srk news
Metallurgy & Mineral Processing

Mine-to-mill optimisation: effect of feed size on mill throughput

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Over the past 15 years, mine-to-mill studies have focused attention on the impact blast fragmentation has on concentrator throughput. Blasting provides the first opportunity for comminution – or size reduction. It is also a cheaper and more efficient process, compared to both crushing and grinding.

One of the most valuable aspects of blasting is the generation of very fine particles (e.g., smaller than 12mm) that will pass through the primary mills and onto the secondary ball mill circuits, alleviating a common bottleneck.

Modifying blasting practices to achieve a more suitable mill feed size – which varies according to the crushing/grinding circuit – can achieve up to a 30% increase in throughput. Following an initial benchmarking of an operation's practices, SRK can advise on how value-added blasting will deliver improvements in both mill capacity and overall consistency of performance. SRK employs modelling tools to simulate the effect of upstream changes in blasting and crushing on grinding circuit tonnage.

To demonstrate the expected improvements, extended plant trials of higher-energy blasted feed are arranged so the benefits can be monitored directly.

...continued

Mine-to-mill optimisation *(continued)*

If drill and blast costs need to be increased to improve the quality of fragmentation, these costs are far outweighed by the reduction in mill operating costs – typically 7 to 10 times any increase in mine costs.

At the same time, the concentrator must be prepared to take advantage of the much improved, higher quality feed material. A review of the current crushing and grinding practices is undertaken, with the assistance of simulation tools, to make it clear where the benefits can be obtained. Therefore, a well-managed mine-to-mill project must consider both sides: how well the mine (supplier) delivers a consistent quality feed and how well the mill (customer) is working to maximise the benefit.

For operations that have undertaken such an exercise in finer, improved fragmentation (for the mill's benefit), the mine rarely is willing to return to the old ways of cost-minimised blasting. The reason is that the mine also benefits greatly from more consistent fragmentation with less oversize material to deal with.

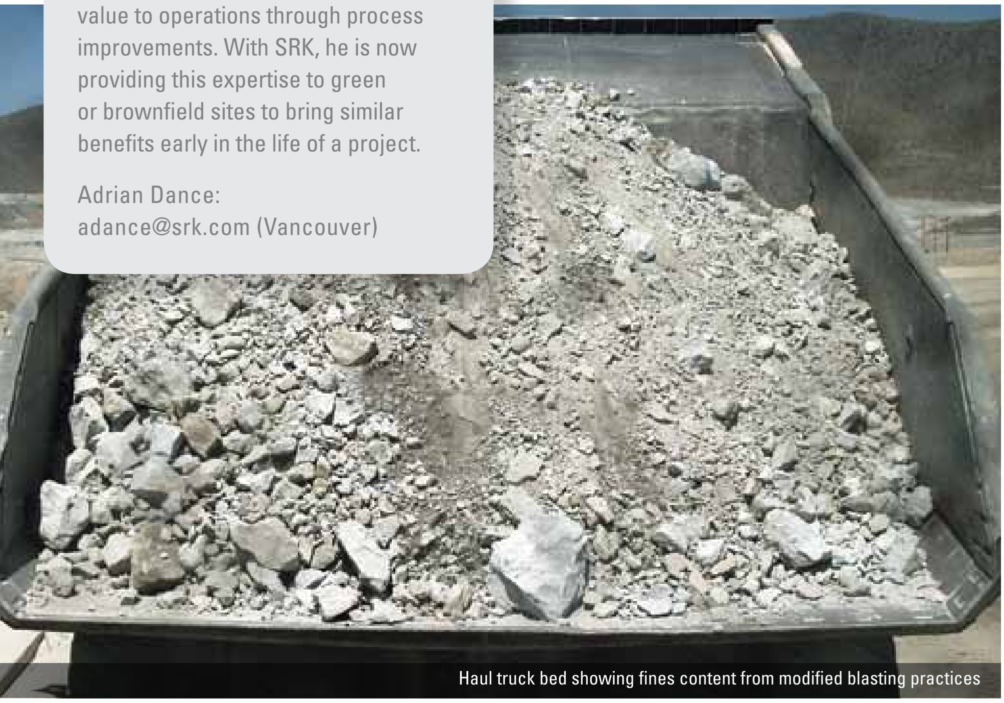
The overall productivity improvement when easier-to-handle material is passed from the mine to the mill is appreciated by all involved; especially those looking at the bottom line … and who isn't these days?

Adrian Dance: adance@srk.com

ADRIAN DANCE

Dr Adrian Dance is a Principal Metallurgist with SRK Vancouver who completed a Bachelor of Applied Science degree at UBC in Canada and a Doctorate in Mineral Processing at the Julius Kruttschnitt Mineral Research Centre in Australia. With over 20 years in his field, Adrian has both industrial and consulting experience, working at operations in Australia, Canada and Peru. He has established himself as an authority in the optimisation of crushing/grinding circuits and adding value to operations through process improvements. With SRK, he is now providing this expertise to green or brownfield sites to bring similar benefits early in the life of a project.

Adrian Dance:
adance@srk.com (Vancouver)



Haul truck bed showing fines content from modified blasting practices

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The process design of a metallurgical plant follows logical steps, one built on another, to define the circuit requirements. The methodology used and documentation produced is the same for a pre-feasibility study, feasibility study or a complete design, regardless of the process complexity or the commodity. The only difference is the amount of detail developed at each stage.

The first element is collecting metallurgical testwork or operating data from an existing plant. The testwork identifies the process, the metallurgical recoveries and product qualities, and establishes the process parameters for economic recovery of the commodity. Test samples must represent both the whole orebody and the feed over the life of the mine, showing the mineral's variability. With this data available, the process design can be developed.

