs. Again, this is due to more precisely controlled separation conditions and greater effective magnetic force, typical for the most advanced RERMS. A comparison in laboratory scale testing is sometimes misleading, since in full-scale production, there is often a difference in performance. While the scale-up for RERMS is 100 per cent (if the optimum system is selected), which is a unique technical feature, the scale-up for IRMs is not. In-plant trial is the way to go for real-life comparisons.

For zircon applications, an effective remedy to reduce electrostatic charge interference may be required. Sometimes, this is also needed for rutile processing. Such a remedy is commonly used in the form of corona charging equipment ('ionisers').

Since permission to publish data has not been granted by most HMS plant operators, examples on yield improvements in an other industrial mineral application are shown in Table 1. The logical consequence is often that the magnetic product from IRMs is reprocessed with RERMS to obtain an improved product yield. It can even be economically justified to completely replace IRMs (Arvidson, 2001).

Verbal information from one chief metallurgist and a plant metallurgist, indicated ilmenite recovery of about 95 per cent using IRM, somewhat lower recovery by using REDMS alone (88 to 90 per cent), 97 per cent by using a combination of RE drum and roll separators and 99 per cent by using RERMS only. All yield data were for comparable product quality.

TABLE 1

RERMS vs IRM comparison in high-grade feldspar process.

Magnetic separator type	IRM	RERMS
Magnetic product	12 - 14 %	4 - 4.5 %
Non-magnetic product	86 - 88 %	95.5 - 96 %

For an 'easy' zircon application, the recovery of a good quality product was about two percentage points higher compared to an IRM. For more difficult zircon processing, new product quality levels have been reported.

Perhaps the most convincing evidence of better selectivity achieved with RERMS, is the reprocessing of zircon sand waste, originated in a plant using the best IRMs on the market. Saleable products are now recovered, but the data cannot be published unfortunately.

RERMS usually generate two distinct products with no or small amount of middlings. It is possible to extract three products in some situations for each stage of separation. In one such case, seven products were discharged from a triple-stage machine. The products were then combined to obtain the desired final product grades.

An example on the superior separation efficiency from one of the first RERMS installations is shown in Table 2. Note that the Rare-Earth Magnetic Roll Separator produced an order of magnitude less middling material. In this case, instead of recycling the ten per cent middling product from IRMs, the recycle stream could be eliminated. With more advanced RERMS today, the products are even cleaner and the middling portion even less.

TABLE 2

Comparison of IRM and RERMS in ilmenite - rutile separation.

	IRM @ 2.5 tph/m	RERMS @ 4 tph/m
Magnetic product wt %	25	30.5
Non-Mags in Mags wt %	2.5	0.46
Middling wt %	10	0.8
Non-magnetic product wt %	65	68.7
Mags in Non-Mags wt %	0.5 - 0.6	0.28

Of course, it is important that the magnetic system is optimised for the material to be processed. An example on how the selection of optimised Rare-Earth magnetic rolls may affect the separation performance is shown in Figure 3. It is of interest to note that the 'prior-art' roll performance was an improvement over the cross-belt separators used in the same plant.

TECHNICAL FEATURES OF DRY REDMS

The dry drum separator principle is shown in Figure 4. Particles to be separated are traveling over a large magnetic zone arc, which permits relatively high peripherical speeds to be used. This translates to high processing capacity per unit width of the separator. The centrifugal forces are not as high as in an RERMS process. However, the separation forces are adequate for the most common ilmenite materials today.

To remove chromium-bearing 'highly-susceptible reject' (HSR) contaminants is relatively easy with a correct balance of magnetic force and inertia forces, but it may require a separate stage of separation to achieve steady, reproducible, products if there are some variations in the feed characteristics.

