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Physical Separation Technology
External Newsletter

Contents

Separation Solutions

Outotec
More out of ore

Water, water everywhere, and not a drop... for processing

The irony is that even 'potable' water may be useless for processing certain minerals. Drawing on experience gained from over 20 industrial Cryofilter® High Gradient Magnetic Separator installations, water issues that directly affect kaolin (china clay) processing are highlighted. The number and range of factors that must be considered are discussed, with emphasis on processing stages through Cryofilter® operation and the subsequent treatment of the product and waste streams.

To move forward we must first go back and discuss the origins and nature of kaolin, and the function of water during the extraction and processing stages. Only then will we begin to understand their behavior when mixed together as slurry.

Formation of Kaolin

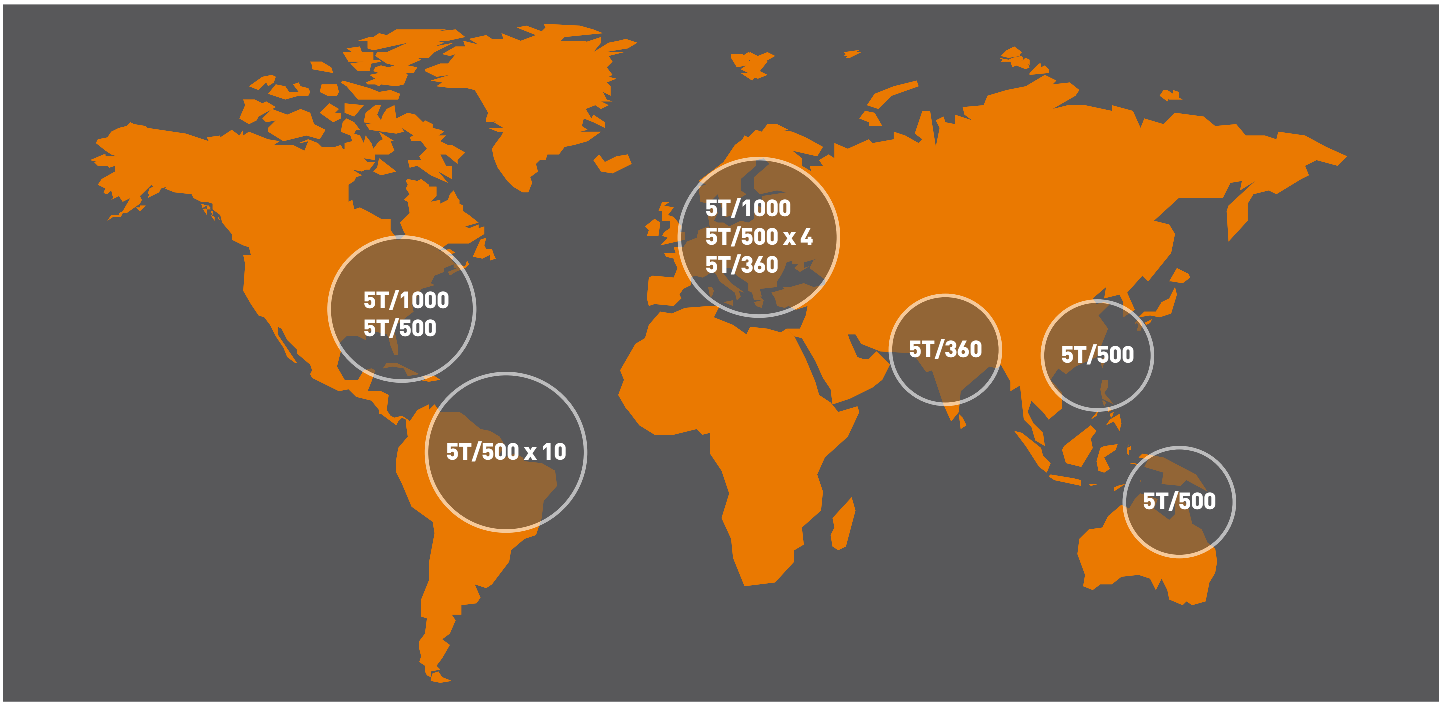
Kaolins from around the world are formed over millions of years from the gradual water and heat forced decomposition of feldspar or micas found within granite. Kaolins which have been altered in-situ will be mixed with components of the parent rock and are called primary or residual deposits. If the clay is transported by water and/or wind, and then re-deposited some distance away, they are termed secondary or sedimentary deposits. The kaolinite content of a primary deposit may be as low as 10% (Cornwall, UK). In sedimentary deposits (Georgia, USA and Northern Brazil), due to the natural size sorting that occurs during transportation, kaolinite content can rise to 80-95%.

