Magnetic Separation in Sand Processing
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General

Traditionally the sand industry has not considered magnetic separation as a process alternative except in a few special applications.

The sand deposits exploited to supply the glass and ceramics industries have until recently been of low enough iron content to enable production with little or no processing of the sand. Whenever processing was required screening and attrition scrubbing techniques have been employed together with a certain amount of the froth flotation.

Now that high quality reserves are diminishing and quality specifications are becoming more strict, more processing is required to maintain quality standards. Additional environmental pressures have also reduced the attractiveness and cost effectiveness of the chemical based froth flotation process. As a result there has been a resurgence of interest in the purely physical processes of gravity and magnetic purification.

Factors Effecting Physical Processing

Of course not all sand deposits respond to physical treatment, methods and the response is dictated by the form in which the iron appears.

Generally where the iron is in the form of a discrete mineral such hematite, magnetite ilmenite chromite and biotite micas, physical separation processes work very well as the iron is in a liberated form.

Often this is not the case, with iron bearing minerals being included within the silicon particles. Much higher magnetic fields are required to remove such grains as their effective magnetic susceptibility is reduced by the extra silica mass. This type of particle is very difficult to separate using gravity means as the particle S.G. is only slightly increased. The S.G. difference between pure silica and included silica grains is therefore very small and if any separation by S.G. does occur it results in the appearance of such grains in the middlings fraction.

Similarly, with the 2 types of iron coating which appear on the surface of grains. Iron bearing clay minerals can be physically bonded to the silica surface but these bonds can easily be broken with attrition techniques.

However, silica grains with iron chemically bonded to the surface cannot be treated by physical means as such grains tend to be effectively non-magnetic or have a 2.0 S.G. difference chemical processing is the only way to purify such grains.
Magnetic Separation Techniques

Normally silica sand producers prefer to process material in the wet state to obviate the need for costly drying, although some producers process after any drying stage to achieve maximum benefit.

Wet Separation

Until recently the only wet high intensity magnetic separation or WHIMS available was based on the Jones carousel design as produced in the 1950’s. The design is based around a rotating annulus or carousel containing a magnetic matrix. As the matrix passes through a high intensity magnetic circuit, a high intensity magnetic field and gradient are induced in to the matrix. The feed passes vertically through the induced matrix section capturing magnetic particles.

Many types of matrix have been used ranging from expanded metal matrix to steel grooved plates.

The main disadvantages perceived by operation are:

- High maintenance costs (matrix)
- Prone to matrix plugging
- Dirty operation requiring supervision
- Inefficient separation due to wiping effect of product flow

Eriez Europe recognized the problems associated with the WHIMS units and undertook the development of an alternative system.
**Fundamentals**

It is important to understand the basic principles of a induced matrix separator.

Many people incorrectly associate the separation power of a magnet with the gauss figure it is said to generate. This is only part of the ability of a magnet to separate. The magnetic intensity which is measured in gauss or tesla (1 tesla = 10000 gauss) is the number of magnetic flux lines per unit area. If we examine a particle inserted in a uniform magnetic field (fig 1), we see that the force exerted on the particle is equal and no relative attraction will be seen. If however we insert the same particle into a non-uniform field with a differing intensity across the gap we see that the magnetic field intensity changes across the gap and a unequal force is exerted on the particle resulting in movement to the area of highest intensity. This changing flux intensity is termed a magnetic gradient and is the moving force behind separation. In short, intensity magnetises the particle and magnetic gradient moves the particle. When a matrix wire is inserted into a uniform magnetic field, the field is distorted passing through the matrix wire and polarising the wire to creating points of high intensity and gradient. In a separator matrix there are thousands of such points available ensuring a high contact ratio with magnetic particle.

**Separation Parameters**

As part of the process investigation separation parameters were explored identifying the following as the most important.

- **Particle magnetic susceptibility**
  The ability of a particle to be magnetised

- **Field intensity**
  The intensity of magnetic field required to magnetise and hold a particle of specific susceptibility.

- **Effective medium viscosity**
  The resistance of a medium to the movement of a particle through it. With sand this is normally relation to the solids density.

- **Particle velocity**
  This controls the dwell time that the particle is exposed to the magnetic field. A low velocity will enable the magnetic field to capture and hold a particle, whereas a high velocity will result in only a deflection and no capture. This effect is more important as magnetic susceptibility decreases.
The HI Filter

The concept of the HI Filter is taken from the large high intensity devices developed to produce magnetic fields of up to 20,000 gauss for the treatment of fine kaolin suspensions.