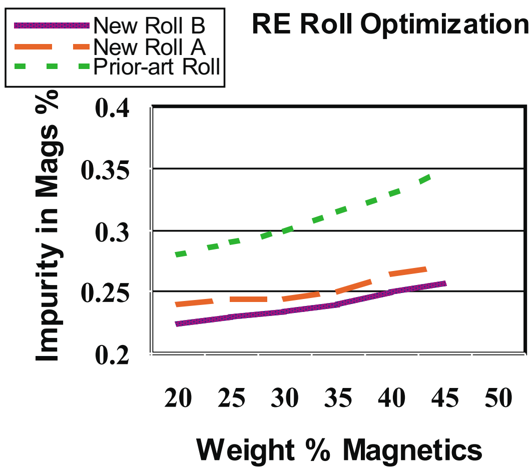

FIG 3 - Separation efficiency improvement by RE roll optimisation.

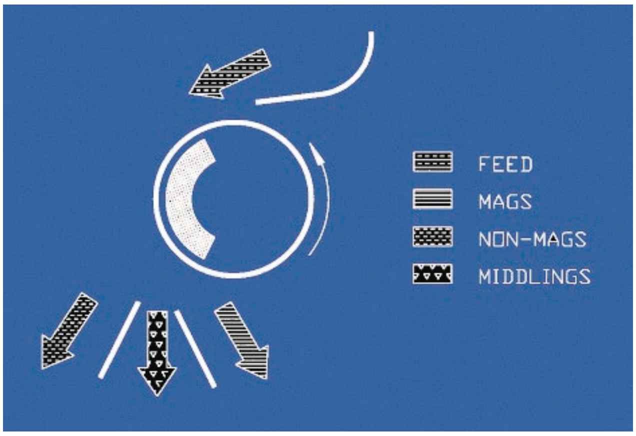

FIG 4 -Dry rare-earth drum separator operating principle.

In contrast to RERMS, the drum separator provides a fan of separated particles, which can sometimes be seen as fairly distinct streams (see Figure 5). Hence, in the ilmenite case, it is possible to achieve a final ilmenite concentrate, a middling and a final reject or a nonmagnetic product stream. The middling product can then be processed with roll separator stages, achieving the overall desired performance. One of the main benefits to a HMS plant is the small space requirement compared to prior art separators and even the most common size RERMS. However, the development of a large diameter roll separator for fine particle processing may further reduce the plant space requirement.

Probably even more important, is the possibility to enhance the efficiency of the overall plant performance by using REDMS+RERMS or RERMS alone before using electrostatic separation, which will be discussed later.

Development of larger diameter drum separators is in progress. These require improved shell manufacturing methods for the very thin drum shells that must meet exacting tolerance requirements to enable reproducible high-capacity performance. This has not always been the case in current installations of drum separators for ilmenite recovery, even at the 380 mm diameter size. In one such plant, the performance of the several drum separators varies for each one, due to non-uniformities in drum shells that can be seen and inadequate feeding systems.

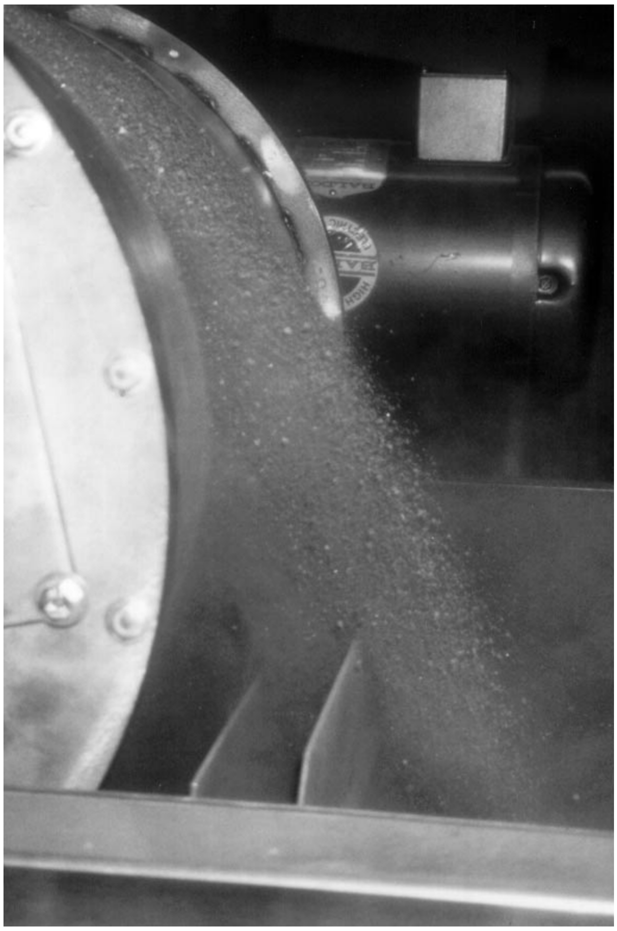

FIG 5 - Dry REDMS product streams.