A *Design Criteria Document* summarises the main parameters used to size the plant and equipment.

The overall process is tracked on Process Flow Diagrams (PFDs) that show all

The building blocks for plant design

the process streams – water, reagent and utilities – and identify each piece of process equipment by number. The process streams are marked and linked to the mass and metallurgical balance.

The *Process Description Document* details the main requirements and process steps; complex processes may include detailed descriptions of the chemistry. Any special requirements, environmental issues and mitigation measures are addressed.

The mass and metallurgical balances are the main calculations used to size the plant. Processes using physical separation are simple while complex processes involving chemical reactions, heat, phase changes, etc. can be very involved. The balance for a simple flowsheet can be developed using spreadsheets, however a proprietary design package is typically required for a complex flowsheet.

An *Equipment List* identifies all items of process equipment with a unique number and key details, such as process duty, equipment type, sizes, installed power, materials of construction, etc. This is further developed into a *Mechanical Equipment List*, which is used for estimating costs.

Once the flowsheet is defined, the mass and metallurgical balances completed, and the equipment list prepared, a *Process Data Sheet* is developed for each piece of equipment, which identifies the duty it performs and its process-specific features. These process data sheets are incorporated into the mechanical equipment specifications. For the more detailed process design work required for a feasibility study or an actual plant design, the PFDs are developed into *Piping and Instrumentation Diagrams* (P+IDs). These drawings detail every pipe, valve, in-line equipment, all instrumentation and control loops and construction materials. *Process Data Sheets* are then developed for these additional equipment items.

A *Process Control Philosophy Document* outlines the overall process control requirements.

At every stage of development, pertinent hazards, operability, environmental protection issues and mitigation measures are addressed in detail. The engineering team uses all these documents to complete the plant design.

David Pattinson: dpattinson@srk.co.uk

DAVID PATTINSON

Dr David Pattinson has over 31 years' experience in the non ferrous mining industry. Prior to joining SRK's Cardiff office in 2005, he worked for more than 23 years in metallurgical plant design, where he headed up a process design department as part of an international engineering group. David has been involved in testwork, feasibility studies, design, and commissioning around the world, on facilities treating a number of different commodities. He has experience in a consultancy or project audit environment and in reimbursable, EPCM and lump-sum type contract work.

David Pattinson:
dpattinson@srk.co.uk (Cardiff)

Froth flotation circuit design and basic testwork requirements

ERIC OLIN

Eric works in SRK's Denver office and has more than 29 years' experience in the minerals industry. He has extensive consulting, plant operations, process development, project management and research & development experience with base metals, precious metals, ferrous metals and industrial minerals. Additionally he has been involved with numerous third-party due-diligence audits, and preparation of project conceptual, prefeasibility and full-feasibility studies. Eric has also served as the plant superintendent for several gold and base metal mining operations. Eric specialises in consulting to plant operations; process development; project management, and research and development experience with base metals, precious metals, iron ore and industrial minerals.

Eric Olin: eolin@srk.com (Denver)

Froth flotation is a very important mineral concentration process that is used to recover a vast array of different minerals containing valuable commodities such as copper, lead, zinc, nickel, molybdenum, tungsten, silver, gold, phosphate and potash. In the flotation process, ore is ground to a size sufficient to adequately liberate desired minerals from waste rock (gangue); it is conditioned as a slurry using specific chemicals, generically referred to as 'collectors', that adsorb to the surfaces of the desired minerals. This makes these mineral surfaces hydrophobic – they tend to repel water – and endows them with the propensity to attach to air bubbles. The conditioned mineral slurry is then processed in flotation cells, which are essentially agitated tanks into which finely-dispersed air bubbles are introduced. The desired hydrophobic mineral will then attach to the air bubbles and float to the top of the flotation cell, where it will be skimmed off as a mineral-laden froth. The remaining unfloated mineral slurry will be discharged as tailings.

Most flotation circuits include an initial stage of rougher flotation, followed by a scavenger stage of flotation. The objective of passing through the rougher and scavenger flotation circuits is to maximise recovery of the desired minerals into relatively low grade concentrates that may typically contain 5-15 weight percent of the ore feed, (directly related to ore grade). Depending on the specific mineral liberation characteristics of the rougher and scavenger concentrates, these concentrates may be subjected to regrinding before upgrading in subsequent stages of cleaner flotation.

As shown in the figure (right), a typical flotation flowsheet might include rougher flotation followed by scavenger flotation. The rougher and scavenger concentrates may be reground to a

predetermined liberation size and then subjected to two or three stages of cleaner flotation to produce a final flotation concentrate. Cleaner flotation tailings is an intermediate product and is recycled within the flotation circuit.