Differences in formation and location will confer each kaolin deposit with its own particular qualities, influencing how to best treat the kaolin for optimum results. The nature of the deposit will dictate the amount of water required to extract the kaolin initially, as well as the water needed during the downstream processing stages. Experience from Cryofilter® processing in various locations illustrates how these factors affect the selection of processing equipment, the associated water consumption and overall processing costs. No matter the location, the recurring necessity for each application has been to find the right quality water, since the physical properties of kaolinite can actually be controlled, when in slurry form, by changing its chemical surroundings.

The slurrying effect

The physio-chemical activity that occurs at the surface of the kaolinite particle is key. Kaolinite particles (sized between 2-5µm) possess a natural and variable negative surface charge when suspended in water, the magnitude of which is influenced by dissolved chemicals present. This surface charge causes particles to repel each other, and so maintain relatively stable suspension. The slurry stability can then be manipulated by adding reagents that absorb onto the surface of the kaolinite particles and either increase the charge (dispersants) for more stable suspension, or reduce the charge (coagulants or flocculants) for destabilization. Both methods also affect the slurry's working properties, such as viscosity and appearance. Enhancing dispersion is generally essential to processing up to and including the Cryofilter®, whereas flocculation is deliberately induced during waste treatment.

Like the reagents, the positively charged ions commonly found in ground or process water (calcium, magnesium and iron) will also adsorb on kaolinite particle surfaces, influencing their degree of negative charge. When the net surface charge is sufficiently low, single particles can approach closer and clump into larger groups called agglomerates or 'flocs', causing them to collectively act like a single, much larger particle. Maintaining proper dispersion throughout processing is critical because effective separation occurs when particles behave as single entities. Special attention must be paid to ensure correct slurry chemistry and adequate process



Industrial -scale Cryofilter® installations around the world.

water quality. Kaolinite is especially sensitive to water containing calcium and magnesium ions, and levels as low as 20-30 ppm (mg/l) can be problematic.

The hydrogen ion concentration (generally expressed as pH) in water is another important parameter. Most natural waters have a pH between 5-8 and within this range most kaolin slurries are stable. When acid is added to reduce the pH to less than about 4, kaolin slurry flocculates into a thick homogeneous mass, an ideal state for filtration, whereas dispersed or un-flocculated slurry cannot be filtered. Adding alkali to raise pH will readily and quickly re-disperse the slurry with no ill effects, and indeed some plants do this after both filtration and pumping.

Primary deposit practice

At the primary deposits in Cornwall, kaolin is commonly extracted from the open-pit mines using high-pressure water jets that wash the kaolin loose from the previously blasted surrounding rock. The water for this purpose comes from rain or local rivers and can be used without any treatment since it naturally contains negligible levels of the impurities mentioned.

The large amounts of water required for jet washing the kaolin from the waste host rock produces dilute slurry of about 5% solids. This slurry is collected in the pit bottom, classified to remove the coarsest size material and then pumped out of the pit. Subsequent processing stages to prepare products of various sizes involve low cost simple classifiers such as hydrocyclones. The drawback to using such devices is that the slurry enters the Cryofilter® with only about 10% solids. Moving this low solids content slurry through the process circuit requires a great deal of water per ton of kaolin treated. A high proportion of this water enters the dilute waste stream containing the magnetic impurities flushed from the Cryofilter®.

Some plants have adequate water supplies and sufficiently large areas for storage where this waste can be contained to allow the fine solids to settle and separate. Where large storage areas are not available, the low solids waste stream is injected with very small doses of flocculant solution (often about 2 ppm). With the flocculation process initiated, the stream passes into large diameter separation 'thickening' tanks, where the quiescent conditions allow the flocs to settle quickly to the bottom. The settled flocs are pumped away and the now clear water 'overflows' for recycling. Water consumption is greatly reduced since about 80-90% can be recycled directly and demand for a storage area is considerably reduced.

Cryofilter® HGMS systems treating a sedimentary kaolin deposit

Though thirsty, these primary deposits do have several major redeeming features. Firstly, the process feed water often contains very low or negligible levels of impurity ions and thus requires no pre-treatment. Secondly, the rock in the pit bottom is impervious, and once exhausted of kaolin, can be used to store rain or process water for recycling, hence the water supply and storage can be very low cost items.