Consequently, the ilmenite losses are higher than projected, even after scalping with secondary drum separators at much reduced temperature.

Another possible development is a drum separator that can operate at very high feed material temperatures (over 100°C), preferably without air or water-cooling. Roll separators can operate at 120°C already without permanent magnetic force reduction, if the design is properly made.

TECHNICAL FEATURES OF WET REDMS

A wet drum separator is similar to the dry drum with regards to the rotating shell and magnet systems. Various tanks can be employed. Figure 6 shows a typical concurrent wet drum separator.

Naturally, different magnets than those used in high-temperature dry drums can be used, since there are no temperature concerns with a slurry process. However, a wet drum separator should not operate in dry mode for extended periods of time. Eddy-currents in the rotating shell are strong in a high-power REDMS, and can heat up the magnet system to unacceptable levels if there is no slurry or water in the tank.

Ever increasing magnet strengths is making the wet REDMS a candidate for replacing a portion of WHIMS processing, if not the entire WHIMS process. Pilot testing has shown that this is feasible (Arvidson, 2001).

A wet MIMS can be used to remove chromium-bearing components. The magnetic strength requirement (field intensity typically 3000 - 3500 gauss) is only a fraction of the strength required for clean ilmenite recovery. Due to the relatively low

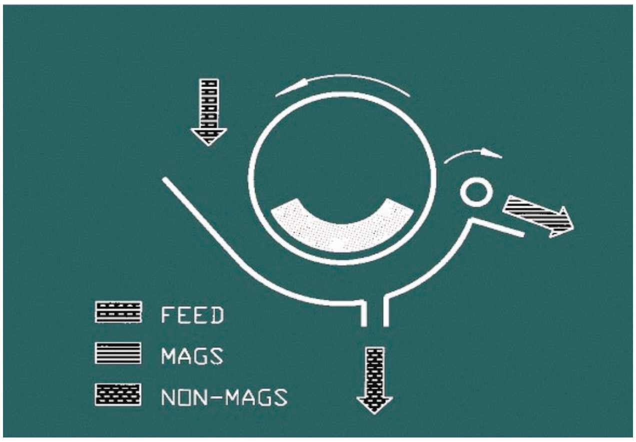

FIG 6 - Wet REDMS operating principle.

magnet strength specification, the drum shell thickness and tolerances can be similar to those of a conventional LIMS. Therefore, large diameter (about one metre) size separators can be used for such an application.

HMS PLANT EFFICIENCY IMPROVEMENT

High capacity, low-cost REMS technology can be applied to HMS processing flowsheets in different ways compared to conventional electromagnetic separators, particularly for ilmenite production. In the following, we will compare a typical conventional flowsheet that includes WHIMS (see Figure 7), with a new flowsheet that is under serious consideration by several operators (see Figure 8). Both flowsheets are simplified to make it easier to illustrate the principles. For example, some plants have now included REMS *before* HT (see Figure 7) to take the load off the electrostatic separators, improving their efficiencies.

