Cutting comminution energy

The industry needs to cut energy costs across the board, particularly in comminution. One way to do that is to reduce the amount of waste rock that wastes energy by being crushed and ground, John Chadwick investigates

Australia's JKMRC recently surveyed the comminution energy requirements of gold and copper producing mines to provide reliable benchmarking data which can be used to compare comminution energy consumption across different mine sites. The study showed that comminution of gold and copper ores can be expected to consume about 0.2% of global, and 1.3% of Australia's electricity consumption.

MEI's Barry Wills notes that "the best way to reduce comminution energy is not to comminute, therefore concentrating the ore via gangue rejection prior to grinding is likely to achieve the largest positive effect on comminution energy efficiency. Dense medium separation has long been used to do this on amenable ores, such as Pb-Zn vein deposits, but electronic ore sorting is showing great potential, by identifying the metal values in a run-of-mine stream and separating the rock containing valuable mineralisation from barren material.

A US paper in *Minerals Engineering* provides quantitative discussion on the impact of this technology. "Dual-energy X-ray transmission was used to sort ore from different mines, and an analysis identifying the economic impact of these results is presented. Ore sorting has been identified as a technology with potentially broad reaching impacts on the industry. With the implementation of ore sorting significant energy savings or throughput increases are realised during comminution, and these effects are then felt throughout the plant."

Orchard Material Technology (OMT) has been working extensively on mineral sorting developments for a number of years and says the technology "promises to revolutionise the economic outlook for metal mining and processing by rejecting run-of-mine (ROM) material after crushing that does not contain economical target metal values. The only crushed material sent to the milling and processing plant, and the only material to be afforded significant additional energy and reagent investment, is the ore that contains a pre-determined fraction of the target metal value.

Applied Sorting Technologies explains that "ore sorting is a process for upgrading mineral bearing materials at large particle sizes, typically between 150 and 10 mm. Some particularly high value materials justify sorting down to even smaller sizes. [It] involves evaluating the mineral content of individual rocks as they pass through the ore sorter and separating them into accept and reject fractions, based on predetermined selection criteria.

"By providing an economical way to reject sub economic grade materials at large particle sizes, ore sorting is an ideal tool for:

- Making low grade ore deposits viable to develop
- Recovering valuable fractions from waste dumps
- Accelerating cash flow and payback
- Removing nuisance materials e.g. talc
- Improving processing plant recoveries and efficiencies
- Reducing transport & processing costs.

"Depending on the size range of the material being sorted Applied Sorting can engineer machines to achieve throughput rates up to 100 t/h per machine."

Machine sensitivity and the cut-off grade for the accept/reject split can be adjusted so ore sorting machines can generally be fine-tuned to suit individual operating requirements e.g. high upgrade ratios or maximum recoveries etc.

The latest ore sorting development from Applied Sorting is its X-ray transmission sorter, intended primarily for upgrading the ores of steel alloying elements like tungsten, molybdenum, vanadium, nickel, manganese and chromium as well as several other high value materials like tin, bismuth, tantalum etc.

The system generates an X-ray image for each rock as it passes through the sorter and uses high-speed digital image processing to determine the amount of the desired mineral within each rock. It has the advantage of not relying on rock surface information, unlike alternative sensing methods which rely on surface optical fluorescence or light reflectance properties to indicate grade. Instead, it effectively measures the weight of the valuable material contained within each rock and computes the corresponding rock grade.

Applied Sorting installation at Leinster (nickel, Western Australia)

X-ray transmission sorting is highly effective in ores where the mineralisation occurs as particles or lenses within the rocks being sorted, even if they are only a few millimetres in size. The X-ray system is able to look inside the rocks, add up the weight of the valuable particles and decide whether a particular rock should be accepted or rejected.

Applied Sorting says it can quickly assess the suitability of particular deposits or stockpiles for ore sorting by running trials on small samples of crushed rock or drill core.

Another specialist supplier in this field, TOMRA Sorting Solutions, has become a member of the international AngloGold Ashanti Technology Innovation Consortium. The consortium, based in South Africa, was established in 2011 by AngloGold Ashanti and, including TOMRA, comprises 46 industrial companies, eight universities and research institutions all of which are seen as innovators in their field. The aim of the consortium is to create new ways of thinking and new opportunities for deep level mining.