Secondary deposit stats

In contrast, the secondary deposits, typical of Georgia and Brazil, contain very high proportions of kaolin at relatively shallow depths making extraction easier and cheaper using simple mechanical equipment. Often, the kaolin is put directly into stirred tanks called blungers within the pit area, and agitated with water at 50% solids content together with a dispersant (such as an inorganic phosphate compound or preferably a polyacrylate type)

Two examples of problematic water supplies. Left: process water with obvious color staining. Right: process water with not so obvious suspended particulates.

to keep the particles dispersed and dispel any effects of flocculation. An alkali, such as sodium hydroxide, is also often needed to correct the pH level to above neutral so that the dispersant works most effectively.

The advantage of the high solids content during the initial slurry preparation continues downstream. By using classifying centrifuges, the solids content of the Cryofilter® feed slurry is often at least 30%, leading to higher production rates and much lower water consumption. Many plants are blessed with ample supplies of high quality well water and large dumping areas for waste streams. Unfortunately, a typical river water source often contains miscellaneous suspended animal and vegetable matter, and mineral particulates that inevitably get sucked into the supply.

A case for clean water

In some areas of the world, where the process water permeates limestone, the calcium and magnesium levels can rise to punitive levels and corrective action is required. The negative affects of these impurities can be illustrated through one case study where the client switched water sources between laboratory testing and plant operation without examining the new water source. The water quality issues were not discovered until commissioning, when the entire Cryofilter® became blocked with flocculated kaolin after only several hours of operation.

The source of the problem was quickly traced to the high level of calcium and magnesium discovered in the water used to prepare the slurry. Fortunately, flocculation by these ions is usually reversed by suitably adjusting the chemical environment; in this example large quantities of sodium carbonate (about 5 kg/t solid) were added to the slurry feed tank. The sodium ions gradually replaced the calcium and magnesium over a period of about two hours. Dispersion was restored and the calcium and magnesium were precipitated, thereby rendering them inactive.

Operation continued using this reagent regime, though strong recommendations were made to avoid the need for such action, i.e. by upgrading to a process that would both treat the water and minimize fresh water consumption.

Staying afloat

Partnering with someone well schooled in the issues affecting kaolin processing can be key to success. Evaluation of both your deposit and your water supply will reveal any obstacles so that subsequent testing and careful flowsheet development can ensure a profitable endeavor. Remember, whilst humans can easily tolerate water with some levels of "impurities" a seemingly passive kaolinite particle cannot!

» Richard Allen - HGMS System Consultant, United Kindgom
David Richards - Magnet Systems Manager - Jacksonville

Method to the magnets

Various types of magnetic separators have historically been used for the separation of minerals. Recent advances in magnet composition and design have led to higher magnetic field strengths and the ability to separate more weakly magnetic minerals. All combined, these advances have allowed for the greater production of a variety of mineral products and derivatives.

Historical perspective

The transition from energy consuming induced-roll magnetic separators to permanent rare-earth and superconducting magnetic separators began in the late 1960s. The field strength of permanent magnets was greatly increased (up to 2 Tesla) when the rare-earth element samarium was combined with cobalt and iron. These early SmCoFe magnets were soon replaced with the less expensive neodymium–iron-boron magnets. Today rare-earth magnetic separators comprised of NdFeB magnets are supplied in a variety of designs and are routinely found in applications requiring the separation of paramagnetic minerals and particles.

In the 1980s, the study of superconducting magnets (field strengths >2Tesla) became more than an academic interest. Today, superconducting magnets with field strengths up to 5T are cost-effective, and are used in applications requiring the separation of the most weakly magnetic minerals.

The following article will cover some general rules regarding the placement of select types of magnetic separators, and reveal the rational for such choices. Specific instances will then be offered to further illustrate the process of selecting the appropriate type of magnetic separator for a particular application. When finished, the reader will have a strong grasp on where and how to begin the process of selecting the most appropriate magnetic separator for their application.

First Question: Wet vs. Dry

Is the separation process wet or dry? Generally this is the first question in the selection process. As a rule of thumb, if an operation is "wet" it is best to stay "wet" in order to reduce drying, operating and storage costs. Employing wet magnetic separation early in a process can benefit an operation if a low-grade final tailing, or a clean marketable product can be produced.