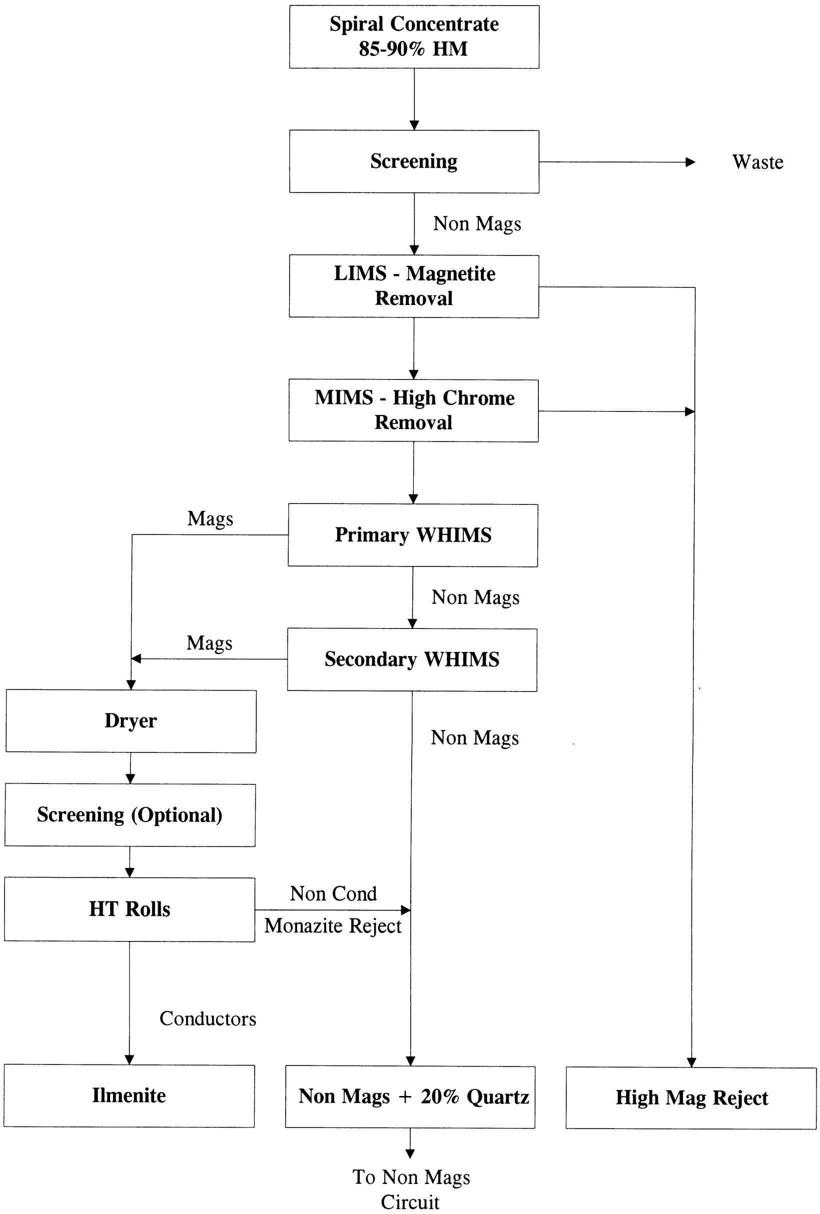

FIG 7 - WHIMS flowsheet - wet.