Mike MacFarlane, Senior Vice President Technical Development at AngloGold Ashanti says: "The consortium facilitates solutions by bringing the world´s leading innovators to solve mining´s toughest problems. Next generation mining requires collaborative breakthroughs."

TOMRA was chosen as an expert partner for sensor-based solutions for gold ore sorting. Hartmut Harbeck, Technical Director, comments: "This partnership will allow us to network with exclusive partners and share knowledge."

Last year TOMRA began a strategic partnership with Rio Tinto to develop commercial scale sorting systems for upgrading bulk minerals. At the time the company noted that "currently there are no solutions in the market that fulfil Rio Tinto's specifications for a requested platform. A dedicated R&D program will therefore be initiated by the two partners to develop an adequate solution.

"This work will include scaling up Rio Tinto's iron ore and copper sorting technologies IronX™ and NuWave™ - which convert potentially waste rock into a commercially valuable resource – to have each machine capable of sorting 1,000 t/h of rock. TOMRA Sorting Solutions has previously been a key supplier to both IronX and NuWave.

It is a leading provider of sensor-based sorting solutions for optimal resource productivity and has provided state-of-the-art sensor-based sorting technology for dry material separation in various minerals and ore applications since 1988.

TOMRA Sorting Solutions installation at Gold Fields' Kloof gold mine: PRO Secondary COLOR

X-Ray Transmission Sorting

OMT has specifically evaluated only run-of-mine (ROM) ore from operating mining facilities to assess different potential sorting technologies. After extensive geologic, petrographic, and analytical testing, sorting campaigns were conducted to identify the potential for automated sorting, evaluating these techniques in detail.

(1) Optical Sorting
(2) Microwave/Infrared Sorting
(3) Dual Energy X-Ray Transmission Sorting
(4) Laser Induced Breakdown Spectrometry (LIBS)

"All four technologies were extensively evaluated, but Dual Energy X-Ray Transmission showed significant promise as applied to the subject planar vein structured molybdenite deposits."

The recent case study conducted by OMT on an operating molybdenum resource determined that 98.9% of the total molybdenum contained in the ROM ore was present in only 28% of the crushed ore (20-80 mm size).

"This work provided the necessary impetus to identify a technology capable of (a) 'seeing' the molybdenum in the stones in a manner that did not require significant energy investment, (b) differentiating between stones with molybdenum and stones without, and (c) providing a means of sorting out those stones identified as containing molybdenum from those that did not. In terms of total energy investment, crushing is far less costly as compared to milling. As such, it is reasonable to expect a mineral sorting operation to act on the ROM ore stones as it exits the crushing circuit."

In the study discussed here stones sized in the range of 20-80 mm were used.

In cooperation with wTe Corp (a recycling company outside Boston, Massachusetts) a bench scale test rig consisting of an X-ray source, a dual energy X-ray transmission (XRT) detector, and a rotating 'swing arm' sample holder capable of simulating conveyor belt speeds was constructed and calibrated for this test program. Individual stones were passed through the X-ray beam and their XRT profiles were collected by computer. A series of computer image processing algorithms were then performed to determine the relative content of molybdenum in each stone.

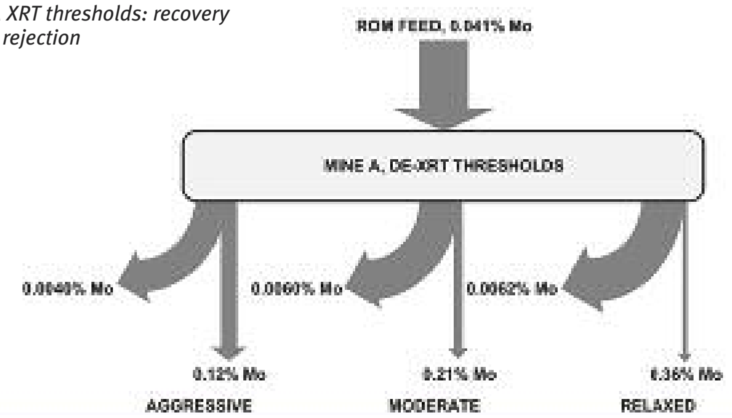
OMT explains that "XRT functions much like the X-ray one would receive in a doctor's office; as X-rays pass through a material they are either absorbed, reflected, or transmitted. The level of transmission is dependent on the density of the material; therefore, denser metals (like molybdenum) will transmit less X-ray energy than lighter metals (like silicon, iron and aluminium). The dual energy XRT detector measures the amount of X-ray energy passing through the sample and converts it into a grayscale image indicating the degree of transmission pixel by pixel. Because the host rock in many refractory metal ores is comprised of silica, aluminates and similar light minerals, differentiation between the heavy refractory metals and lighter host rock is possible. The heavy refractory metals appear dark under XRT while the host materials are lighter.