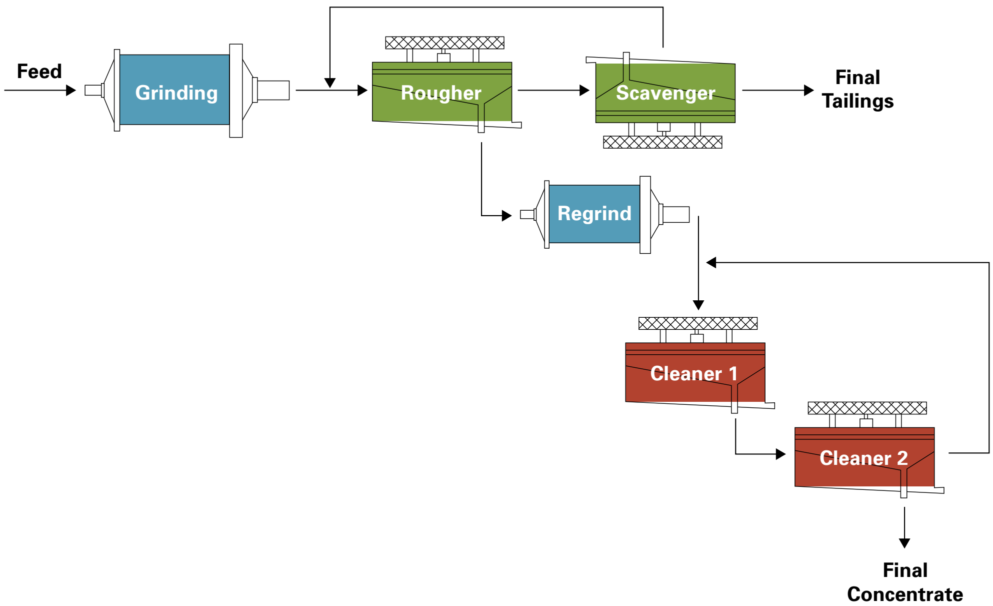
Many ores contain multiple valuable minerals that can be floated into separate concentrates. Examples would include a lead-zinc ore, in which the lead and zinc minerals are recovered sequentially into separate concentrates. Another example would be a copper-molybdenum ore in which the copper and molybdenum minerals are first recovered into a bulk copper-molybdenum concentrate, which is subsequently conditioned with appropriate specific reagents and then processed to produce separate copper and molybdenum concentrates.

Each ore is different, and requires laboratory testing to evaluate the grind size, slurry pH, slurry density, required reagents and retention time to maximise recovery of the desired minerals into a flotation concentrate. Testwork necessary to define the design parameters for a flotation circuit generally includes:

- Grindability studies to establish grinding power requirements
- Chemical and mineralogical analyses of test composites to establish ore grades, mineral associations and liberation characteristics
- Reagent evaluations required for rougher and cleaner flotation, including:
  - o slurry pH
  - o collector dosages and types
  - o mineral depressants and activators
  - o frothers
- Rougher flotation grind-size versus recovery, including flotation of timed concentrates to evaluate flotation retention time requirements
- Cleaner flotation grind-size versus recovery, also with timed flotation concentrates
- Locked-cycle flotation tests under optimised conditions to evaluate the effect of recirculating intermediate test products on overall mineral recovery and concentrate grade
- Thickening tests on flotation tailings and final flotation concentrates
- Filtration tests on the final flotation concentrate.

It should be noted that flotation retention times determined by laboratory testing are generally scaled-up by a factor (depending on the mineral in question) to establish the retention requirements needed in a commercial concentrator.

Eric Olin: eolin@srk.com



Testwork at Dominga IOCG project, Chile

SRK Chile is managing a pre-feasibility study (PFS) for the Dominga Iron Oxide-Copper-Gold Project located in Region IV of Chile. The project is owned by Andes Iron SpA. Prior to the PFS, SRK managed a scoping study for the project, with the metallurgical testwork supervised out of SRK's UK office.

A key initial metallurgical objective for the project was to determine the relative value of the contained metals, as this dictates the focus of flowsheet development. For Dominga, the iron mineralisation holds the greater value. The primary mineralisation types are magnetite (iron) and chalcopyrite (copper).

JOHN WILLIS

Dr John Willis has over 25 years' experience in the minerals industry, in research and development, operational technical support, project development and consulting roles. He has Bachelor and Doctoral degrees in Mineral Processing Engineering from the University of Queensland and the Julius Kruttschnitt Mineral Research Centre in Brisbane, Australia. Since joining SRK's Cardiff office in 2008, John has been involved in due diligence audits and technical studies covering a range of commodities including iron ore, gold and base metals, phosphate and potash. His prior experience includes consulting in comminution and flowsheet development for refractory base and precious metal ores.

John Willis: jwillis@srk.co.uk (Cardiff)

The metallurgical testwork in the scoping study considered the iron and copper separately, with copper flotation conducted by SGS in Chile and iron magnetic separation testwork conducted by SGS Lakefield in Canada. Further testwork on the oxidised and transitional iron mineralisation was conducted by SGA in Germany. The scoping study testwork set the initial parameters for the integrated flowsheet, incorporating iron recovery by magnetic separation, followed by copper (and gold) recovery by flotation.

The PFS study testwork program is ongoing. A total of 13 metallurgical domains have been identified and are being tested separately. The bulk of the testwork, undertaken by SGS Lakefield in Canada, concerns the integrated iron-copper flowsheet developed in the scoping study, together with further testing to assess the properties of the process ore that affect tailings storage, environmental impact and the transport of both concentrates and tailings by slurry pipeline. SGS in Chile is undertaking comminution testwork, and SGA in Germany is taking on further flowsheet development work on the oxide and mixed (transitional) ore types.

SRK would like to thank Andes Iron for their permission to discuss the Dominga project in this edition of SRK News.

John Willis: jwillis@srk.co.uk

Dominga banded magnetite-sulphide-quartz mineralisation

Evaluation of mining projects generally start with an initial scoping-level study, and if justified, proceeds to more detailed prefeasibility and feasibility evaluations. A scoping-level study is generally conducted to the +/-50% level of accuracy, with flowsheet development and processing assumptions based on limited testwork. A prefeasibility-level study is typically conducted to +/-25% level of accuracy, and metallurgical testwork is sufficient for preliminary flowsheet development and equipment selection. A feasibility-level study is usually conducted to +/-15% level of accuracy and metallurgical testing is sufficient for definitive flowsheet development, process design and equipment selection.

