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Additional copies: £100
Challenges ahead for mineral processing

Mining companies are becoming anxious about the dwindling number of high-grade mineral deposits around the world—and with good reason.

Today’s mines are much less productive than they were 20 years ago, and there are few signs that exploration will unearth many rich, easily accessible mineral deposits in the future.

Many existing processing methods are struggling to recover minerals from low-grade, complex ores and a lack of automation means that mining firms have to employ more people over more hours just to achieve economic recovery rates from mineral deposits.

This has led to a 200% increase in real wage payments, according to recent research by Bloomberg Industries.

Energy costs are also going up (see p10), and are presently around 125% higher, on average, than prices paid for power a decade and a half ago. Severe skills shortages are also affecting the sector.

Combined, these factors have been responsible for many of the capex overruns in mining projects seen in recent years. Overruns of 40% are typical in today’s bearish market, according to Bloomberg Industries, and in the pre-2009 bull market, capital overspends of 70% were not uncommon.

The potential of processing

Given these mounting pressures, miners are being encouraged to reconsider their processing capabilities as the most effective methods of improving operating efficiencies.

However, traditional methods of processing are often ill-suited to the grades of ore they are now being required to process, and in some instances these methods are even destroying the value of deposits.

The problem of waste disposal, and the impact of certain gangue materials, such as sticky clays, on processing efficiency, the requirement to treat more complex feed materials and the obligation to comply with environmental standards are among the chief challenges that processing engineers are being tasked with overcoming.

Better processing technology and improvements in technical services are undoubtedly needed, but these must deliver long-term economic benefits necessary to justify ever greater equipment costs (see p6).

Global leaders in processing technology such as Ecotec, Metso, Comex and Eriez have responded to these needs by shifting away from working out improvements to existing technology, based on current operating efficiencies, to develop new, problem-based solutions.

Industry buy-in and co-operation are also important for developing new processing systems, because companies that encounter practical challenges during their commercial operations are best placed to identify problems and provide case studies for the trialling of new technologies (see pp7-9).

The availability of robotic particle separation, automated mineral analysers (see pp24-25) and increasing use of X-ray and infrared technology (see pp12-14), laser spectroscopy and nuclear magnetic resonance are initiating more innovative transformations in ore characterisation and plant control.

Improvements in characterisation technology over the last 30 years have also enhanced understanding of factors that contribute to inefficiency in separation and flotation, while appreciation of inefficiency has led designers of mineral processing plants to target minimising wastefulness.

These design concepts are being applied in tandem with better technologies to improve results for separation and flotation (see pp16-17).

Strategic importance

In addition to the profit-based drivers of developments in processing technology, there are political and strategic motives for upping the efficiency of mineral recovery.

Official designations of ‘strategic importance’ and ‘criticality’ for certain minerals, such as rare earths, in the US, European Union and elsewhere in the world, are often accompanied by calls for more mining projects to combat potential shortages.

However, it takes an average of 7-10 years to take a mineral deposit into full mine production in the US, and mineral processing engineers argue that supply security can also be aided by more efficient recovery technology and recycling.

New processing systems have been designed to produce valuable by-products simultaneously with target mineral extraction (see pp30-32), and recover economic quantities of minerals from mine tailings.

Yet, while lab-based process trials (see pp26-29) are proving the potential of new technologies, persuading industry to break with traditional systems and invest in more sophisticated solutions is proving to be processing’s toughest challenge.

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Economics drive change in processing

Mounting economic and practical challenges in mining are set to force wholesale transformations in mineral processing solutions, Laura Syrett discovers.

The global mining industry cannot afford to destroy inherent value in mining operations by using inappropriate and outdated processing technology.

While miners are reluctant to stump up cash for new beneficiation solutions, particularly in a climate when mineral commodity prices are weakening and project finance is hard to come by, there is a grudging acceptance that investment is needed in more sophisticated technology that is capable of yielding more profitable returns.

At the Physical Separation 13 conference in Falmouth, UK, in June, processing experts agreed that the need to maintain profitability would force a step-change in the mining industry’s approach to processing.

“Economics dictate that change must come,” David Bowman, study manager at the Australian mining consulting firm, Bear Rock Solutions, told the meeting.

Robert Morrison, chief technologist at Julius Kruttschnitt Mineral Centre, University of Queensland, said that persistent underlying problems were driving engineers to develop processing systems that were significantly more advanced, but also more expensive, than the industry was used to seeing.

“This is a good thing,” Morrison said, adding that the need for investment in processing technology was imperative, since there are no signs that things are set to improve on the exploration front.

Lower grades mean more waste

The gradual decline in ore grades and increasing complexity of ore body extraction, coupled with fewer discoveries of new mineral deposits are not new challenges for the mining industry.

“The grandfather ore bodies are starting to get a bit long in the tooth, and processing engineers are being tasked with finding ways of squeezing the last drops of value out of both old existing and new lower-grade mines,” Bowman said.

He added that the anecdotal view of many in the industry is that known ore bodies that are still in the ground are there for good reason, namely that they are deemed too difficult or costly to extract.

The reliance on engineering capital to undertake the full extraction of valuable minerals contained in these ore bodies is based on an established view of mineral extraction and tailings generation, Bowman said.

“But, given the amount of extra waste associated with processing low-grade ores, we now need to critically re-consider the flow sheets mining companies have been using for decades,” he added.

Input costs could be considerably reduced, Bowman suggested, if miners invested in more efficient methods of handling waste.

He advocated a multi-step waste rejection model, whereby unwanted rock is ejected from the processing stream at several stages, resulting in less waste being carried forward throughout the process, which would lower energy consumption.

“Adopting this view of waste handling represents a huge overall change for most mining systems, but it is an area that needs to be addressed if miners are to be successful in tackling today’s challenges,” Bowman said.

Reducing costs

Most advances in the field of resource recovery can be attributed to the need for reduced operating costs through improved productivity.

Speaking at the annual Society for Mining, Metallurgy and Exploration (SME) meeting in Denver, US, in February, independent processing consultant Bo Arvidson said that entrepreneurial innovation in the second half of the 20th century coupled with commercial muscle power from established engineering firms meant that mineral processing had become a highly sophisticated industry, capable of adapting to changes in circumstances.

He said that processing had overcome misconceptions associated with high costs and the restriction of technology to higher-value applications, and is now seen as an area worthy of investment.

Dr Patrick Taylor, director of the Kroll Institute for Extractive Metallurgy (KIM), which includes the Center for Resource Recovery and Recycling (CR³), at the Colorado School of Mines (CSM), noted that cost is one of two key catalysts behind innovation in mineral processing and extractive metallurgy, the other being the need to meet increasingly stringent environmental criteria.

“The goal [of mining and technology companies] is generally to find economical ways of getting the minerals out of their ores,” Taylor said.

He added that the chief opportunities for processing engineers lie in improving methods for reducing ores to valuable minerals using the most efficient methods available.

From a sustainability point of view, the industry needs to attract the best engineers into the field of mineral processing and extractive metallurgy, Taylor said, something that is proving challenging in a world where information technology is proving the main draw for much of the world’s top engineering talent.
The applications for ground limestone of various particle sizes are wide-ranging and include power generation, plastics, building materials, refractories, paint, agriculture, environmental protection and highway construction, to name but a few.

The demands made on product quality and the necessary levels of fineness have risen steadily in recent years, due to the diversity of the applications for these materials. Plant operators are accordingly obliged to modify their product portfolios to meet these demands from customers. Loesche has reacted by developing an industrial minerals mill with throughputs of 5-100 tonnes/hour, featuring an integrated grit extraction screw.

Incorporated into the standard configuration of the Loesche vertical roller mill, the grit extraction system makes it possible to produce not only fine products (<100 μm) but also a larger product (>100 μm), simultaneously.

The functioning of Loesche vertical roller mills
Since 1934, Loesche mills have been used around the globe for processing minerals. The industry generally requires that minerals can be processed at throughput rates of between 5-100 tonnes/hour and yield finenesses ranging from 1% R 25 μm to 1% R 300 μm.

The Loesche mill features the following properties:

- a flat grinding track;
- tapered grinding rollers;
- two, three, four or six grinding rollers (depending on mill size, the grinding rollers being individually mounted in rocker arms); and
- a hydropneumatic spring system for generation of the necessary comminution force in the grinding bed (see flow sheet, p9).

Loesche’s limestone testing partners

**Kraft Steinwerke**
Kraft Steinwerke, based at Heidenheim, Germany, operates a Loesche mill LM 19.2. The company uses high-purity calcium carbonate extracted from a quarry adjoining its processing facility, which is used for the production of ground limestone, dried Jurassic marble grades, gravel base courses, sand and chippings, predominantly for the building materials industry.