"However this work is complicated because we are looking at various sizes and shapes of crushed stones. Stone thicknesses 'point to point' across the surface has a very significant effect on the 'perceived' density of these samples. In most applications of this technology this random thickness effect is a serious problem. In our work we are able to adjust for variations in sample thickness and sample contour through the application of the Dual Energy sensor and computer algorithm technologies. Also, since we are dealing with the speeds of an X-ray beam and the decision making speed of a powerful computer these effects are handled and an 'Accept or Reject' decision can be made in milliseconds. This is a very important capability.

"In our previous study we investigated three different thresholds of sorting rigor on the ROM material from Mine A. Individual stones [1,301 in number] were examined. When the computer algorithm analyses the image of a given stone, it counts the number of darker pixels it sees in each image. The level of rigor the threshold requires then determines how many dark pixels must be identified in an image in order for the stone to be classified as containing our target metal, in this case, molybdenum. In the study of Mine A, the 'relaxed' threshold required many dark pixels while the 'aggressive' threshold permitted fewer dark pixels in order to gain a positive molybdenum-containing classification. As a result of these thresholds, it was expected that while more molybdenum would be identified (i.e. higher total recovery) at the 'aggressive' threshold, this would also increase the number of false-positives (i.e. stones identified as containing molybdenum but not actually having any economical levels of molybdenum)."

"Even with the 'aggressive' threshold, >66% of the total ROM ore was rejected as not containing economically recoverable levels of molybdenum; this threshold also resulted in>93% total molybdenum recovery. The ROM average molybdenum content (grade) in this material as a whole was 0.04%. "Therefore, one benefit of this mineral sorting effort was the effective upgrading of the material's head grade going to the milling circuit; an upgrading factor of circa 3-9 was realised in this study.

Mine A XRT thresholds: recovery versus rejection



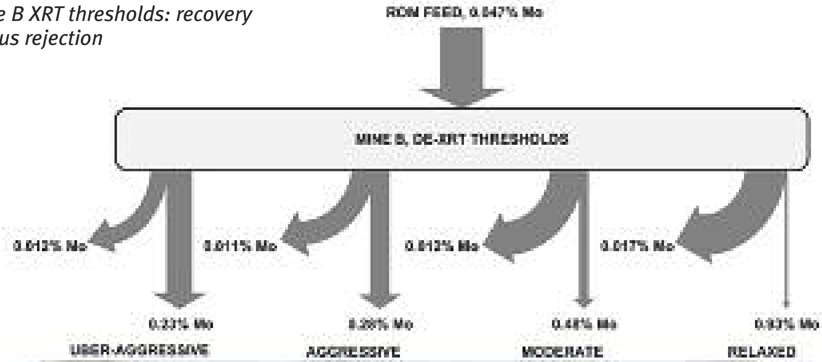
Mine A				
Threshold	Mo Recovery, %	Mass Rejection, %	Mo Content in Added Stones, %	Upgrade Factor
Relaxed	86.4	90.0		8.8
Moderate	88.0	82.9	0.0091	5.1
Aggressive	93.4	66.5	0.020	2.9

"A second campaign of mineral sorting using the same test rig was carried out on Mine B, which was also an operating molybdenum mine with very different geology from Mine A. In a similar manner to previous studies, individual stones [448 in number] were sorted using the Dual Energy XRT instrument and computer algorithms. In this work, however, four thresholds were used: relaxed, moderate, aggressive, and uber-aggressive. The added 'uber-aggressive' threshold was developed to study an upper limiting case of just how much molybdenum could be recovered and at what mass-rejection cost. The relative rejection rigor of the four thresholds was similar to the thresholds previously used; i.e. 'relaxed' required a higher count of dark pixels, while 'uber-aggressive' required the least."