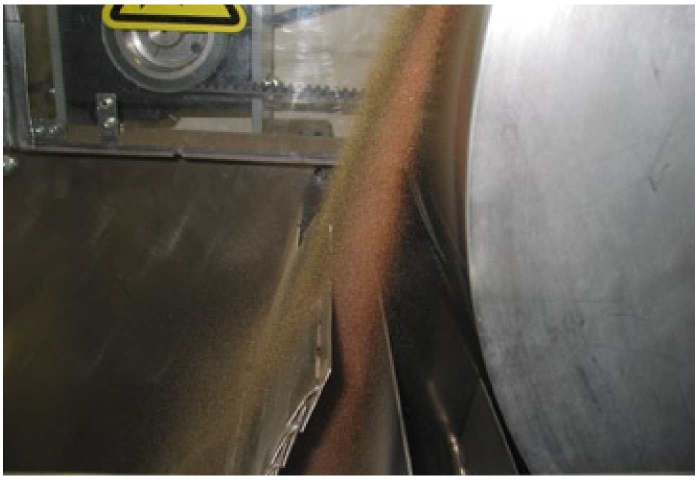
Wet High Intensity Magnetic Separators (WHIMS), like the Jones-type, are traditionally used in the removal of weakly magnetic materials from feeds with predominantly magnetic assemblages. A common drawback of many conventional WHIMS designs is the entrapment of non-magnetic minerals in the magnetic product. This drawback is more pronounced when treating finer particles. This shortcoming has been addressed with the SLon® Vertically Pulsating High Gradient Magnetic Separator (VPHGMS), and this advance has extended the use of the WHIMS into finer applications previously considered untreatable by conventional WHIMS or gravity concentration.

Dry rare-earth magnetic separators, both drum and roll designs, generally offer a more precise separation than that of a wet magnetic separator. As the separation

SLon Vertically Pulsating High-Gradient Magnetic Separator medium for dry magnetic separation is air, an additional advantage is the ease of operation and control. The ability to control more than a simple magnetic / non-magnetic separation of a material allows for the production of a variety of products.

RED vs. RER

Deciding between a Rare-Earth Drum (RED) or Rare-Earth Roll (RER) magnetic separator is often determined by particle size and unit capacity. RED units are most often used to separate two or more relatively coarse paramagnetic minerals into separate finished products (or semi-finished products for further polishing). REDs are typically used in the early stages of a dry separation process flowsheet where higher unit capacity is an advantage.



An Outotec laboratory RED processing heavy minerals.

A RER is more commonly applied to residual streams after removal of the more highly susceptible magnetic minerals such as ilmenite, hematite, chromite or garnet. A RER is also commonly used for recovery improvements and final cleaning of high value products like rutile, zircon and glass sands.

Induced-Roll

Until the mid-1980s the IRM separator was the "work-horse" of mineral separation circuits. Although IRMs are still in use, their applications have become limited as the RER provides the same performance in the vast majority of applications, and RERs have over 50% greater capacity per unit operation. The smaller plant footprint coupled with lower capital and operating cost, (about 30% and 60% respectively) have made Rare-Earth Roll the magnetic separator of choice in most operations.

An Outotec laboratory RER processing heavy minerals.

Superconducting High-Gradient

Superconducting high-gradient magnetic separators are most commonly found in kaolin operations where their primary goal is to remove magnetic impurities from feeds with minor amounts of color influencing contaminants. Recent test results have the industry expecting these separators to become more routinely used in the production of additional "white" mineral products with end uses in the paper, paint and ceramic industries.

The are two main advantages of a superconducting magnet:

- Used in a persistent mode, (i.e. with the magnet constantly energized) the unit is essentially a permanent magnet and requires and consumes very little power.
- The higher magnetic field strength's of superconducting magnets more effectively "attract" and "hold" contaminant particles allowing for higher processing rates.

Material	Feed Specifications			Product (Unbleached)	
	Type	*Grade*	*% Solids*	*Grade (gain) [% reduction]*	*Production Rate (tph)*
Kaolin	Coating Grade	54 to 84 ISO	23 to 28	67 (13) to 88 (4) ISO	6 to 45
Kaolin	Ceramic	77 ISO 1.4% $Fe_2O_3+TiO_2$	23	81 (4) ISO [45] $Fe_2O_3+TiO_2$	6
				80 (3) ISO [38] $Fe_2O_3+TiO_2$	13
				79 (2) ISO [26] $Fe_2O_3+TiO_2$	22
$CaCO_3$	General coating/ filler	~90 ISO	up to 75	~91 to 93 (1 to 3) ISO	56
Nepheline Syenite	General ceramic	0.36% Fe_2O_3	30	0.10% [72] Fe_2O_3	11
				0.13% [64] Fe_2O_3	22

Examples of gains achieved during Cryofilter® 5T/500 superconducting magnetic separation tests.