**Kilwaughter Chemicals Co. Ltd**
Kilwaughter Chemicals, founded in 1939 and based in Larne, Northern Ireland, operates a plant for the production of calcium carbonate powder, pulverised limestone and other minerals. A Loesche mill LM 15.2 has been used for this purpose since 2010.

The feed materials processed, which are obtained from the company’s own quarry, are used in the construction industry, the agricultural industry and also in horticulture, amongst other markets.
From here, the particles of material are conveyed to the classifier by a flow of gas or air. Particles of the required product fineness flow through the classifier and leave it in the flow of gas to the downstream dust separator. Oversize material is rejected by the classifier rotor and either drops back via the grit cone onto the grinding table to be further comminuted, or can be diverted off via a separate extractor system and used as an end product.

The mill is driven by an electric motor with a special gearing system. A thrust bearing in the gearbox absorbs the forces exerted by the grinding rollers. The latter are raised hydraulically from the grinding track for starting the mill. The hydraulic pressure necessary for this purpose is supplied by the cylinders of the spring system.

### The grit extraction system
In the two plants mentioned above, a grit extraction screw is installed between the mill and the classifier; additionally to the standard configuration described above. This makes it possible to produce two products of differing finenesses simultaneously and in a single process.

The fine product, or product 1, is routed via the classifier into a downstream filter and conveyed from there into product silos. The grit, or oversize material, is rejected by the classifier.

Product 2 is collected via a grit cone in a screw and extracted from the mill. The grit cone can be designed either to extract the whole flow of grit (as is the case at Larne, see Table 2 above, and case study below) or only a part-flow (as in Heidenheim, see Table 1 above, and case study below). Where only part of the flow is removed, the remaining grit is returned to the grinding table for regrounding.

The grit removed from the mill is conveyed by means of screws and bucket elevators for further treatment, and routed to various individual processes.

### Karl Kraft and Kilwaughter case studies - testing and results
In order to quantify the mass flows and particle-size distributions in the fine product and the grit, Loesche has conducted test measurements in co-operation with two limestone processors: Heidenheim, Germany-based Karl Kraft Steinwerke and Kilwaughter Chemical Co. Ltd, an Northern Ireland firm based in Larne.

The tests performed in these two plants demonstrate the expansion of the product portfolio and the flexibility of the installations, enabling the operators

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**Table 1: Operating data and product rates at Heidenheim**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>1% R 63 μm limestone</th>
<th>1% R 63 μm limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate</td>
<td>tonnes/hour</td>
<td>30.6</td>
<td>33.0</td>
</tr>
<tr>
<td>Material moisture content</td>
<td>%-H2O</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Moisture in fine product</td>
<td>%-H2O</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Target fineness</td>
<td></td>
<td>1% R 63 μm</td>
<td>1% R 63 μm</td>
</tr>
<tr>
<td>Measured fineness</td>
<td></td>
<td>0.1% R 63 μm</td>
<td>0.5% R 63 μm</td>
</tr>
<tr>
<td>D50 fine fraction</td>
<td>μm</td>
<td>3.1 μm</td>
<td>3.3 μm</td>
</tr>
<tr>
<td>Product rate, fine fraction</td>
<td>tonnes/hour</td>
<td>26.03</td>
<td>28.13</td>
</tr>
<tr>
<td>D50 grit</td>
<td>μm</td>
<td>100 μm</td>
<td>137 μm</td>
</tr>
<tr>
<td>Product rate grit (sensor measure)</td>
<td>tonnes/hour</td>
<td>4.02</td>
<td>4.38</td>
</tr>
<tr>
<td>Specific energy consumption</td>
<td>kWh/tonne</td>
<td>9.83</td>
<td>8.92</td>
</tr>
</tbody>
</table>

**Table 2: Operating data and product rates at Larne**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>20% R 63 μm limestone</th>
<th>10% R 45 μm limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate</td>
<td>tonnes/hour</td>
<td>31.93</td>
<td>27.87</td>
</tr>
<tr>
<td>Material moisture content</td>
<td>%-H2O</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Moisture in fine product</td>
<td>%-H2O</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Target fineness</td>
<td></td>
<td>20% R 63 μm</td>
<td>10% R 45 μm</td>
</tr>
<tr>
<td>Measured fineness</td>
<td></td>
<td>17.6% R 63 μm</td>
<td>9.2% R 45 μm</td>
</tr>
<tr>
<td>D50 fine fraction</td>
<td>μm</td>
<td>4.3 μm</td>
<td>3.6 μm</td>
</tr>
<tr>
<td>Product rate, fine fraction</td>
<td>tonnes/hour</td>
<td>11.20</td>
<td>6.06</td>
</tr>
<tr>
<td>D50 grit</td>
<td>μm</td>
<td>380 μm</td>
<td>205 μm</td>
</tr>
<tr>
<td>Product rate grit (sensor measure)</td>
<td>tonnes/hour</td>
<td>19.8</td>
<td>21.0</td>
</tr>
<tr>
<td>Specific energy consumption</td>
<td>kWh/tonne</td>
<td>6.10</td>
<td>6.91</td>
</tr>
</tbody>
</table>

Source: Loesche
to react to specific customer requirements.

**Performance of tests**

**Heidenheim**

An LM 19.2 has been in operation at Heidenheim since 2011. It currently produces two different fine products: 1% R 90 μm and 1% R 63 μm calcium carbonate.

In addition, grit is extracted simultaneously and screened into various particle size fractions, if necessary. These products are used mainly in the power generation and construction industries.

Solids-flow measurement sensors were used at Heidenheim for determination of grit product rates. These sensors incorporate the latest microwave technology and are installed only in metal pipes.

A measuring field is generated by means of special decoupling of the microwave in conjunction with the metal pipe. The microwave radiation injected into the pipe is reflected by the solids particles and received by the sensor.

The frequency and amplitude of the signals received are evaluated. The sensor functions as a Muhlenbech particle counter, determining the quantity of particles flowing per unit of time. Frequency-selective evaluation ensures that only flowing particles are measured, and that depositions are suppressed.

The sensors are calibrated in situ by feeding a weighed amount of material above the sensors. The sensors are calibrated for this material using the time measured (the mill was not in operation at this time).

A number of tests were performed for a range of different finenesses and grit throughputs registered simultaneously via the sensors. The operating data were kept as constant as possible during this period; only classifier speed is varied to adjust the fineness.

The material feed rate must also be modified when the fineness is changed, in order to assure stable, low-noise operation of the mill.

**Larne**

The principal product manufactured at Larne is a 20% R 63 μm pulverised limestone, which is used as limestone sand in the construction industry. The grit is used for the production of mortar. Maximum particle size is approximately 1300 μm.

The throughputs for fine product and grit are determined in the Larne facility via a silo weighing system. In order to weigh the fine product and the grit, the flow of material for a specific time is conveyed in each case into a previously drained silo, and then weighed.

The special feature of the Larne system is the fact that the grit is withdrawn entirely from the classifier via the grit extraction screw and then routed via a bucket elevator to a screen. The screen overflow > 1300 μm is returned to the mill as recirculating material.

Constant mill operation was also assured in Larne.

**Test results**

The data shown in Tables 1 and 2 are average values determined across the period of the measurements.

At Larne, the change in the particle-size distribution in the fine product is influenced by increasing classifier speed at a ratio similar to that observed at Heidenheim.

The grit, on the other hand, exhibits a different distribution, a fact which is clearly attributable to the design of the grit cone. The coarse fraction is correspondingly greater at Larne, since the entire mass flow is diverted out at this plant, and the material is ground only once.

The maximum distribution of the percentages by mass was 75% grit and 25% fine fraction for this facility. The percentage of the fractions up to 1000 μm rises when classifier speed is increased. Above this point, the coarse fraction tends toward zero.

At Larne, the grit is removed 100% from the mill. It is apparent that the percentage of grit rises as fineness becomes greater.

**Conclusions**

In the standard process configuration, product 1 is routed via the classifier to a downstream filter and further processed as fine product. Product 2 is extracted via the grit extraction screw and routed to a separate process.

The particle-size distributions of both products are a function of the classifier-speed setting. The fineness of Product 1 increases at higher classifier speeds.

The grit, on the other hand, exhibits the opposite behaviour. The percentages of the mass flows are also dependent on classifier speed setting. The higher the classifier speed is, the lower the percentage of fine fraction by mass. The percentage of grit rises correspondingly.

The second product obtained from the grit extraction screw significantly expands the range of different product finenesses which can be produced. A particle-size distribution of up to 3000 μm was determined after completion of these tests.

Throughput rates are dependent not only on machine size, but also on material feed and the design of the grit screw and cone.

The products generated can be further divided in downstream operations (screening or classifying), permitting a large and diverse range of potential uses.