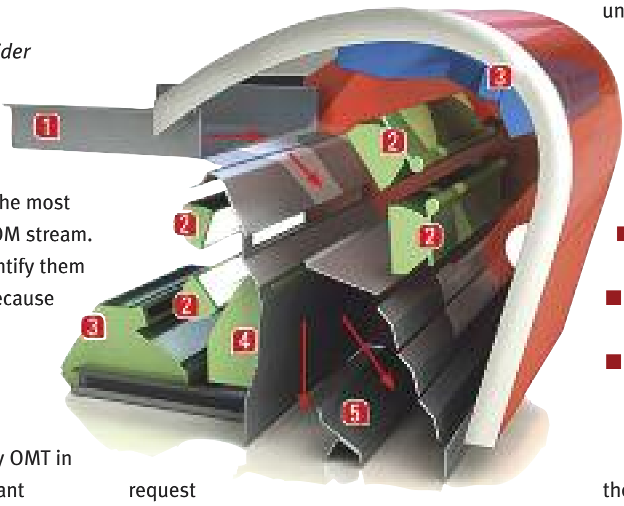
"The ROM material studied from Mine B had a head grade of 0.058% Mo; therefore, at the different thresholds used in this study, the feed to the milling and flotation circuits was enriched by a factor ranging from 4.5 to 15 while decreasing the mass flow by 37-91%. Furthermore, the material rejected as waste contained molybdenum that is likely below the cutoff grade at most mining operations. Anyone familiar with the operation of molybdenum mining projects understands that in the usual ROM material from the primary or secondary crushing circuit a few of the stones in the pile are essentially massive 'chunks' of molybdenite. OMT used the computer algorithm to identify these particular stones and learned that it could recover:

- 40% of the total molybdenum in <0.9% of the ROM material

Mine B XRT thresholds: recovery versus rejection



Mine B				
Threshold	Mo Recovery, %	Mass Rejection, %	Mo Content in Added Stones, %	Upgrade Factor
Relaxed	65.6	93.7		19.8
Moderate	79.7	79.2	0.046	10.2
Aggressive	87.0	54.8	0.014	6.0
Uber-Aggressive	89.4	40.2	0.0077	4.9



REDWAVE C sorting - material flow: 1. vibration conveyor 2. light source 3. camera unit 4. ejection unit and 5. divider plate

- 57% of the total molybdenum in <1.6% of the ROM material

"These particular stones represent the most economically valuable stones in the ROM stream. The algorithm is able to accurately identify them as the stones to mill on a 'rainy day' because they constitute an enormous molybdenum value at a fraction of the cost. This might be considered a fifth, 'extremely relaxed,' threshold.

"In summary, the work completed by OMT in this study demonstrates that a significant reduction in the energy expenditure in the milling and flotation circuits of a molybdenite processing plant is possible without sacrificing economically viable metal recovery. In studies conducted on two different mines, the total amount of ore processed in the milling circuit can be reduced by ~30-60%, meaning a reduction in the capital expenditure in the mills and/or a significant increase in the operating capacity of an existing mill. Many other additional benefits to the overall capital costs, energy costs, reagent costs, manpower costs, and maintenance costs of ore processing will also be realised through the successful implementation of these advanced mineral sorting technologies."

Economic ideas

REDWAVE C is an optical sorting system using colour recognition. For mineral sorting, the machine is equipped with a high-resolution RGB camera. The sorting width is 600 mm to 2,000 mm and the capacity depends on material and grain size. Feed Band (single-sided detection) or chute (two-sided detection) systems are available.

Infeed material is spread over the entire REDWAVE sorting width by a vibration feeder or an acceleration belt. The material is then scanned and identified by the sensor system (single or double sided sensing), while in free fall. If the identified minerals meet the set ejection parameters, a signal is sent to the ejection units.

Individual high speed air jets, operated by compressed air, eject the identified mineral. The number of activated solenoids depends on the size of the identified particle.

Feichtinger is a private company from Esternberg (Upper Austria) and provides some 30,000 t/y of quartz to the RW Silicium company. The company has been active in the mining of quartz since 1972 and currently employs 18 staff. Due to more stringent customer demands it became necessary to sort out impurities (the green and red stones) in high quality quartz. Consequently, Feichtinger issued a tender request in 2012 for elimination of these contaminants through a sensor-based sorting machine.

This resulted in several successful sorting trails being conducted by BT-Wolfgang Binder in collaboration with the customer. A visit was also made to the Leube company in Golling, which already has REDWAVE mineral sorting machines in use for two years. It was also possible to successfully implement the customer requirement to install the sorting machine directly onto the existing screening machine and thus have minimal influence on the operation.