Consider this

Though there are many general practices, as mentioned above, not every decision is straightforward. These 'rules of thumb' are best used as guides to direct process development testwork. Knowing the general practice provides a starting point, but seldom the end point. The following two case studies illustrate the need to be open-minded when doing test work. Some times, the answers you find will defy convention.

An example of Wet vs. Dry Magnetic Separation

Initial studies of a chromite-rich mineral sands deposit had a problematic overlap in the magnetic susceptibility of chromite and ilmenite, a titanium bearing mineral contaminant. For this reason, early testwork had defined an overall saleable chromite recovery limit of 60-70%. Further process development testwork was then carried out to increase chromite recovery without compromising product quality.

Assays of the pre-concentrated wet product revealed that using magnetic separation alone would produce a chromite product contaminated with other magnetic minerals including magnetite, ilmenite and garnet. Due to the poor quality of the product, the cost-effectiveness of using a WHIMS was questioned. Although contrary to the convention of 'when wet stay wet,' it was found that electrostatic separation of the pre-concentrate, followed by dry magnetic concentration of the conductor fraction was most practical, so to the dryer the material went. The electrostatic stage was utilized to separate the magnetite, ilmenite and chromite from quartz and other nonconductor silicates.

The magnetite was then easily removed from the ilmenite and chromite product with a low cost, low intensity magnetic drum separator. The LIMS stage was followed by a circuit of higher intensity double-stage rare-earth drum separators of high capacity, which proved to be most cost-effective for separating the chromite from the ilmenite. The new magnetic circuit increased chromite recovery approximately 20% over the previous process.

The electrostatic conductor fraction contained 87% of the head feed Cr_2O_3 units, and of the head feed, 82% of the Cr_2O_3 was recovered in the new rare-earth drum circuit versus the 60-70% Cr_2O_3 recovery from earlier tests. Of the recoverable Cr_2O_3 units entering the magnetic separation stage alone, the combined Cr_2O_3 recovery was 95.9% with an average product quality of 44.5% Cr_2O_3.

Criteria	Roll Separator	Dry Drum Separator	SLon WHIMS
Ferromagnetic material (magnetite, tramp iron)	Scalper model (low strength) with long-lasting thick belt	Small amount tolerated (<1%), using release bar	Needs to be scalped first by LIMS
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	High efficiency if wet process is desired
Moderately paramagnetic (biotite, leucoxene, monazite)	High efficiency, higher grade and recovery compared to electromagnets.	No Use	High efficiency if wet process is desired
Weakly paramagnetic (muscovite, amphiboles, pyrite) Cleaning of quartz, feldspar, zircon, rutile	High efficiency, higher grade and recovery compared to electromagnets	No Use	Moderate efficiency
Operations and maintenance	Low attendance. Belt change easy.	Minimal operator attendance. Replacing drum shell requires qualified shop work	Minimal attendance, significantly less than a horizontal WHIMS configuration.
High Capacity	150mm versions providing 1.5x capacity of 100mm roll	Very high capacity with 610mm diameter drums. Larger drums are also available	80-150 tph with largest model 2500
High Temperature	+120°C if needed	Up to 100°C	Not Applicable
Process Control	Wide range of parameters, great control flexibility	Moderate range of adjustments	Moderate range of adjustments

Comparison of magnetic separators used for processing industrial sands

How the SLon fared against a traditional WHIMS

One iron ore operation yearly processes 8M tons of oxidized iron ore; producing iron concentrates of 2.7Mtpa. The deposit consists of a low-grade ore with hematite, magnetite and quartz ranging in size from 5µm - 1.0mm (averaging 50µm) graded almost 30% Fe; but also containing the contaminant elements of sulfur and phosphorous. The plant had implemented a roasting process, yet the concentrate was limited to a maximum recovery of 63% Fe.

Hoping to avoid drying, the operation decided to test WHIMS technology as a way to improve their final iron product. Because the feed material was <75µm, both a traditional separator (horizontal ring) and a SLon (vertically pulsating ring) were tested. It was found that the SLon provided higher-grade (67% Fe) and recovery (78% Fe) while operating at higher capacities. In addition, the matrix never plugged allowing for increased operating time.

Armed and ready

The overview, as well as the case studies, reveals that though it is helpful to understand the rules of thumb, it is important to remember that they are simply that – guides, and not finite answers. Armed with the basics, it will be that much easier to delve into your search for the best magnetic separator. For more information on these magnetic separators, like principle of operation and more specific application examples, visit www.outotec.com or contact your local Outotec office.

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