*Michael Schmidt, is head of customer support for Loesche GmbH, Dusseldorf, Germany. www.loesche.com*
Energy efficiency in comminution

The process of grinding and crushing ore – known as comminution – is, on average, the most energy-intensive step in mining. The Coalition for Eco-Efficient Comminution* is seeking to raise awareness of the impact this has on processing costs and encourage energy-saving practices in the field.

According to a 2012 report by Natural Resources Canada, comminution represents a minimum of 10% of a mine’s total production costs.

The problem of declining ore grades is causing this figure to increase. As the target minerals comprise lower factions of mined ore volumes, the ore must be crushed and ground into smaller particles in order to liberate the minerals, which requires more energy.

Added to this, the rising cost of energy, plus capital outlays for other inputs such as labour and infrastructure are putting significant pressure on margins.

The CEEC roadmap

In response to this trend, the US-based Coalition for Eco-Efficient Comminution (CEEC) has commenced a number of initiatives designed to raise the mining industry’s awareness of energy consumption in comminution, and promote practices for the reduction of power inputs and costs.

The CEEC was established in 2011 and is supported by a broad range of mining sector companies keen to accelerate awareness and knowledge transfer in this field of mineral processing.

In 2012, the coalition ran a workshop in association with mining technology consultancy, JKTech Ltd, which brought together senior industry figures to develop the roadmap for eco-efficient comminution.

Why energy use matters

Comminution energy includes all energy directly consumed in size reduction as well as energy consumed in the manufacture of comminution consumables.

According to the CEEC, mineral processing plants are being designed and operated at less than optimal energy efficiency.

It argues that the benefit of better performance is not well understood in many sectors of the industry and neither is the relative ease with which some efficiency measures can be introduced.

The CEEC has identified the key factors that contribute to poor efficiency in processing operations as:

- More difficult ore bodies, with lower grades, complex mineralogy, access difficulties and high infrastructure costs;
- Difficulty in attracting skilled people, leading to a poor understanding of nature of the efficiency problem;
- Focus on maximising production capacity and throughput;
- Inconsistent work structures and metrics across an organisation;
- A general reluctance in industry to adopt new technologies;
- Lack of open information exchange, often related to protection of intellectual property;
- A lack of operational focus in many R&D activities and lack of funding;
- Project valuation practices which may support capex savings over opex; and
- Energy efficient strategies that lack support from senior management.

The CEEC argues that failure to improve comminution energy efficiency increases exposure to:

- Higher energy costs;
- Reduced energy security; and
- Negative impact on license to operate.

Benefits of solving the problem

Although the potential improvements will differ substantially from project to project and between commodities, it is estimated that improvements of up to 50% kWh/unit are feasible within 10 years, and more beyond that.

One-off interventions that result in an efficiency step-change are rare. Substantial gains can be made by the cumulative effect of relatively small improvements.

The benefits of improving energy efficiency in processing operations include:

- Immediate opex benefit through energy cost savings;
- Enhanced ability to manage more complex, lower grade ores;
- Reduced carbon emissions, energy footprint and potential for reduced water usage;
- Better community relations from reduced energy and water footprint;
- Improved energy security; and
- Reduced generation of fine waste.

What should industry be doing?

The CEEC acknowledges that not all possible actions will be applicable to all situations, but the organisation has used its research in this area to outline some options for site-based or company-based action plans for reducing energy-use in comminution.

These options include: measuring performance against pre-determined base-lines for energy use and performance targets; adopting best practices in technology, which may require further investment in research and development; implement strategies for cross-team engagement and external collaboration; and, finally, communicate the benefits of energy efficiency through regular discussion and train and motivate staff to monitor energy performance within their own areas of influence.

*www.ceecthefuture.org
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- Ball mills
- Roller-press
- Cylinder mills
- Hammer mills
- Chain mills
- Lump breakers
- Mechanical air-classifiers
- High efficiency classifiers

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- Dolomite
- Limestone
- Baryum sulfate
- Bentonite
- Clay
- Coal
- Petcoke
- ...etc

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Mineral sorting techniques with advanced texture analysis

Advanced texture analysis provides new potential for sorting particles with different sizes, colours, shapes, textures and densities. Jacek Kolacz* explains how significant savings are achievable when material separated using this technique is removed from the process in the early stage.

Optical sorting and identification is widely used by a number of different industries, including metals, glass and plastics recycling, as well as mineral processing.

Lately, the importance of sorting minerals more efficiently in order to maximise recoveries from lower ore grades has created new requirements and needs for separation generally.

In response to this industry trend, Norway-headquartered Comex AS has developed a new optical sorting system, based on complex image analysis, which can be used for both material sorting and identification or characterisation, without the need for prior separation.

Comex’s technology makes it possible to separate different mineral particles in a single step by analysing their colour, shape, texture and size. By applying x-ray analysis to the mineral to be sorted, the sorting system also provides additional information about the material’s density and composition.

Advantages of complex particle analysis

The main advantage of the new sensor-based system is that it can be applied universally to particle-sorting to provide highly sophisticated image processing, which can be carried out within one processing unit.

Figure 1 shows the system’s configuration, where many different analysed parameters can be used to enable particle separation.

The system includes a camera, installed either over the transport belt conveyor or at its discharge end, and x-ray attenuation analysis through the XRT system in the central part of the conveyor belt.

The sorting system can be used with both optical and XRT analysis or separately. Infrared (IR) and ultraviolet (UV) light can also be used to extend particle recognition in the same sorting unit.

These sophisticated analysing functions require significant computation power, and must be optimised to allow high capacity sorting. This is done by specially programmed architecture and algorithm solutions, which allow for efficient management of the calculation routines and sorting priorities.

This results in both a high separation capacity and extremely high efficiency, and the purity of the final product can reach 99.9%.

Application of X-ray sorting

Advanced texture analysis can also be applied to using sensing techniques other than visual light.

By applying XRT techniques, it is possible to measure the internal structure of the particles and provide new separation criteria. When the XRT images are available from this type of sensor, they can offer a valuable picture when the texture of the projected particles are exceptionally complex.

By using the texture recognition algorithms for the XRT images, it is possible to achieve much better results.
Sensor-based sorting has been around for many years, but it is still a developing technology which is rapidly evolving. Improvements are continually being made in terms of sorter robustness and measurement sensitivity, and its successful application to the recycling industry has helped to elevate sensor-based sorting to the mainstream of sorting technology.

Central to its success has been the sophistication of the optical detection systems used by the technology, which can concentrate minerals and eliminate waste with pinpoint accuracy at an early stage in the sorting process.

A wide range of sensors are now available and in development. These include X-ray transmission (XRT), which is used to sort materials by their average atomic number and works well on, for example, separating silicates from carbonates; near-infrared (NIR), which recognises objects just outside the visible wavelength spectrum and has proven to be an excellent tool for talc and borate separation; and electromagnetic (EM) detection, which has become a good tool for pre-concentration of base metal ores.

Table 1. Sorting results during purification of the limestone particles (size range 4-10mm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Sorting results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed material purity</td>
<td>%</td>
<td>81.5</td>
</tr>
<tr>
<td>Product fraction purity</td>
<td>%</td>
<td>99.8</td>
</tr>
<tr>
<td>Waste fraction purity</td>
<td>%</td>
<td>5.6</td>
</tr>
<tr>
<td>Product recovery</td>
<td>%</td>
<td>98.7</td>
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<tr>
<td>Waste recovery</td>
<td>%</td>
<td>99.0</td>
</tr>
</tbody>
</table>

Source: COMEX

Table 2. Sorting results during purification of the iron ore (size range 40-100mm)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Weight distribution in [%]</th>
<th>Concentration of Fe in [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEED material</td>
<td>100.0</td>
<td>58.8</td>
</tr>
<tr>
<td>PRODUCT fraction</td>
<td>78.3</td>
<td>63.6</td>
</tr>
<tr>
<td>MIDDLE fraction</td>
<td>12.2</td>
<td>49.8</td>
</tr>
<tr>
<td>WASTE fraction</td>
<td>9.5</td>
<td>30.1</td>
</tr>
</tbody>
</table>

Source: COMEX
could be directly used in the furnace without any enrichment (the Fe content of the remaining 22% middle and waste fractions were 49.8% and 30.1%, respectively), allowing for huge savings in energy and processing costs.

*Dr Jacek Kolacz is the manager of Comex AS, and holds a doctorate in engineering from the Norwegian Institute of Technology, Department of Geology and Mineral Resources Engineering. He can be contacted at jacek.kolacz@comex-group.com

For more information, please visit www.comex-group.com

**Particle recognition**

Particle recognition used to separate different materials is based on a complex shape and colour analysis where the particles can also be identified by over 20 parameters used for shape description.