The unit consists of a hollow solenoid coil enclosed in a steel box, with a matrix inserted in the centre of the hollow coil. This design of separator although a batch type unit provides close control of the separation parameters with an efficient magnetic circuit producing minimal magnetic field leakage.

Normally this type of unit is bottom fed with the feed suspension passing upwards through the matrix under controlled conditions.

The minimum velocity attainable in such a system is directly proportional to the maximum particle size present in the feed. With silica sands of <0.6mm, velocities of 4.0-5.0 cm/sec are high enough to maintain the particles in suspension and prevent sedimentation.

HI-Filter operation follows a defined sequence which is controlled by a PLC unit.

The initial operation of any cycle is a water wash to ensure that the matrix is clean before the first processing operation.

A small delay then occurs to allow the magnetic field to reach maximum intensity before the feed is admitted.

At the end of the process part of the sequence the feed and discharge valves close but the magnet remains energised. A separate pair of valves open to allow material in the canister to be discharged as the middlings fraction.

The water wash then operates with the magnet de-energising to release the magnetic particles.
**Separation**

By undertaking comparative laboratory trials with the conventional WHIMS it was discovered that the separation performance of the filter was an improvement over the WHIMS even at lower magnetic fields.

The problem of the HI Filter being a batch separator, with a finite magnetic capacity, was solved by utilising 2 filters operating as a pair. When one filter of the pair is processing, the other unit is cleaning and vice-versa. The processing time was designed to be 60 s processing and 60 s cleaning giving the added advantage of providing a continuous process flow, preventing sedimentation in the feed pipework.

The capacity of such a system is controlled by the magnetic content of the feed which in turn relates to the dry solids input. Tests can accurately determine the maximum magnetic loading for any size of filter, from which the dry solids feed rate can easily be calculated. A series of tests with increasing mass of solids which is proportional to the magnetics content, are conducted and a plot of Fe₂O₃ content against matrix loading plotted. From this load curve it is possible to scale up to a production system.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Pegmatite &lt;200 micron</th>
<th>Silica sand &lt;400 micron</th>
<th>Silica sand &lt;450 micron</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEPARATOR</td>
<td>WHIMS</td>
<td>Hi - Filter</td>
<td>WHIMS</td>
</tr>
<tr>
<td>VELOCITY (cm / sec)</td>
<td>&gt;25 4.0</td>
<td>&gt;25 6.0</td>
<td>&gt;25 6.0</td>
</tr>
<tr>
<td>TARGET Fe₂O₃</td>
<td>&lt;0.015%</td>
<td>&lt;0.012%</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>ACHIEVED Fe₂O₃</td>
<td>0.0175%</td>
<td>0.0172%</td>
<td>0.07%</td>
</tr>
<tr>
<td>MAGNETIC FIELD (Gauss)</td>
<td>20,000 4,500</td>
<td>8,000 5,000</td>
<td>8,000 5,000</td>
</tr>
</tbody>
</table>

Product % Fe₂O₃ vs Feed 0.1% Fe₂O₃

Matrix Loading (g/cm²) vs Product % Fe₂O₃
The standard production system to date has been based around a pair of model 200-50 HI Filters with a typical capacity of 8.0-12.0 t/h. The units are supplied with air-operated butterfly valves which require a minimum of 6.0 bar compressed air pressure. Control of the system is via a small microprocessor system and is completely automatic resulting in minimal supervision.

An option exists with the middlings fraction produced as to recirculation to the feed or blending with the product. Middlings output is in the order of 10% of the feed.

Typical operating conditions for the above system would be 9.0 t/h of dry solids in a 25% solids suspension with an average particle velocity of 4.8 cm/sec.

Results from a 2xfilter plant installed in a Czech sand operation are illustrated in the following graphs. Target specification was to produce a sand of <0.015% Fe₂O₃ but generally under <0.010% Fe₂O₃ which has been achieved with a 50% increase in capacity. Operational costs of this system are extremely low at 0.2 pounds sterling per ton of sand.

The flowsheet for a 4xfilter plant installed in France to handle 16t/h is illustrated in flowsheet 1.
Eriez currently has experience on the operation of 5 magnetic filter plants each processing silica with model 200-50 HI-Filter units. All plants are computer controlled and operating on the 60sec Flip-Flop cycle principle with middlings recirculation. Minimum supervision is required for the automatic process.
Typical wash water consumption is 250l/min per filter (200-50 HI-Filter) although this dependant on canister volume.
System wear is reported in all cases to be very low, with only the lower 2 or 3 sheets of matrix being replaced every 15k-20k tons of sand processed.
No problems have been seen with the butterfly valves used over the operational period of 3yrs.
The customer has since purchased a further pair of 200-50 filters to double his capacity.