Scoping-level metallurgical programs are conducted to establish how the resource material will respond to standard metallurgical processes, such as flotation, gravity concentration and

Metallurgical testwork from scoping to feasibility study level

leaching. They are conducted on coarse assay reject material using standard test conditions. The objective is to determine how the resource material reacts to commonly accepted recovery processes and gain a preliminary estimate of metal recoveries and, in the case of flotation, concentrate grades that are likely to be achieved. Additional testing may be done at this level if initial testing demonstrates that material does not respond adequately to standard test conditions.

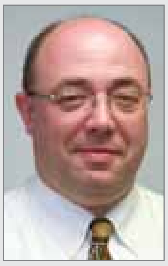
Prefeasibility-level metallurgical programs are significantly more comprehensive than scoping studies and are typically conducted on drill core samples combined together, or composited, to represent the various major ore types that have been identified. Testwork will include chemical and mineralogical analyses of each test composite followed by metallurgical testing to evaluate the recovery process, whether it is flotation, agitated cyanidation for gold or silver recovery, heap leaching for gold or copper recovery, etc. Testwork is directed at developing a preliminary flowsheet and material balance and establishing preliminary process design criteria, such as ore hardness, crush and grind size requirements, flotation or leach retention times, reagent consumptions, metal recoveries and concentrate grades.

Feasibility-level metallurgical programs are often an extension of earlier prefeasibility studies, but are conducted to a level needed to set up detailed flowsheets, material balances, process design criteria, equipment sizing and specification. Testwork should be conducted on drill core samples that have been composited to represent the various ore types that are anticipated. In many cases "metallurgical" holes are drilled specifically to obtain sufficient quantities of material for testing. In addition, variability composites are developed to assess the range of metallurgical performance that might be expected throughout the orebody. Variability composites are developed to assess ore variations of specific concern. They could include ore grade, hardness, contaminant levels, lithology and spatial location within the deposit. Flotation testwork at the feasibility-level will include locked-cycle testing to evaluate the impact of recirculating intermediate products within the process and may include large bulk tests, or even pilot plant testing to generate sufficient quantities of intermediate product for definitive process evaluation. Testwork for heap leach evaluation will include full lift-height test columns at the crush sizes that have been determined appropriate for the ore. For processes that use cyanidation for gold and silver recovery, it is important to run cyanide detoxification studies on the leach residues to demonstrate the residues can be detoxified to required limits before being discharged to the tailings storage facility.

Eric Olin: eolin@srk.com

Determining gold balance in refractory gold ores

ROB BOWELL



Dr Rob Bowell, Corporate Consultant (Geochemistry), has internationally recognised expertise in the geometallurgy of complex ores, particularly for uranium and rare metals, such as gallium, germanium, indium and the rare earth metals. He has over 23 years' experience applying geochemistry and mineralogy to mining and engineering projects, characterising refractory gold ores, autoclave mill residues and complex base metals. With a background in mineral exploration and environmental geochemistry, environmental engineering and mineralogy, Rob specialises in mineral processing and geochemical characterisation and treatment of mine waste and waste cyanide solutions, acid rock drainage and saline waters.

Rob Bowell: rbowell@srk.co.uk (Cardiff)

SRK completed several studies on gold-bearing, complex-sulfide ore feed and autoclave tailings from a mine on the Carlin trend in northern Nevada. Feed, mill and autoclave products were studied at different stages of an autoclave process to identify the reason for variable recovery in some ores.

Under the standard operating conditions of the autoclave mill, there is a high recovery of gold, which occurs predominately as chemically included gold within arsenian (arsenic-containing) pyrite. This pyrite is exposed through crushing and oxidises almost completely within the autoclave. Typically, recoveries above 90% are observed.

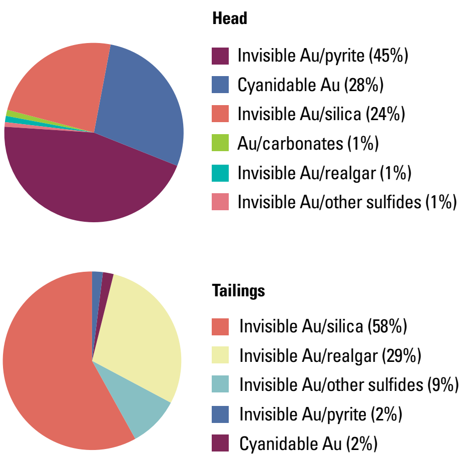
Where recovery is poor, two mineralogical forms were identified via microscopic analysis that may have prevented complete oxidation of the arsenian pyrite and/or leaching of the gold:

- Arsenian pyrite occurs as fine inclusions (<40 µm in size) within quartz and illite; even with fine grinding, these inclusions also appear in the autoclave residue. Such pyrite is still present in mineralogical sections of the residue reflecting the lack of exposure to leaching solution and protection from thermal decay and thus does not get oxidised.
- Trace amounts of gold with a mixture of illite/smectite clay, montmorillonite and free carbon were observed by Laser Ablation Inductively Coupled Plasma Mass Spectrometry, indicating potential for preg-robbing by clays and carbon. Preg-robbing is a process that prevents some of the gold from being recovered, making extraction less effective.

To investigate these concerns, metallurgical testwork was completed and the following options identified to overcome the loss of gold:

- Finer grinding would release the gold-bearing pyrite
- Adding an oxidant, such as MnO, may pacify carbon, thus inhibiting potential preg-robbing; or
- Using a surface suppressant to depress the capacity for surface cation exchange on clays and carbon in the carbon leach step to pacify 'preg-robbing' phases

Mineralogical balance for complex gold ore – head and tailings samples



A better understanding of ore and tailings mineralogical balance (as illustrated in the circle graph above) can provide valuable information for process engineering. Mineralogy may guide flowsheet development, troubleshooting and process optimisation efforts in operating mines. A critical aspect in the success of this work was the strong links with university research that SRK has developed and our ability to access such micro analytical methods of investigation.