These parameters include:

- diameter in different orientations;
- perimeter;
- centre of mass;
- moment of inertia;
- particle elongation factor;
- edge sharpness.

Additional combinations of these parameters can also be used for distinguishing particles of interest.

The surface of particles, where different colours or contours vary in intensity and frequency, can be analysed by Fast Fourier Transformation (FFT) filtration to recognise differences in texture and structure of the processed particles.

Such analysis yields more complex information about the target particles rather than simple colour recognition alone.

Finally, the XRT picture is integrated into the optical analysis, which provides information about the particle surface properties and their internal structure.

**Separation of white quartz particles**

Figure 2 illustrates some examples of image processing where darker and coloured particles are defined and separated as waste from the white quartz material.

In this case the separated particles are identified by their colour, shape and texture. The picture shows four cases of different material combinations used during system tuning.

The first group of particles represents the clear product fraction without any contamination; the second group shows the product particles contaminated by small intrusions of other minerals; the third group represents the particles contaminated by different colours and in different degree; finally, the fourth group shows the particles with completely different colours.

In the case of the first and the fourth group the separation is very clear; however in the case of the second and third group it is necessary to carry out advanced texture analysis.

For these groups, the particle contours are defined and the texture information is analysed in the software. The percentage of the contaminated surface is divided by the total projected particle surface to determine whether the analysed particle can be qualified as waste.

The threshold can be adjusted by the user, so the contamination level for the accepted material can be changed according to individual requirements. This allows high separation capacity and extremely high efficiency where the product purity can reach 99.9%.

Some of the results from the practical applications are shown in Table 1, where the OSX sorting system has been used for purification of limestone with texture analysis algorithm.

The initial material had a purity of 81.5% white particles, and had been defined as low-quality filler.

After sorting, however, the material has improved to 99.8% white particles, and the waste fraction contained only 5.6% white particles.

An important point to note is that the 98.7% of the white particles were recovered to the concentrate fraction and 99% of the contaminating particles were recovered to the waste fraction.

If the processed material is difficult to differentiate in the visual light, IR or UV light can be applied for finding other particle features.
Advanced technologies for mining industry

Sorting technologies

Key Benefits:
- Advanced sorting using simultaneous analysis of:
  - Colour
  - Shape
  - Texture
  - Transparency
- High separation efficiency up to 99.9%
- Possibility to process materials with high moisture content and surface contamination

Examples of the produced ultra-fine fractions in the UCX air classifier

Separation examples using optical properties of calcite (OSX separator series)

Material from mine (feed)  Upgraded material  Separated waste material

Separation of coarse coal 80–200 mm contaminated with rock particles. Green and blue colour represents contaminating particles

Separation of tungsten ore 80–200 mm contaminated with waste rock particles. Black colour represents tungsten

Other application examples:
- High purity quartz
- Alumina/Bauxite
- Lithium/Spodumene
- Dolomite
- Diamonds

Separation examples using X-ray sorting (CXR separator series)

Other application examples:
- Iron ore
- Manganese ore
- Magnesia
- Chromite ore
- Graphite
- Apatite
- Diamonds
- Barite

Powder technologies – grinding and fine classification

Ultra-fine jet milling and air classification technologies
- Product fineness D97: 1.8–300 µm
- Capacity: 0.3–100 t/h
- Very wide range of particle size distribution possible to be produced in the same equipment
- Very high classification efficiency
- Low pressure loss and power requirement
- Low wear rate of moving parts
- Reduced maintenance and operating cost
- On-line control of the product particle size

Examples of the produced ultra-fine fractions in the UCX air classifier
Costing the earth: rare earths processing

Of the various processing methods available to mineral processors, which is the most commonly used by the rare earths industry? Excluding the Chinese ‘clays’, the current rare earths producers are using froth flotation, as well as gravity separation for some by-products.

The projects that are likely to come into production in the next year or two will employ methods of physical beneficiation (froth flotation, gravity separation and magnetic separation), followed by one or more types of leaching to separate the rare earth elements from various minerals.

For concentrating rare earths, which, in your view, is:

(a) The most effective method?
The most effective method always depends on the minerals of interest, the minerals of waste, and the differences in the physical characteristics of each.

(b) The most cost-efficient method?
The liberation grain size and the impurities in the minerals of interest all play into the decision of which method will work best.

It is important to remember that all mineral deposits are different – if all the deposits were the same, then there would be no need for me and my expertise.

I have spent most of my career in the froth flotation beneficiation of industrial minerals and am, therefore, not fully impartial.

(c) The most environmentally sensitive method?
Any method that does not employ chemicals is a relatively environmentally-friendly method.

Underground mining generally disturbs the least amount of the surface, but typically is the most costly. Underground mining allows for better monitoring and collecting of the radioactive dust/radon products.

In open-pit deposits, the problems of radioactivity are more difficult to manage, with the ore and waste being exposed to rain, wind and water-spray.

Any process that generates waste should look at ways to market the waste to other industries. However, since most of the rare earth deposits contain measurable levels of radioactive elements, this will always be a problem for sales.

If regulations can be adapted to allow for replacement of the radioactive materials back into the underground mine, the exposure could be minimised. My view is, it came out of the hole, so why not put it back where it came from?
We hear a lot about the limitations of the various methods of rare earths processing, but not so much about the benefits. What are key advantages of each process?

At the coarse particle size, sorting offers the best advantages of no water/high throughput and no chemicals.

At the slightly finer sizes, dry magnetic separation does not use any chemicals or water.

If the liberation size is very small, say below 75-microns, then froth flotation would be the method of choice.

On materials that can be liberated without grinding, (weathered-in-place, beach sands, or other deposits where liberation was done for you by nature) then attrition scrubbing, particle sizing and gravity separation need to be studied. Again there are no chemicals used in this method, but you do need water.

Finally, if froth flotation is the only way to go, due to liberation size or the need to grind to liberation for separation, it can result in selective separation, if designed properly.

Mineral processing equipment for froth flotation plants is well known, and several sizes of processing equipment are off-the-shelf items that do not require special design or construction.

In your experience, which is the processing step that most producers overlook?

All operations can have high grade concentrates or high recovery of the values – but not both.

To increase both, at any operation, will generally require changes that the owner does not often want to pay for. So they have to learn to live with lower grades/recoveries, or pay for the improvements, which are achieved through applied research and equipment.

The old FRAM oil filter analogy of “pay me now, or pay me later” should be on all the bulletin boards at operations.

In the processing of industrial minerals, the ore deserts are not uniform. Every beneficent process plant needs to be able to change plant separation conditions as the feed to the plant changes.

An average grade of the feed of X% on a yearly basis means nothing to the plant operations if the plant feed varies from ½ X% to 3X% on an hourly basis. Plants need to be able to adapt rapidly. Blending in the pit, or in the stockpile, is a wonderful idea, but upsets do occur and people make mistakes from time to time.

When upsets occur in the processing plant, most operators would rather send the valuable minerals to the tailings, than send waste to the concentrate. So the plants generally work on a ragged edge of grade vs recovery. If you are selling your concentrate to someone else for refining, the plant will want to operate on the basis of final product grade.

If they are processing the concentrate internally, they will generally look for recovery, and let the next part of the company figure it out.

What are your final words of wisdom for would-be rare earths processors?

There are currently very few operations that can take a rare earth mineral concentrate and produce the separate elements, oxides or metals.

Before undertaking the design and construction of a beneficiation plant, be sure where you are going to sell your concentrate.

If you are planning to sell a mineral concentrate to someone else, expect the price to change between now and when your plant is in operation.

Lead times can be a year or longer for some equipment, then add the times for permits and construction and the fact that others may enter the market before you – so plan on the price changing.

Demand for your rare-earth elements may also change due to new technologies in the end-products.

*Edwin H Bentzen III is the senior project manager at Denver-based Lyntek Inc, Colorado, US. Email ebentzen@lyntek.com
A look at frac sand processing

Though fracking has been taking place for over 50 years, the recent boom in shale gas drilling has boosted demand for frac sand. Tim Sheenan* takes a look at frac sand processing and its latest developments

The boom of shale gas in the US has been accompanied by a surge in the process called ‘fracking’. Fracking is a more than half-century old, but more recently it has become a widespread method of maximising oil and gas recovery from deep rock formations by pumping a mixture of sand, chemicals, and water into wells to increase the permeability of the formation. Injection of the fluid mixture at pressure promotes fissuring in the formation, and the frac sand, or ‘proppant’, serves to prop open these fissures so that gas or oil can flow more freely through the formation.

Frac sands consist of well-rounded, spherical, high-strength grains, generally classified using American Petroleum Institute (API) specifications for various grades by size. The most important qualities for natural frac sand are quartz content (>99% SiO₂), sphericity of the grains, high crush resistance (at pressures of 4,000-6,000 PSI, or more), and a narrow size distribution (>90% within the designated sizes).