The first of a larger generation of filters has now been installed in Italy to operate on a crushed quartzite.
The single model 800-50 unit was installed to process 12-15 t/h with the objective of reducing the feed Fe₂O₃ from typically 0.125% to less than 0.095%. This unit has met the expected performance and has produced material of 0.065%.
Model 800-50 HI-Filter operating on quartzite in Italy

Separation Data for 800-50 HI-Filter.
Dry Separation

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The part played by dry magnetic separation for the treatment of silica sands and more commonly feldspatic sands, has always been confined to relatively specialist grades produced in small quantities. Production of such materials is normally for a bagged material, and a lower iron specification is often associated with such a product. Therefore this premium type of material can command a higher selling price and therefore stand additional process costs.

Early magnetic separators used in the sand industry were the Induced Roll Magnetic separator or IMR. The IMR system is an electromagnetic system relying on the induction of a high intensity field into a laminated roll. The separating roll is comprised of alternate discs of mild steel and a non-magnetic metal. The roll is situated between the 2 poles of the electromagnetic circuit and high intensity and high gradient fields are induced into the steel discs. The intensity of the induced field is controlled by the force generated by the electromagnet and also the air gap between the pole and the roll. Consequently the smaller the air gap between the roll and the pole, the smaller the space available for the feed to pass, the smaller the acceptable granulometry and the lower the capacity.

Maximum fields of 18,000 gauss can be generated on the IMR roll but at a minimal capacity.

As a result IMR systems gave effective separation on a limited size range but at a high capital and operating costs.

Although the power consumption of the electromagnet on IMR units is relatively low at typically 2.0 - 4.0kw, the motor drive power consumption is high at typically 3.0 kw because of the magnetic drag produced on the induced rolls.
**The Rare Earth Roll Separator**

The rapid development of high energy rare earth permanent magnet material over the last 15 years has enabled new high intensity permanent magnet designs.

The rare earth roll was developed as a low energy replacement for the IMR and utilises alternate discs of magnet material and steel. The magnetic field is then induced into the steel disc in a similar manner to the IMR. Material is fed onto the permanent roll using an extremely thin transport belt which in turn removes the magnetic particles from the underside of the roll.

The magnetic field generated on the induced poles is between 18000 and 21000 gauss but this drops with the addition of the transport belt to nominally 13000 gauss.

Total energy consumption is very low, at nominally 0.75kw per roll with the only other consumable being the transport belt.
As the magnetic field produced by the permanent roll decreases rapidly with distance from the roll surface, a very thin transport belt and feed depth are required for the best separation. Normally for sand separations a 0.15mm kevlar transport belt is used with a life of up to 2000 hrs.

The biggest problem associated with the 75mm diameter designs which are commonly produced is the capacity limitations. For sand 2.0 - 3.0 t/h per meter width is usual. Obviously, for higher capacities the number of units required will be large with the attendant problems of feed splitting and a larger number of belts to maintain.

Firstly Eriez Magnetics has approached the problem of capacity by exploring by developing increased diameter roll which have increased capacity. A comparison of capacities against grade is shown on the graph below for 75, 100 and 300 mm diameter units on a single pass.

The maintenance and changing of belts has been problematical with roll designs utilising bearing supports at either end of the rolls.

Eriez have overcome this problem with a cantilever design which allows unrestricted access to the non-drive side of the rolls enabling a simple belt change in under 2.0 minutes.
Often material being fed to the rare earth roll separators will have passed through a drier and still be at a relatively high temperature.
For material in the range of 80-120 deg C, it is necessary to use a high temperature grade of rare earth in order to minimise the reversible and non-reversible energy losses from the magnet material due to the temperature effect.
It is a particular property of standard neodymium-iron-boron magnet material that as the temperature rises above 70 deg C there are gradual losses in the stored magnetic energy which is available from the magnet. These losses take the form of reversible losses, where the magnet returns to its original energy capacity on cooling, and irreversible losses where the magnet returns to a lower energy level on cooling. In the latter case the magnet can only be returned to its original power by re-magnetisation.
The high temperature neodymium-iron-boron has a lower energy level at room temperature than the standard material, but has a much higher temperature stability resulting in an overall higher energy after being subject to >80 deg C temperatures.
Therefore it is very important to consider the temperature of the feed when ordering Rare Roll type or any rare earth magnet permanent separators.

**Summary**

To conclude, developments in magnetic separators have produced user friendly wet and dry separators which are suitable for the economic processing of silica sands at high capacity to produce superior grade materials or open up new reserves which were previously unusable.