SRK has completed similar studies on complex gold ores and gold occurrence in tailings for projects at other sites in Nevada, and also in Montana, Mexico, Peru, Brazil, South Africa, Mali, Zimbabwe, Tanzania, Russia, Armenia, Malaysia, Greenland, Serbia, Spain and Turkey.

Rob Bowell: rbowell@srk.co.uk

Bowell RJ, Gingrich M, Bauman M, Tretbar D, Perkins W, and Fisher P, 1999: "Occurrence of gold in the Getchell ores", Journal of Geochemical Exploration, v.67, 127-143.

Bowell RJ, Perkins WF, Tahija D, Ackerman J, Mansanti J, 2005: "Application of LAICPMS to trouble shooting mineral processing problems at the Getchell mine, Nevada", Minerals Engineering, v.18, 754-761.

Philex Silangan – the effects of copper mineralogy

Since 2010, SRK has been working with Philex Mining Corporation on their Silangan project, located on Mindanao Island in the Philippines. For this copper-gold project, SRK was requested to investigate block caving as the mining method; a particular challenge considering this is a high rainfall area. However, Philex personnel are very knowledgeable about this mining method since they have used it successfully at their Padcal operation.

One of the features of the Silangan ore is its variable mineralogy, where copper can exist as sulphides, carbonates, oxides and silicates. As block caving must balance many aspects to maintain a steady draw-down of ore, it is not easy to mine certain areas selectively and the process is somewhat inflexible in terms of ore blending. Consequently, the Silangan process flowsheet must be developed to handle a wide range of ore types.

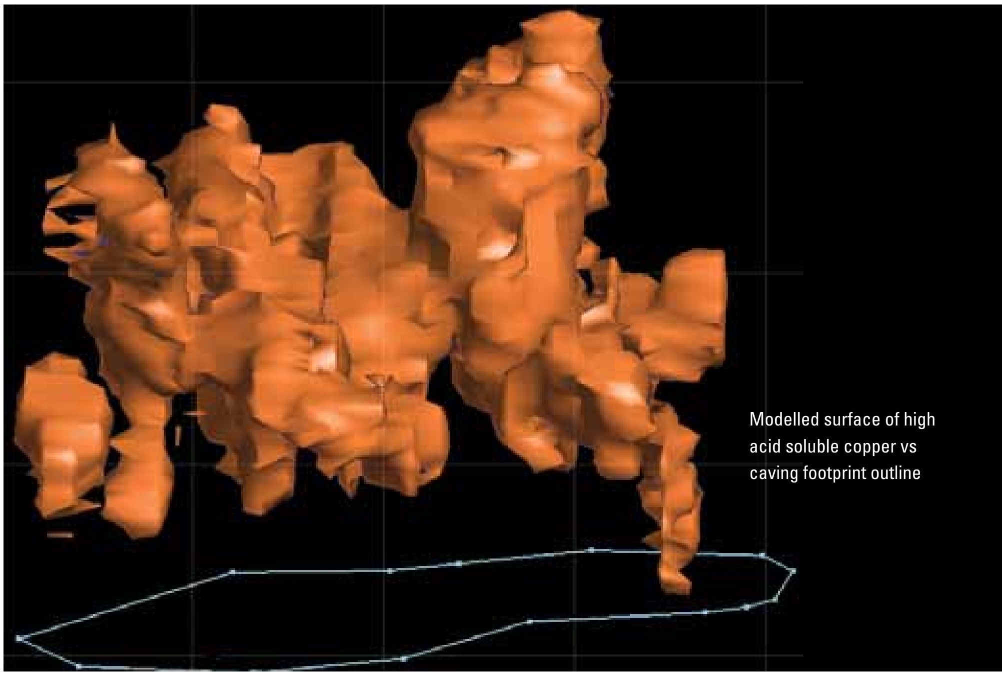
To better estimate the impact of mineralogy on process recovery, copper speciation analysis is being included in the resource block model. Copper speciation analysis estimates the relative amount of non-sulphide (acid soluble) and secondary sulphide (cyanide soluble) copper minerals.

In the figure below, the color shaded surface represents the volume of ore contained in one of the Silangan deposits that has a relatively high, acid-soluble copper content. SRK is using Gemcom's PCBC™ software to simulate the mixing that is expected to occur as the ore is removed from the drawpoint level beneath the caving zone. The white outline (or footprint) of the drawpoint level, as determined by PCBC is also shown.

The combination of block cave simulation with PCBC, along with copper speciation results collected on drillcore samples, will allow SRK to accurately estimate copper and gold composition and performance for a range of ore types. This information allows more detailed economic analysis of the mine scheduling/planning process.

SRK would like to thank Philex for their permission to discuss the Silangan project in this edition of SRK News.

Adrian Dance: adance@srk.com



Modelled surface of high acid soluble copper vs caving footprint outline

Grinding circuit design principles

Many people in the mining industry have heard stories about how the ore was 'harder than expected' or the mill is 'not achieving design throughput'. How can this problem be avoided? It comes down to three main factors: varying hardness across the samples, using different testing methods to check for unexpected behaviour, and considering the effect of feed size.

SRK can help determine how these three factors affect the performance of a particular grinding circuit.