These characteristics promote conductivity of flow through the fissures even as the formation undergoes a decline in hydraulic pressure. Low acid solubility and turbidity are also requirements, as these indicate low presence of fines and less competent minerals such as carbonates, clays, feldspars, or iron coatings that reduce performance.

A boom in shale gas drilling throughout much of North America has taken place, and accordingly, the demand for frac sand has grown, especially for the coarser 20/40 and 30/50 (mesh) grades that have been found to provide higher conductivity for shale gas wells.

Frac sand deposits and end markets

The largest sources of frac sand in the US are sandstone formations known as the St Peter (or Ottawa) sandstone (primarily mined in Illinois, Wisconsin, Minnesota, and Missouri), the Jordan sandstone (Minnesota and Wisconsin), and the Hickory sandstone (Brady, Texas region).

Generally, the Northern, or ‘Ottawa White’ sands are higher-strength, and while the Southern or ‘brown’ frac sands are considered lower strength, they are still in high demand as they can be used in lower pressure wells, or be resin coated to improve their strength. Figure 1 shows a comparison of a common generic sand with an Ottawa-region frac sand.

While frac sand production has increased dramatically as major producers add capacity, smaller operators have also entered the market. Prices appear to have stabilised after hitting records over the last year.

However, the logistics of getting product from mine to market have become crucial. According to Jen Casebier, president of DownHoleTrader.com (an independent frac sand clearinghouse representing some 60 producers), the cost of the logistics in delivering the sand to the user often exceeds the FOB mine price. While a 20/40 frac sand might be sold for $55/tonne at a Midwestern producer, the FOB cost for a Barnett area location can exceed $120 or even $140/tonne.

*Tim Sheenan is a Managing Director at Sheenan International Ltd, UK.
Truck and rail costs have risen due to high fuel costs, rail congestion, greater demand for leased rolling stock, and limited loading and handling facilities. As a result, while premium frac sands can always command a premium price, producers are finding opportunities to move lower grade or small-tonnage products to market due to a logistical advantage. Producers of other similar silica sand products, such as glass and foundry sand, in some cases can modify their processes to make higher-margin frac sand, assuming their deposit is suitable for use in this way.

Making frac sand
Ore is typically blasted and crushed using jaw and/or impact crushers, or is dredged, before being wet screened to remove oversize and begin liberating clays and fines. The sand is next subjected to washing and classifying using hydrocyclones, hydraulic classifiers, and/or wet screening.

Where excess clays or agglomerated sand grains are present, an intensive high-solids attrition scrubbing step is employed. For this stage, two or more stirred tanks arranged in series blend the sand at minimum 70-75% solids, causing the sand grains to polish one another and liberate coatings, clays and cemented grains.

The hydrocyclones and hydraulic classifiers then reject fines to produce a coarse sand stream, such as 10x100 mesh. The coarse sand is then dewatered using either screens or stacking cyclones, and is allowed to drain before being thermally dried.

In the final step, the dry sand is screened using numerous vibrating screens into common frac sand grades such as 20x40 mesh, 30x50 mesh, and 40x70 mesh. If the hydraulic classification has not adequately removed the oversize and fines, a large screen area is required to meet the >90% in-class requirement.

Hydraulic classification
A variety of hydraulic classification methods for washing and sizing frac and other sands have been employed, including classifying screws, hydrocyclones, and teeter bed separators (TBS), see (figure 2b). Many varieties of the TBS have been developed and sold since the 1930s.

TBS operate on the principal of hindered settling of particles against an evenly-distributed upcurrent of fluidising water. Classic TBS designs utilise a downcomer to introduce...
As the particles settle, they form a fluidised bed (teeter bed) above the fluidisation water injection point. Material is then segregated based on terminal, hindered-settling velocities. Fine or light particles report to the overflow, while coarse and high-density particles report to the underflow. Particles that settle through the teeter bed are discharged through an underflow control valve.

The density of the teeter bed determines the smallest size particle that can descend to the underflow, and is regulated by the amount of teeter water that is added. The rate of underflow discharge is generally regulated using a PID control loop.

Classic TBS designs can produce an inconsistent separation due to a number of factors; one of these is the manner of feed injection which leads to higher water upflow velocity above the feed point than below it. So, as the feed water volume changes, so does the separation size.

A common approach for sand plants has been to produce a single coarse fraction, such as 10x100 mesh using the TBS, and following drying to use multiple stages of screens to correct the imperfection of the wet separation and produce the required grades.

The Eriez CrossFlow Separator uses a novel feed well that presents the feed tangentially to the surface. This allows water associated with the incoming feed to flow directly to the overflow without affecting the upflow velocity in the classifying zone (Figure 3).

A deep dewatering cone forces thickening of the underflow ensuring a consistent high-solids coarse discharge, whereas older, flat-bottomed designs suffer from variable underflow pulp density depending on the position of the control valve. An advanced control loop directly measures the density of the teeter bed and adjusts the water addition to maintain the set point.

Compared with older designs that only infer the average bed density, the CrossFlow allows a consistent separation efficiency even as the feed rate, feed size and density vary. This allows the operator to produce tightly-sized splits that will require less final screening in subsequent dry processing. Multiple small CrossFlow separators in series may be employed to produce 20x40, 40x70, and -70 mesh fractions (splits and sizing from a -1.4mm sand are shown).

**Flotation**

For sand deposits containing more deleterious minerals, froth flotation has been employed in making glass, foundry and other specialty sands since the 1930s. The process uses chemical reagents to render one or more mineral species (carbonates and iron minerals, for example) hydrophobic, allowing these particles to be selectively separated by contacting the slurry with fine bubbles and skimming them off as a froth.

Mechanical flotation cells, which use multiple tanks in series and employ large motor-driven agitators to suspend the sand and shear the bubbles, have historically dominated the silica sand flotation industry. The cells are ineffective for material coarser than 35-50 mesh (0.3-0.5mm) however, because coarse particles cause high wear, settle rapidly out of suspension and detach easily from bubbles in the highly-mixed turbulent cells.

The Eriez HydroFloat coarse particle flotation device is a different technology that combines the fluidising teeter bed separator with the fine bubble generation of a column flotation cell. The result is a very high capac-
ity device with a small footprint and with no moving parts other than a control valve that releases the product from the conical bottom (figure 5).

The HydroFloat has been widely applied to upgrade industrial minerals such as phosphate and potash, floating particles as coarse as 3.4mm. Like the CrossFlow, the HydroFloat uses injected fluidising water near the top of a dewatering cone to produce the desired upflow velocity.

Fine bubbles are sparged into the teeter water, and a quiescent fluidised and aerated bed of sand is created, forming a long-residence time contacting zone in which the hydrophobic particles can attach to bubbles. The attached particles are then easily lifted out of the fluidised bed and hydraulically carried to the overflow.

For a silica sand application, the upgraded quartz product settles downward to the underflow where it is discharged by a control valve at >75% solids. The dilute overflow, containing the rejected waste minerals, is piped to waste treatment and water reclamation.

The successful application of the HydroFloat for a frac sand operation can enable the producer to meet the >99% SiO2 specification, while also improving the crush test performance by rejecting weaker non-quartz minerals. Figure 6 shows a raw silica sand feed in comparison with the resulting cleaned product after treatment by CrossFlow and HydroFloat separation.

**Magnetic separation**

Deposits that contain iron-bearing minerals can also be upgraded at either the wet or dry stage of the process using magnetic separation. Where highly magnetic contaminants such as magnetite, rust, or iron fines are present, dry permanent magnet separators such as Eriez CC Drum separator can reject a majority of the contaminants in a single pass.

Paramagnetic (weakly magnetic) contaminants such as iron carbonates, or iron-coated quartz particles can be removed with more powerful wet high intensity magnetic separators (WHIM-S), which use an electrically induced magnetic field to capture magnetic particles in a steel matrix. In the dry process, rare earth drum or roll magnetic separators may be utilised. Rare earth drums are 12-30 inch diameter separators up to 60 inches in length, with very high capacity and medium field strengths (approximately 6,000-8,000 Gauss).

Rare earth roll separators (figure 7) can produce magnetic field strengths over 21,000 Gauss, and are employed as 2 or 3-pass systems with 4 or 6 inch diameter rolls. While dry induced roll magnetic separators (IRMs) capable of producing fields exceeding 10,000 Gauss have long been available, because of their high power consumption and lower capacity they are increasingly rare in North America since the advent of rare earth roll magnetic materials.