This facilitated the minimisation of additional costs as well as savings in space. The mineral sorting machine has been in successful operation separating impurities from quartz since June 2013. These contaminants can be readily identified and sorted with the REDWAVE 1300 S (mineral sorting machine). The installation of the machine and the adaptation of the existing plant were carried out by the client.

The owners, Joachim and Fritz Feichtinger, also commented that: "We have been very impressed with the REDWAVE technology and the existing established system at Leube, and we are very pleased with the sorting equipment."

Comex offers "complex and robust optical sorting systems, in a user-friendly platform, for the identification and sorting of particles based on different physical properties. This is achieved under recognition of individual response to colour, density, shape, conductivity, size, surface texture, thermal transfer, transparency, electromagnetic induction and X-ray transmission."

Comex notes key benefits of:

- High separating efficiency up to 99.9 %
- Complete 2D/3D analysis of particle geometry
- Possibility for on-site waste material separation
- Possibility to separate materials by recognition of many different properties in the same unit.

Advanced sorting based on 2D particle scan; the OSX-1000 can separate particle sizes of 15-300 mm at capacities of 5-250 t/h. Its standard size is 7.1 m long, 2.5 m high and 1.7 m wide. It offers multi-parameter sorting and a sorting efficiency of up to 99 %, Comex reports.

And on 3D particle scan, VSX can separate particle sizes of 20-300 mm at capacities of 5-40 t/h per line. The standard size is 10+ m long, 1.8 m high and a width of 0.6 m/line. Features include detailed full 3D scan of the particles, sorting efficiency up to 99.9%, unlimited number of fractions and the possibility to connect parallel lines.

Comex offers an iron ore case study as an example. It assumes a material stream out of the mine at 500 t/h. This stream has a waste material content of 30 % and enters the OSX, which in this case has a separation efficiency of 90 %.

"A typical iron ore processing plant used about 315 kWh/t iron ore. By implementing OSX into the existing iron ore plant facilities; you can achieve huge cost savings:

- Energy consumption reduction -26%
- Waste disposal reduction after processing -90 %
- Reduced transport requirement from the mine to the plant -27%.

An example gold case study has a material stream out of the mine at 100 t/h. This stream has a gold bearing material concentration of 20 %. The material stream enters the OSX, which in

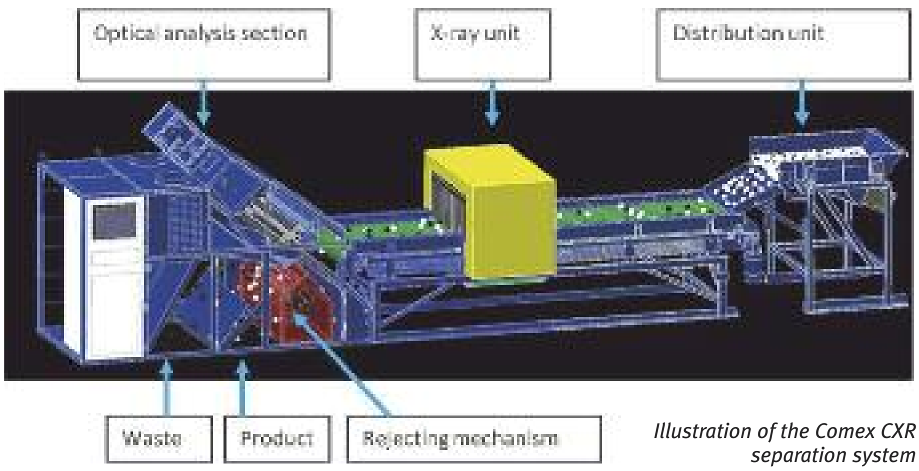


Illustration of the Comex CXR separation system this case has a separation efficiency of 80 %.

"By implementing OSX into the existing gold processing plant facilities, you can achieve huge savings when it comes to energy consumption and waste disposals:

- Energy consumption reduction - 67%
- Waste disposal reduction - 64%.

"Let us assume that we have the same material stream into the processing plant as before (100 t/h). However by using the OSX, we upgrade the gold bearing material concentrate from 20 to 56%. In this configuration, it is possible to increase the gold production by 180%."

Microwave sorting

Gus Van Weert, Adjunct Professor at UBC and President ORETOME Ltd is exploring the phenomenon that sulphides, being semi conductors, heat up in a microwave field while silicates and carbonates do not.