A number of comminution (size reduction) tests are available and each one is focused on a particular piece of equipment and size range. Hardness depends on the application, and measuring resistance to impact breakage is very different from measuring resistance to abrasion. The number of samples required depends on how the results vary across the deposit. It is well worth conducting additional hardness tests to better define a particularly difficult part of the orebody rather than hoping it doesn't exist.

In determining sample size requirements, nothing beats measuring hardness on the actual size of material to be processed. Keep some full or half core around for hardness testwork; it will be broken but not destroyed and can be used later. While a single measure of hardness is useful, it is always best to double check a number of samples using different methods.

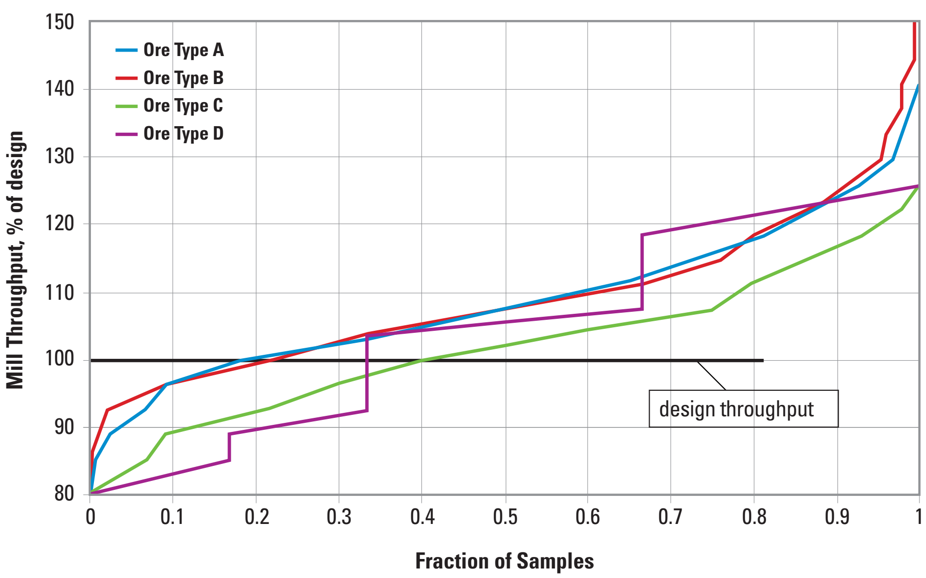
For semi-autogenous grinding (SAG) mills, there are two basic forms of testing: single particle breakage and tumbling tests designed to recreate the actual mill environment. For high pressure grinding rolls and regrind mill sizing, a specific test designed for that piece of equipment is best.

Basically, the test results estimate the specific energy requirements for crushing, SAG milling and ball milling. Using a power modelling approach, different mill sizes are selected to meet the power requirements that achieve the design tonnage.

In the figure below, the range of expected throughput for different ore types are plotted for a fixed grinding circuit; each ore type can process between 80% and 120% of the design throughput. An alternate power model was used to estimate mill throughput using the same mill sizes. In this case, a greater variation in throughput was predicted for the samples using the alternate power model – or was more sensitive to the test results. Coarser or finer mill feed size can result in a ±15% swing in tonnage for the same hardness of material.

Adrian Dance: adance@srk.com

Throughput estimates for different ore types for a specified grinding mill design



Copper sulfide represents the main source of produced copper. The three main types of copper sulfide deposits are high grade massive and disseminated copper-porphyritic and copper-bearing sandstone. Unlike the copper sulfide deposits presented by massive ores, copper-porphyritic deposits contain only 5-10% of the ore minerals, mainly represented by chalcopyrite, pyrite, bornite, tennantite, and molybdenite. These minerals are spread throughout the rock as separate grains – 'porphyritic' nodules and thin veinlets. The usual grades for such polymetallic ore types are 0.3-0.6% copper, 0.1-0.2% zinc, and 0.1-0.01% molybdenum.

The porphyritic ore features the tight intergrowth of sulfide minerals, and different sizes of sulfide minerals tend to show up. Based on this material composition, bulk sulfide flotation with further regrind and cleaning steps will be used to process such ores. Pyrite occurs commonly with copper sulfides,

Processing copper-porphyritic ore

while pyrrhotite occurs less often. Nonmetallic minerals encountered most often are quartz, silicates, sericite and barite.

All copper sulfides are processed through flotation using xanthates at 6-12 pH. When pH values are lower, it is better to use aeroflot-type reagents instead of xanthogenates. If molybdenite flotation is required to separate it from copper sulfides, the pH should be no more than 11 to provide pyrite depression, and lime is added with a small amount of cyanide and soluble silica is used to suppress gangue minerals within the molybdenum flotation circuit.

The molybdenum recovery from bulk copper-molybdenum concentrate might use the following method:

- Copper-molybdenum concentrate treatment with sodium sulfide. In this case, the copper sulfides and other sulfides are suppressed and the molybdenite could be recovered by flotation with non-polar (hydrocarbonic) collectors.
- Oxidative steaming of (copper-molybdenum concentrate) with lime. In this case the chalcopyrite and pyrite lose their adsorptive surfaces, oxidize and sorb suppressing calcium ions. The thickening that is carried out to remove excessive lime is followed by molybdenite flotation with multiple cleaning stages, adding sodium sulfide at higher temperatures.

The number of flotation stages in both copper and molybdenum circuits depends on the content of the respective materials within the feed, and their grades in the final products.

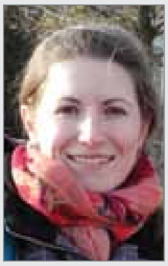
After thickening, filtration and drying, the concentrates are shipped to the smelter for further processing.