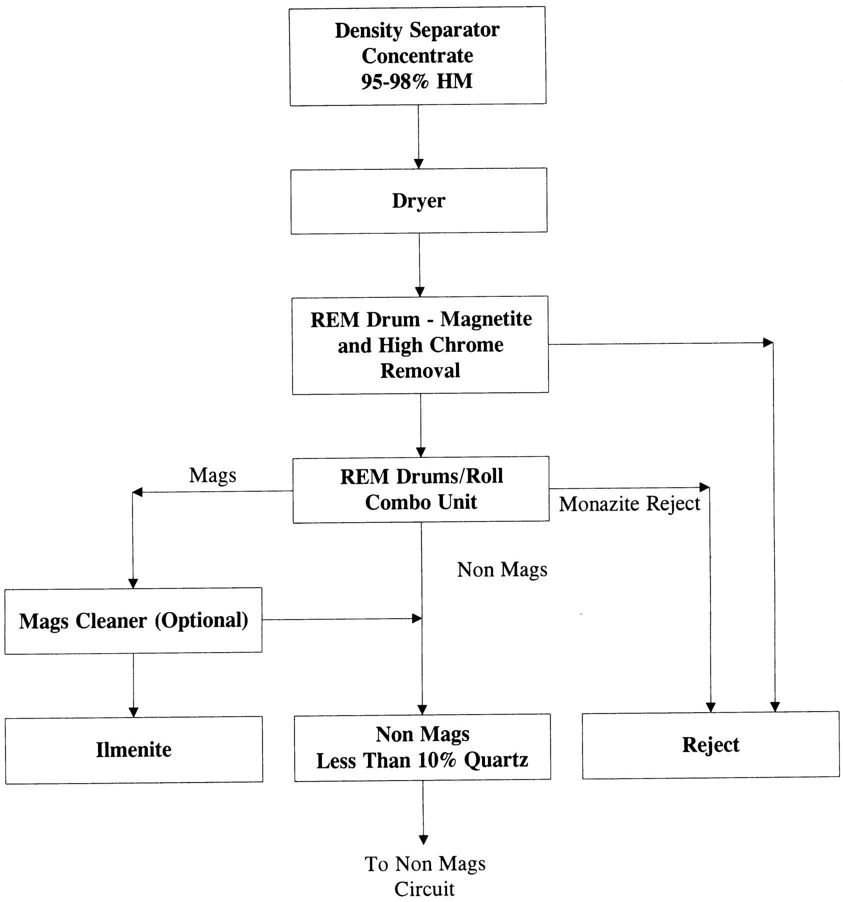

FIG 8 - Rare-Earth flowsheet - dry.

A high-efficiency dry ilmenite process will provide an overall higher yield than a WHIMS process. It is estimated that if the ilmenite yield increases two to five per cent (depending on drying costs and other mineral values than ilmenite) compared to the conventional process, this will more than compensate for the additional drying cost due to more material going through the drying process. That is not including the economic benefit of increased ore reserves for a given ultimate ilmenite production. Now, if an enhanced efficiency gravity separation process, which is presented during this conference, is also used, there will be both a better heavy minerals' recovery and an even further reduced need for a WHIMS process.

ECONOMIC ADVANTAGES OF REMS TECHNOLOGY

A comparison was made for a plant that had changed from cross-belt separators and IRM to new REDMS and RERMS for ilmenite processing. Operating costs in relation to the cross-belt process are shown in Table 3.

The ilmenite product quality was improved by applying the REMS. The possible economic benefit of enhancing the ilmenite recovery was not reported.

Other cost savings relate to smaller plant size for a given capacity. Since a rare-earth magnetic separator plant would use between six and 20 per cent of a cross-belt plant space, depending on which separator options are chosen, the cost saving can be substantial. Compared to IRM for non-magnetic product cleaning applications, the space saving can be 50 - 70 per cent.

TABLE 3

Comparative ilmenite operating costs.

Magnetic separator type	Cost %
Cross-belt	100
IRM	42 - 53
REDMS	17
RERMS 1 (short belt life)	21 - 42
RERMS 2 (long belt life)	11 - 15

By revising the flowsheet with REMS positioned up-front for primary separation, additional savings can be realised due to a reduced electrostatic separation capacity requirement.

The number of separation equipment units is reduced due to the following factors:

1. larger capacity per unit;
2. greater separation efficiency reduces circulating loads, decreasing middlings reprocessing capacity needs; and
3. high operation availability.

With fewer pieces of equipment to operate, and a reduced maintenance requirement, the labor cost is also reduced. In one simple plant flowsheet (no middlings retreatment), the operating cost reduction was reported to be 40 per cent by changing from IRM to RERMS. In more complex plants, the cost reduction would be even better, as seen in Table 3.

CONCLUSIONS

By maximising the use of rare-earth magnetic separation technology in heavy mineral sands processing flowsheets, the following benefits have been established:

- lower operating costs, often in the range 40 to 75 per cent, compared to IRM, and more compared to cross-belt separators;
- enhanced product qualities;
- improved products yield;
- economic recovery of valuable minerals from waste materials;
- in combination with a more efficient gravity circuit, they may eliminate the need for wet high-intensity magnetic separators (WHIMS), further reducing the processing complexity and costs;
- better overall dry processing efficiency, reducing plant size and capital costs;
- reduces the need for operators as well as the required skill levels; and
- enhancing ore reserves due to overall greater efficiencies, resulting in an enhanced product yield.

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