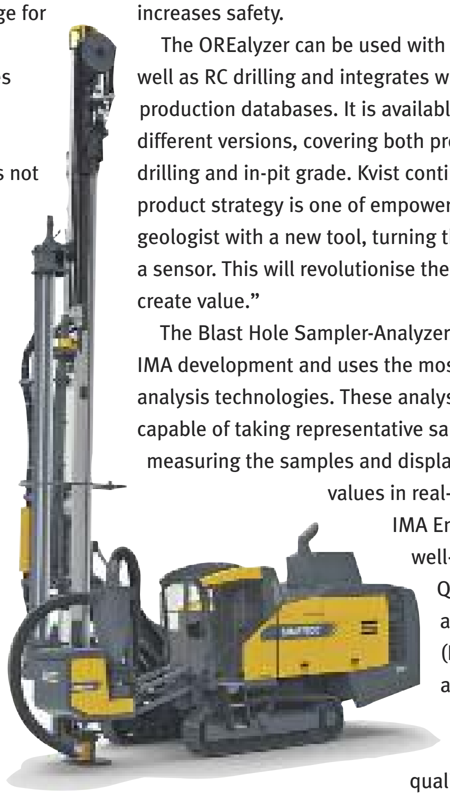
However, he cautions that the microwave/infrared sorting approach suffers from the same problem as all the other sensor based machine sorters: they are relatively expensive to operate. This is due to the use of compressed air to blow the desired rock fraction into a different trajectory. That costs several dollars per tonne sorted. When one sorts diamonds, it is affordable. There are also many cases in the processing of industrial minerals where machine sorting is (highly) profitable, because the value of the product is often in the hundreds of dollars a tonne.

"Gold or base metal ores are generally worth tens of dollars a tonne, in the low range for open pits, in the high range for underground mines. Sorting these ores costs more than it saves in processing/milling.

"Microwave/IR machine sorting has not offered a solution to the problem of costs and since it has not been shown (yet) to be applicable to industrial minerals sorting, sorting equipment producers have ignored the technology. However, it has been reported that Rio Tinto has spent millions of dollars exploring the possibilities in a pilot plant in conjunction with Nottingham University in the UK."

Van Weert is now trialling a demonstration/ research ore sorter which does not use expensive sensors, or the costly operating expenses of air blasts. The principle is simple. Sulphide ore passes through a microwave oven/zone and falls on a belt, coated with thermoplastic adhesive. The warm sulphidic rocks stick (somewhat) to the belt, the silicates/carbonates do not, hence creating different discharge trajectories. A proof of concept model has been successfully operated and an exploratory demonstration machine is now under construction at Humber College in Toronto.

German ore sorting equipment manufacturer Steinert has also joined the project.



Leave it in the pit

Of course another way of reducing the amount of waste in the processing plant is to leave it in the mine. Atlas Copco plans to offer a device for bench drilling that enables open-pit mines to track and analyse valuable minerals while drilling is in progress.

The OREalyzer, based on technology from IMA Engineering, is integrated into Atlas Copco's SmartROC D65 drill rig. It pinpoints the location of the ore, analyses its quality and identifies waste boundaries while drilling is in progress.

Olav Kvist, Product Portfolio Manager at Atlas Copco, says: "By knowing exactly where the ore is located, the mine can potentially get far better ore recovery. This means that mines can extract more value from the blasted material and increase the amount of sellable material in the bench."

Log files are sent automatically to the mine office through the RRA (Rig Remote Access) option, enabling early decision-making on blast design as well as loading priorities. In addition, the OREalyzer reduces the need for personnel to collect and handle samples on the bench which increases safety.

The OREalyzer can be used with both DTH as well as RC drilling and integrates with acQuire production databases. It is available in two different versions, covering both production drilling and in-pit grade. Kvist continues: "The product strategy is one of empowering the local geologist with a new tool, turning the drill rig into a sensor. This will revolutionise the way mines create value."

The Blast Hole Sampler-Analyzer is the newest IMA development and uses the most advanced analysis technologies. These analysers are capable of taking representative samples, measuring the samples and displaying analysed values in real-time.

IMA Engineering is well-known for its QuarCon (XRF) and OreSpex (LIF) cross belt analysers that are used to monitor ore quality on conveyor belts in the mine before the beneficiation plant. QuarCon measures elements. OreSpex enables fast ore mineral and rock identification. Both instruments facilitate the control of dilution and grade in the mine. *IM*