This is a conventional method of copper-molybdenum processing. The use of more efficient flotation reagents could make the process cheaper by reducing the number of flotation cycles; then projects with marginal copper and molybdenum grade ore might be developed with the improved process economics.

The metal price dictates the respective strategies that companies choose for project implementation and production optimisation. SRK takes an active role in implementing such projects.

Kate Ovsyannikova:
eovsyannikova@srk.ru.com

KATE OVSYANNIKOVA



Ekaterina works in SRK's Moscow office and has 6 years of professional experience. During her career, she has tested ore for grindability and other process characteristics using international techniques. She was involved in audits and assessments of existing operations and plant designs and took part in projects at different levels of study: scoping, prefeasibility and feasibility. Her expertise lies in testing ore for grindability and other process characteristics, SAG design tests, developing testwork methodologies, designing recovery processes and flowsheets, equipment selection, and standards and practices of processing operations for international and Russian mining projects.

Ekaterina Ovsyannikova:
eovsyannikova@srk.ru.com (Moscow)

Designing gold project flowsheets

DMITRY YERMAKOV

Dmitry works in SRK's Moscow office and has 15 years of professional experience, including advanced training at Australian operations. He has worked as a chief metallurgist/chief technologist, chief engineer, gold plant deputy director, a fire assay laboratory manager, head of tailings facilities and process plant shift foreman. Dmitry has experience operating modern Russian and western equipment. He has been involved in audits and assessments of existing operations and plan designs, and has taken part in various project studies. Dmitry specialises in developing metal recovery processes, equipment selection, and standards and practices at international and Russian mining and processing operations.

Dmitry Yermakov:
dyermakov@srk.ru.com (Moscow)

It has been said that gold was one of the first metals to be mined. As deposits with free, coarse gold were depleted and the volume of mining increased, process flowsheet design became more and more complicated. Gravity was the first method developed to recover gold from ore. But, currently there are very few deposits left that contain ores suitable for gold recovery strictly by this method. Cyanide leaching now recovers the greatest amount of gold and contributes to a variety of flowsheets from heap leaching to agitated leaching circuits. Newly discovered deposits are often more refractory and resist these methods. Ores in which gold is locked with sulfides are processed by combining flotation with other methods.

To recover gold from sulfide concentrates, roasting or oxidation can be performed first, followed by cyanide leaching. Direct cyanidation of flotation concentrate can often encounter problems. Numerous methods are available for oxidizing flotation concentrates, including biological oxidation, pressure oxidation in autoclaves, roasting, as well as proprietary processes, such as Albion and Leachox. All of these processes bring higher capital and operating costs while each has benefits, disadvantages and limitations. There is no method that can be applied for all types of feed (ore or concentrate). The optimal process flowsheet is selected after analysing the results of a detailed testwork program which evaluates the relative merits of each method.

Another factor that contributes to the complexity of processing gold ores is the presence of adsorption-active substances that trap dissolved gold and carry it with the tailings, i.e. 'preg-robbing'. This is one of the most challenging type of ore. To avoid these traps, the flowsheet designers use methods for separating adsorption-active substances from ore as early in the process as possible.

The collection of samples for metallurgical testwork is also an important procedure. The samples must reflect the full range of characteristics expected throughout the deposit. The geologist, mining engineer and metallurgist need to collaborate to ensure an adequate number of samples are collected for testing. An error at this stage in the project can be very costly if the plant does not meet design criteria during the early, payback period of the mine life. Designing and selecting the optimal process flowsheet is the result of a well-planned testwork program, some creativity and the knowledge a metallurgist has gained from practical experience on similar projects.

Dmitry Yermakov:
dyermakov@srk.ru.com

How process optimisation can improve the bottom line

The mining industry continues to practice using 'operational silos' where different parts of an organisation work in isolation to achieve goals that only affect themselves. While this may keep costs from getting out of hand for their narrow segment of the mining process chain, it can have devastating effects on the overall bottom line. This issue is commonly ignored as, very often, different groups have different opinions on what's important.

Essentially, a mine is a 'metal manufacturing process' where what matters most is overall cost per tonne to deliver a saleable product. So why is it so hard to get everyone 'singing from the same page', so to speak?

In the mining industry, the customer-supplier (mill-mine) relationship is hampered by two issues: the customer is not clear and consistent in communicating what's important to them, and the supplier does not know how to deliver it.

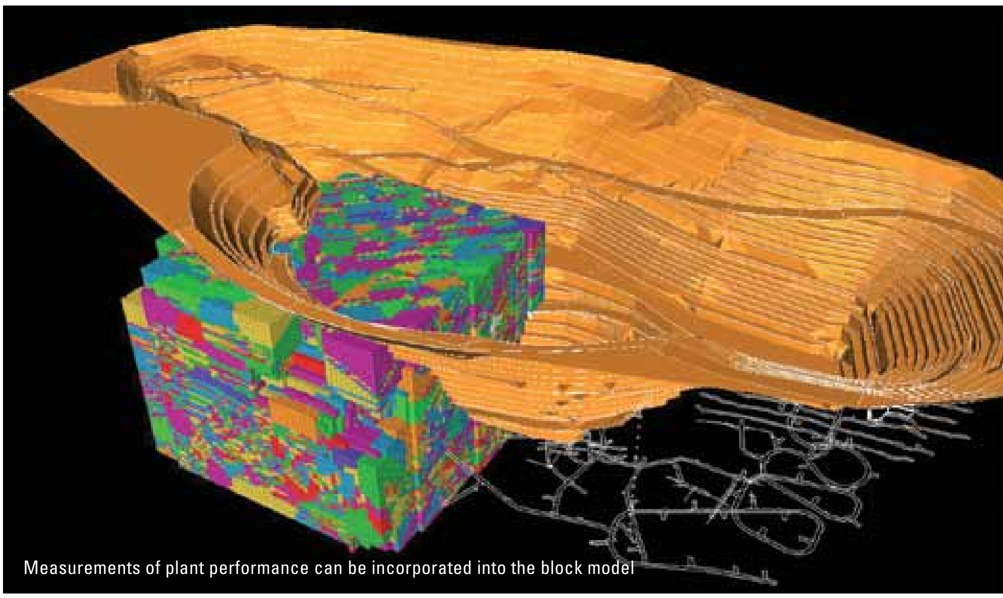
Process optimisation can help all the 'singers' understand how a better quality mill feed affects overall economics. Take blasting. Blast fragmentation can strongly affect mill throughput – particularly for autogenous or semi-autogenous grinding circuits.