**The future of fracking**

While there is little doubt as to fracking’s effectiveness, concerns over its environmental effects are abundant. The rapid growth of the practice has left US regulators scrambling to keep up amongst calls by environmental groups and local interests to ban the practice over concerns for groundwa ter contamination and contaminated surface discharges of produced (flowback) water. Several states have banned or considered banning fracking or enacted moratoriums while the issues are examined. Given the boom in economic activity that has resulted from new oil and gas production, it is probable that these will remain contentious issues for the foreseeable future.

However, the Environmental Protection Agency (EPA) has stated that it plans to issue federal rules covering wastewater regulations for shale gas drilling in 2014 after gathering more data. Drillers are increasingly working to identify ways to process and reuse produced water as attention to water discharge has grown. While methods to eliminate suspended hydrocarbons from produced water exist, water contaminated with brines and proprietary chemicals require more characterisation and perhaps, a more sophisticated treatment.

**Acknowledgements:** Jennifer Casebier, DownHoleTrader.com
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USA

All pictures supplied by Eriez Flotation Division unless otherwise specified.

*Tim Sheenan is the senior process engineer at Eriez Flotation Division*

www.eriez.com
Hydrochloric acid leaching and acid recovery technology

CMI looks to its industrial minerals and metals processing division to mitigate slowing growth in the steel industry

Cockerill Maintenance and Ingénierie (CMI) Groupe is a technology and service company, which specialises in the industrial and steel sectors as well as energy and defence.

While the company’s core business has been the provision of technology for the steel industry, it also has a large presence in technology for industrial minerals markets and will be increasing this focus in the future.

CMI owns the core technology for the total recovery of hydrochloric acid (HCl) from leaching operations. This technology is based on pyrohydrolysis using the spray roaster process or the fluidised bed process.

“The benefits of our HCl-based processing technologies are evident; less environmental impact and lower operating costs through closed-loop operation and greater added-value through the production of high-quality by-products through pyrohydrolysis,” CMI says.

“Our unique know-how in the fields of hydrochloric acid leaching, pyrohydrolysis, and calcination enables CMI to offer mineral and ore processing technologies for chemical grade applications.”

“Our core business is based on technologies used in the steel industry (...) but the steel industry is a market which has its highs and lows,” Egon Sehner, head of CMI’s extractive metallurgy department, explained to IM.

The steel market is one that has historically been linked to the automotive and construction industry as well as a wide variety of other industries that have shown strong growth until recently.

“[In the past], we observed huge growth in Asia, especially in China, where we also operate. This growth will certainly reach a high point in a few years,” said Sehner.

Sehner added that this will not necessarily mean a large decline in business, as CMI see potential opportunities in the revamping business of existing installations, but the business volume for new installations could see a reduction.

3D-Image of a MgO-Plant
- Spray Roasting
- Hydration-/Washing
- Calcining

Source: CMI
To help mitigate this reliance on the steel industry, the company is looking more to its industrial minerals and metals processing division which is involved in a wide variety of materials including alumina, magnesia, molybdenum and titania.

“We are looking to expand this business, and explore up and downstream to strengthen our position in the market,” said Sehner.

CMI’s calcination and pyrohydrolysis technologies are already solid revenue generators, which it will continue to expand on in the future,” the company told IM.

CMI is focusing on the extractive metallurgy market using HCl as leaching agent. As a specialist for HCl-applications, CMI is in the position to offer up- and downstream applications in addition to the calcining- and pyrohydrolysis-units. This includes applications, like leaching, wastewater and waste air treatment units.

With this scope, CMI has the potential to supply complete plants with full environmental and economical integration.

“CMI sees great potential in the development of the metals and minerals market,” Sehner said.

Heat retention for energy efficiency

One area on which CMI is focused is on improving the energy efficiency of its technologies, which is of particular relevance as energy costs are taking up an increasing percentage of overall operating costs for miners and processors alike.

The company’s multiple hearth furnace remains an important focus because of its nature as one of the higher energy-consuming technologies.

Multiple hearth furnaces consist of a series of circular hearths, placed one above the other and enclosed in a refractory-lined steel shell. A vertical rotating shaft through the centre of the furnace carries arms with rabble blades which stir the charge and move it in a spiral path across each hearth.

The design of the furnace permits excellent contact between solids and gases. The furnace hearths are designed alternately as ‘out-hearths’ and ‘in-hearths’. Material is fed to the top hearth, and moved across it to pass through drop holes into the hearth below.

The fumes from the furnace can reach over 1000°C. CMI has improved its heat recuperating technology to capture the heat from the fumes and convert it into usable heat. The company is also working on new technological advances with customers to further increase energy efficiency.

The company’s spray roasting technology also generates significant heat from its reactor core. CMI has improved the construction and operational conditions to reduce energy consumption. “We manage to reduce the energy losses by maybe 2% or 3% of the total energy input without increasing investments,” Ernst Pichler, senior sales manager at CMI, explained to IM.

Significant advances in the heat recovery technologies of the spray roasting process have been made, Pichler outlined. The recovery of thermal energy by usage internally within the CMI production facility or even for production facilities up or downstream of CMI facilities are subjects of our optimisation studies and engineering focus.

Energy efficiency remains a significant driving factor for CMI’s processing technologies and it continues to make advancements and upgrade existing product lines. “Finally our customer define the parameters which will allow CMI to design tailor made solutions and reach maximum efficiencies,” concludes Pichler.
Pressure filtration for industrial minerals

The minerals industry continues to demand lower-moisture products, reduced operating costs from chemical treatment and goods which can be produced with less environmental impact.

Pressure filters, which have been developed for filtration of industrial minerals, metallic minerals, coal and tailings, have shown that they are effective and reliable in meeting these criteria.

Applications for pressure filtration include white minerals such as calcium carbonates and kaolins, as well as clays, gypsums and zeolites.

Pressure filtration is used to separate liquid and solids in a slurry to produce as high a concentration of solids as possible. Pressure filters have advantages over other types of filters as higher flow rates and better washing and drying may result from the higher pressures that can be used.

The technology was developed in response to the prospect of energy shortages as an alternative to energy-intensive thermal drying to eliminate or reduce heatloads.

In most cases the liquid (filtrate) is water and it is important to dewater to the highest solid concentrate level, as this will also reduce transportation costs. In some applications, the liquid is the product and the solids are the waste sent to disposal.

Processing technology specialist Metso* discusses how the demand for lower-moisture end-products has been a driving force behind the development of new, highly-efficient pressure filtration systems.

Tube Press filtration

Metso offers two types of pressure filtration equipment: the Vertical Press Airblow (VPA) Pressure Filter and the Tube Press.

Both types of filters incorporate membrane compression with air drying to maximise cake dryness, however the Tube Press is best suited for the industrial minerals industry due to its ability to handle finer particle sizes (<10 microns) at lower feed concentrations.

Typically, fine particles are more difficult to dewater, but the Tube Press overcomes this issue by applying a mechanical squeeze at 100 bar (1500 psig).

Where traditional mechanical dewatering can often leave the cake too wet or ‘sticky’ to handle effectively, and usually demands further treatment such as thermal drying, the high pressure applied by the Tube Press allows dewatering past the sticky plastic point that most materials have at some point on their dewatering curves, and produces a hard cake that is easy to handle.

The Tube Press is suitable for applications:

- where the process requires very low cake moisture, e.g., smelters;
- where cake handleability is critical, e.g., underground slimes;
- where the filtrate is a valued product;
- where cake transport costs are significant;
- where cake is to be disposed of to landfill; and
- as an alternative to thermal drying

Principle of operation

Filtration takes place between two concentric cylinders. The outer cylinder is the casing, and the inner, the candle.

The process slurry is pumped into the annular space between the filter media and the bladder. Hydraulic fluid, usually water, is then pumped between the bladder and the casing, putting the slurry under pressure, causing filtration to take place.

When filtration is complete, the hydraulic fluid is withdrawn from the Tube unit using vacuum until the bladder is diluted against the casing.

The candle is then lowered to the discharge position and a pulse of air is blown between the candle and the filter media. This causes the filter cloth to expand, fracturing the cake which is discharged under gravity.

When complete, the candle closes to the slurry fill position to repeat the cycle.

Air purge and/or cake wash can be incorporated into the cycle. At the completion of the filtration element, the air or wash fluid is pumped between the cake and the bladder which is then forced through the cake by a further application of hydraulic pressure.

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Tube Press filtration

Metso offers two types of pressure filtration equipment: the Vertical Press Airblow (VPA) Pressure Filter and the Tube Press.

Both types of filters incorporate membrane compression with air drying to maximise cake dryness, however the Tube Press is best suited for the industrial minerals industry due to its ability to handle finer particle sizes (<10 microns) at lower feed concentrations.

Typically, fine particles are more difficult to dewater, but the Tube Press overcomes this issue by applying a mechanical squeeze at 100 bar (1500 psig).

Where traditional mechanical dewatering can often leave the cake too wet or ‘sticky’ to handle effectively, and usually demands further treatment such as thermal drying, the high pressure applied by the Tube Press allows dewatering past the sticky plastic point that most materials have at some point on their dewatering curves, and produces a hard cake that is easy to handle.

The Tube Press is suitable for applications:

- where the process requires very low cake moisture, e.g., smelters;
- where cake handleability is critical, e.g., underground slimes;
- where the filtrate is a valued product;
- where cake transport costs are significant;
- where cake is to be disposed of to landfill; and
- as an alternative to thermal drying

Principle of operation

Filtration takes place between two concentric cylinders. The outer cylinder is the casing, and the inner, the candle.

The process slurry is pumped into the annular space between the filter media and the bladder. Hydraulic fluid, usually water, is then pumped between the bladder and the casing, putting the slurry under pressure, causing filtration to take place.

When filtration is complete, the hydraulic fluid is withdrawn from the Tube unit using vacuum until the bladder is diluted against the casing.

The candle is then lowered to the discharge position and a pulse of air is blown between the candle and the filter media. This causes the filter cloth to expand, fracturing the cake which is discharged under gravity.

When complete, the candle closes to the slurry fill position to repeat the cycle.

Air purge and/or cake wash can be incorporated into the cycle. At the completion of the filtration element, the air or wash fluid is pumped between the cake and the bladder which is then forced through the cake by a further application of hydraulic pressure.
Performance
Once a mineral ore has been filtered using the Tube Press, porosity and cake moisture contents are significantly lower than those obtained with low pressure filters. Consequently, filtrate recovery is high.

Filtration is conducted at a pressure level where the cake is produced as a hard surface-dry, lump solid. Cake handling procedures are therefore greatly simplified compared with those for low pressure cakes, which are typically plastic or paste-like, and frequently surface-wet.

Available data indicates that Tube Press output rates, in terms of dry solids per unit filter area, are much higher than for either vacuum or plate filter presses. This results both from the pressure dependence of filtration rates and the operational flexibility of the Tube Press, which allows results close to optimum levels of filtration. Additionally, filtrate solids concentrations are generally zero, allowing immediate disposal or direct recycling.

The future for pressure filtration
Environmental awareness has been the major driving force in the rapid development of the filtration and dewatering technology, while increasing energy and personnel costs have made tougher demands on efficiency and automation of processes. Accordingly, Metso is seeing a trend towards a requirement for fully automatic controls and a demand for higher capacity machines.

Further, there is a growing need to reduce tailings ponds and reuse/recycle mineral waste after ores have been processed. Tube Presses have been used to reclaim catalysts out of chemical processes so they can be reused where previously they were disposed of after one use.

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Positron emission particle tracking

One way of dealing with the problems presented by lower-grade and more complex mineral ores is to better understand the recovery efficiency of jigging, argue Wynard Roux* and Natasia Naudé**.

With the depletion of higher grade ore reserves and the need to process finer, lower-grade material, there is a need to better understand the recovery efficiency of jigging.

Jigging is a concentration process that uses water and gravitational force to separate a mineral ore into different density classes; it has been in use for thousands of years, and yet we still find it very difficult to model due to the complex interactions that affect separation.

With the development of new technology, new opportunities arise that can give insight into old processes such as jigging, which can then lead to new breakthroughs. Positron emission particle tracking (PEPT) is one such technique that allows a single particle to be traced in a system without interfering with the process.

The use of PEPT was examined as a technique to study the motion of particles inside a laboratory batch jig. PEPT is a non-invasive method that can provide three-dimensional kinetic data of a particle during jigging.

Particles with different densities and sizes were traced using constant jigging parameters to obtain a data set that can be used for the development and verification of jigging models.

From the results, detailed information on the stratification rate of a particle was obtained, with adequate resolution to see particle movement through an individual pulse. Detailed data of this nature are critical for the validation of computational fluid dynamics (CFD) and discrete element method (DEM) models.

### Jigging

A jig consists of a jigging chamber; a screen to hold the particle bed and a mechanism to induce a water pulse that lifts the particle bed.

Figure 1 demonstrates the jigging principles: a mixed bed of particles is introduced into the jig (Fig. 1, a). Water is pulsed through the screen and lifts the bed of particles, expanding the bed and allowing particles to move freely (Fig. 1, b). The lighter particles are displaced further than the heavy particles and when the particles settle down, the heavy particles settle more quickly, resulting in a stratified bed (Fig. 1, c).

The main parameters that influence the stratification behaviour are the pulse cycle and feed properties.

<table>
<thead>
<tr>
<th>Table 1: Jig Operating Parameter</th>
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</thead>
<tbody>
<tr>
<td>Pulse Height</td>
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<tr>
<td>Upward Pulse Velocity</td>
</tr>
<tr>
<td>Top Hold Time</td>
</tr>
<tr>
<td>Downward Pulse Velocity</td>
</tr>
<tr>
<td>Bottom Hold Time</td>
</tr>
<tr>
<td>Run Time</td>
</tr>
</tbody>
</table>

Source: University of Pretoria

Most of the theories aimed at predicting the performance of jigs are verified using empirical data based on the feed and product of the jig, and not on the movement of the material inside the jigging chamber. This however is not sufficient to fully understand the jigging process.

Tracking of individual particles in a jig is therefore important and only two experimental techniques have been used in the past: optical high-speed camera and PEPT.

The disadvantage of the optical techniques is that an artificial see-through sample is used, while with PEPT almost any type of jig feed can be used. PEPT as a research tool shows significant promise in the mineral processing industry.

Using a radioactive tracer, PEPT allows for the tracking of a single particle inside a closed system without interfering with the process. PEPT has been successfully used in mineral processing systems such as mills, hydrocyclones and flotation, and the technique is gaining momentum.

PEPT uses a radioisotope tracer that decays through the beta-plus mechanism and emits a positron – the positive counterpart of an electron.
When an electron collides with a positron, it is annihilated, releasing two back-to-back $511\text{ keV}$ γ-rays, $180^\circ$ apart within ±0.3°. These two γ-rays are detected simultaneously, defining the line on which the radioisotope is found. At a point where these lines cross, the position of a positron-emitting radioisotope can be determined in three dimensions (Fig.2).

PEPT monitors the single particle behaviour inside a jig. Real-life scenarios can be emulated and the movement of tracers with different shapes, sizes and densities can be compared under a range of operating conditions.

The initial objective of the PEPT jigging test-work was to see whether suitable results can be obtained from the PEPT technique when testing an existing iron ore jig feed.

A batch jig was used with a cylindrical jigging chamber with an inside diameter of 160mm. The pulse is generated by a PowerRod Linear Actuator (PRA) and offers better control compared to air cylinders, by making use of a magnetic drive to propel the cylinder rod.

### Experimenting with PEPT

The experiments were conducted with an iron ore sample. The sample was screened to provide a size range of between 5 and 8mm to minimise the effect of size.

From the sample, tracer particles were selected, their density and size measured and a small hole was drilled to accommodate the radioisotope. Before a series of test-runs were done, the tracers were prepared by inserting Ga$^{68}$ isotopes inside the iron ore tracer particle. The half-life of Ga$^{68}$ gave a six-hour window to do test work on one tracer.

The jig was filled to a bed height of 140mm, which corresponded to approximately 8kg of iron ore. The tracer was then placed in position and water was added to ensure that there was at least 50mm of water above the jig bed during the entire jig cycle.

The only variables that were changed during these tests were the tracer particle shape, size, density and starting position. Operating conditions of the jig are shown in Table 1, while Table 2 shows the properties of the tracers.

### Results and discussion

The purpose of the experiments was to validate the possibility of using PEPT as a viable technique to investigate the mechanisms of jigging. The results that follow represent typical results obtained during the tests.

#### General stratification

The top and side view of the jigging chamber is shown in Figure 3 with the trajectory of a tracer particle (SG 5.01).

The pulse was removed from the image with base-line extraction to display the results more clearly. The particle started at the top and moved down the vertical axis until it reached the bottom, where it started to move randomly in the horizontal plane.

From the three-dimensional data, the most important component for modelling purposes is the vertical component. Figure 4 shows the vertical movement of the tracer particle versus time.

The first important feature of this curve is the initial movement of the tracer; the slope of this line gives an indication of the stratification rate of the iron ore.
tracer. Unfortunately, the data set was too small to draw any conclusion on the effect of different variables on the stratification rate.

The second important feature includes the movement of the particle after it has reached its stratification position. The tracer will continue to move up and down in a band along the vertical axis (Fig. 4, curve 'B').

A frequency plot of the tracer position in this region forms a normal distribution around a centre point, providing the statistical probability of where the tracer will end up.

Individual pulse
The resolution obtained from the PEPT camera is high enough to observe the tracer movement during a single pulse. The particle starts settling as soon as the upward pulse ends (Fig. 5); about half way down, the particle seems to stop and remains stationary for about 100 milliseconds. This is probably due to the 'kickback’ that the particles experiences from the jig.

The initial downward movement of the particle bed exerts a force onto the piston, which pushes it back slightly, to produce upward flow that causes enough drag on the bed to hold it stationary for a short time before the bed moves again. When the particle is at the bottom of the bed, this effect is not evident (Fig. 6); the particles at the bottom of the jig are not trapped within the bed and can settle even with the slight upward flow.

Effect of starting position
There are definite differences between the behaviour of tracer particles started at different positions in the jig bed.

The following cases were considered: a high density particle (SG 5.01) with two starting positions at the top centre and one on the top side, and a low density particle (SG 2.92) with centre and side positions at the bottom of the bed.

To see the effect on the stratification rate, the time to the final equilibrium position was noted (Table 3). The settling rate for the heavy particle, started at the side wall, is significantly lower than that of the particle started at the centre. There is no clear difference in settling rates seen for the lighter particle.

Another interesting phenomenon observed when comparing the movement of the tracers from different starting positions is seen in Figure 7.

High density particles starting at the side have a tendency to move to the centre as they settle and low density particles starting at the centre on the bottom move to the side as they move up the bed. This suggests that a secondary flow field is generated in the jig coinciding with results obtained by Williams et al (1998).

They discovered these flow patterns in a lab scale jig using glass beads, with one of the beads containing the PEPT tracer.

The high density tracer at the side experiences this secondary upward flow that slows down its stratification rate. Surprisingly, the same effect is not observed to the same extent on the low density tracer, which indicates that there are other factors involved.

Conclusion
Test-work on jigs using PEPT technology shows significant promise. It provides new insights into a very ancient technique and presents the opportunity to re-evaluate the old theories and to develop new ones.

The data generated by the PEPT technique can be used to validate theoretical models and to provide insight into specific industry problems since a real ore can be tested. The resolution from the PEPT technique is such the movement of a particle can be seen during an individual pulse of the jig.

The particle trajectories suggest that there exist additional currents that strongly affect stratification, which re-
quire more consideration during further studies.

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References

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**Natasia Naudé, Department of Materials Science and Metallurgical Engineering University of Pretoria, South Africa. Natasia.naude@up.ac.za
Whether it is calcium carbonate in plastic applications, barite in drilling muds, or silica in rubber products, many fine powders have to be coated with certain additives to make them into functional fillers.

Since newly developed grinding and classifying processes are able to achieve finenesses which are already in the range of nanoparticle size, the coating systems face a more difficult task to efficiently de-agglomerate these ultra-fine particles; overcoming the Van der Waals forces, while at the same time applying a thin layer of additives on each particle.

**Calcium carbonate case study**

Coating calcium carbonate with stearic acid to prepare it for certain plastic extrusion processes provides an example to demonstrate how new technology developed by Ecutec Barcelona SL can improve the coating process.

Having been involved in the calcium carbonate (CaCO₃) business for many years, Ecutec was able to pinpoint key areas for optimisation when designing a new process solution.

These were:

- the need to fully de-agglomerate the ultrafine filler before applying any coating agent;
- use as little as possible of the costly coating agent;
- aim to achieve a perfect single layer of coating;
- and, avoid creating agglomerates after the coating process.

**Full de-agglomeration before application of coating agent**

As a rule, the finer the particles to be coated, the bigger the Van der Waals forces acting on them will be, and the more energy is needed for de-agglomerating these particles. Typical particle sizes for such coating processes are in the range of \( d_{98} = 3 \mu m \) to \( d_{98} = 15 \mu m \).

The particles of such fine powders can only be separated by high shear forces, which can be generated by devices such as counter rotating pin mills. These mills contain two opposite pin discs, which run at a speed of up to 120 metres/second, resulting in shear velocities of about 240 metres/second.

Only once the particles have been separated can the coating agent be applied; if the agent was added earlier, the agglomerates would be coated rather than the individual particles.
Using as little of the coating agent as possible

In processing technology, everything is about economics. It is therefore important not to waste costly stearic acid, but try to distribute it as efficiently as possible onto the ultrafine particles.

For different end-product finenesses, different levels of coating grades have to be used due to diverse surface areas. To achieve the right coating grade for each individual fineness, the massflow of calcium carbonate, as well as stearic acid, has to be monitored and controlled.

Ecutec has designed a complete computer/programmable logic controller (PLC) loss-in-weight system for both materials. The stearic acid is melted gently in a tank above load cells. These load cells, together with the pump and PLC, form a system where the massflow is constantly monitored and controlled.

For CaCO₃, the hopper for the calcium carbonate powder also sits on load cells, forming, with metering systems and the PLC, another loss-in-weight system.

These two systems are combined in the PLC and certain ‘recipes’ can be created whereby the operator selects one desired end-product, and the plant automatically adjusts itself to the necessary feed rates of CaCO₃ and stearic acid.

This technology ensures that there will not be any over-coating or waste of stearic acid, or under-coating and a loss of product quality.

Aiming to achieve a perfect single layer of coating

To successfully complete this objective of the process, the particle size of the product to be coated, which was reduced by grinding and classifying, will stay the same and only a thin layer of stearic acid needs to be applied.

ECUTEC’s preferred solution for achieving this is to directly inject the acid into a high speed pin mill. The injection is performed by means of an atomising nozzle, where hot pressurised air separates the melted liquid stearic acid stream into millions of small droplets.

These droplets are a minimum size of 10µm, which is still too big to achieve perfect coating of some of the ultrafine particles.

Injecting the liquid into a zone with high shear forces can reduce the size of the droplets, meaning that small particles will not get ‘glued’ to other particles by oversized droplets.

Stearic acid should flow around each particle and build-up a thin layer on the surface, so as not to increase the particle size. Therefore it is crucial to de-agglomerate the particles and apply the coating agent in a hot environment.

There will never be a complete coating of the whole particle, but this is not necessary. The important thing is to avoid increasing the size of the particles by coating them with too much stearic acid.

Melting tank on load cells with pumps, heaters and other necessary equipment, premounted and preconditioned.

Ecutec Barcelona SL

Ecutec’s simple “plug and play” system.
Avoid creating agglomerates after the coating process

In order to reach the final product stage, the particles must be cooled down so that the stearic acid solidifies.

With high temperatures in the ductwork for conveying the particles to the silo or bagging area, there is the risk of the particles agglomerating because the stearic acid remains sticky.

In some coating systems, the full coating cannot take place in the mill and following conveying lines are kept hot to allow for some further coating activity to take place during the transport, but this comes with a high risk of agglomeration.

Classifiers can be found sometimes to take out these agglomerations, but this adds to the cost of the process.

By using Ecutec’s new coating technology, all the necessary coating can be achieved inside the mill, meaning that the particles can be transported to the silo at low temperatures, and are not at risk of agglomerating or requiring any additional processing stage.

*Joe Roettle is the Global Sales Manager for Ecutec Barcelona SL

Well coated CaCO₃ particles: the thin, translucent layer is stearic acid, which covers almost the entire grain.

**Processing investment needed to advance filler developments**

By Kasia Patel

The biggest obstacle preventing mineral compounders from taking advantage of new filler technologies is a lack of investment in processing equipment, according to speakers at the 2012 Minerals in Compounding event in Atlanta, US, last November.

Sweden-based Minelco said that while some industries are willing to embrace new processes, many other producers are afraid of making the necessary initial investment in processing lines.

While some new filler technologies work in the lab, they can then fail on big industrial lines, Stefan Viering, Minelco’s business development manager for functional fillers said.

Viering told IM that many are not investing in processing lines that would allow them to benefit from new additives or mineral combinations that could improve performance.

“We have a chance to get better, stronger, greener and more energy efficient compounds,” Viering said. “But, it’s important to realise when new minerals are introduced, you can’t just throw them into the existing processing chain, you need to change it,” he added.

Frans Venema from Mondo Minerals agreed, saying that packaging producers were hesitant to make the first outlay of capital to upgrade or replace existing technology—an expense which would reap benefits in the long run.

It is up to producers to weigh-up the costs of initial investment against long-term savings, but producers are hesitant to change systems that are tried and tested, Venema told IM.

Applied Minerals’ CTO Chris DeArmitt also discussed new developments using minerals such as halloysite and dragonite for reinforcement, fire retardancy and foams.

Despite the benefits of introducing new minerals into the manufacturing of traditional products, the biggest barrier to producers taking up alternative raw materials is the fact that the processing chain has to change, DeArmitt said.

“What we’ve learnt is that if you don’t have the right processes, then you aren’t going to achieve the properties you were hoping for,” DeArmitt concluded.
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