Finer blast fragmentation can increase mill throughput by 20 to 30% or reduce the specific energy requirements (kW per tph) by 30%. Although changes in blasting practices can increase drill and blast costs by up to 50%, they can reduce mill operating costs by as much as 4 to 10 times. (See the first article in this newsletter on how mill throughput can be improved.)

SRK can perform benchmarking reviews of existing operations and provide clear indications of the benefits of such a process optimisation study. This benchmarking can involve the use of modelling and simulation tools to examine what-if scenarios and show the effect of changes upstream on downstream performance. Such simulation results can justify making operational changes as they can estimate the potential for efficiency gains.

It is also possible to include estimates of plant performance (tph, $/t, kWh/t, recovery, concentrate quality, etc.) in the resource block model. These tools can be used to improve the mine planning/scheduling process and provide a more accurate estimate of plant production.

Adrian Dance: adance@srk.com



Measurements of plant performance can be incorporated into the block model

Geometallurgy: increasing orebody value

Geometallurgy has been described as a 'comparatively young analytical field that aims to bridge the gap between geology and metallurgy'. By that definition, the principles behind geometallurgy have always been best practice in metallurgical process development: developing an understanding of the metallurgical response of an orebody in the context of the deposit or making sure the geologists and metallurgists talk to each other!

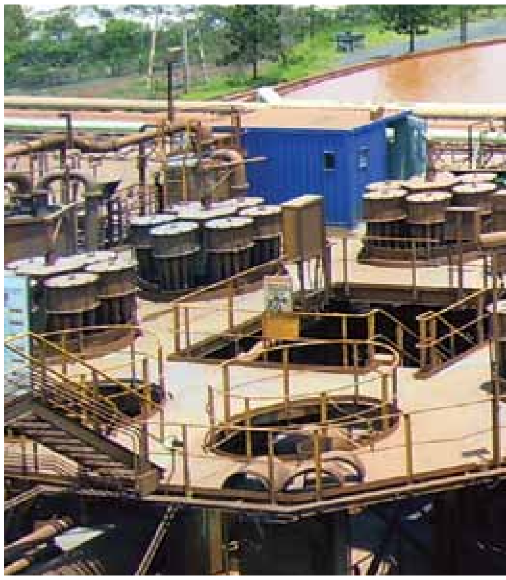
What has brought the principles behind geometallurgy into recent focus has been the desire to incorporate metallurgical data – such as ore hardness and leaching and/or flotation recoveries – into the scale of the geological block model. New analytical techniques and test procedures allow technicians to determine metallurgical responses from smaller samples that can readily be accessed during an exploration program, thus allowing metallurgical parameters to be estimated very early in the project's development. Such techniques include automated mineralogy (e.g., QEMSCAN, Mineral Liberation Analyser), AG/SAG mill ore breakage tests, (e.g., SPI, SMC), and standardised batch scale flotation tests, which many commercial laboratories have developed in-house. These techniques can be readily applied to diamond drill core samples. They add to previous techniques that inherently work well on the small scale, such as the Bond Work Index for ore hardness and Davis Tube assays for magnetite.

Many of the larger commercial laboratories provide a geometallurgical service, which involves the initial establishment of the orebody's behavior through larger scale testwork conducted on a number of composite samples, followed by small scale testwork on drillhole interval samples. 'Full-scale' behavior is estimated by correlating small scale results with the larger scale testwork conducted on the composite samples. This behavior, determined on a drillhole interval scale, then adds input data to the resource model, to assist with mine planning and the technical and economic modelling of the deposit.

SRK's geologists, metallurgists and geochemists have collaborated on a number of geometallurgy projects covering base and ferrous metals and gold, as well as platinum group metals, uranium and rare earth elements, on projects located in Africa, North and South America, Europe and the FSU.

John Willis: jwillis@srk.co.uk

Bowell RJ, Grogan J, Hutton-Ashkenny M, Brough C, Penman K, and Sapsford DJ, 2011: "Geometallurgy of uranium deposits", Minerals Engineering, v. 24, p. 1305-1313.



Processing plants are designed according to metallurgical tests performed on composite samples and the range of recoveries is explored by testing composites for variability. Nevertheless, the day-to-day activities of a mining operation are more dynamic than ever and every project has its range of ore variability.

Mill performance changes may be due to feed variations or deliberate design changes. The feed may change due to natural ore variability; fluctuations in ore blend may occur because of mine scheduling or unplanned changes, such as equipment shutdowns. The plant may add a new unit operation and make minor equipment modifications and, despite all optimisation efforts, the plant may not be performing as expected.

Mineral processing is complex and combines a sequence of interlocked unit operations, each affecting the performance of downstream processes, as well as impacting the overall mill performance. However,

Plant benchmarking: an opportunity for sustained efficiency

sometimes the benefit of optimising a single unit operation may be eclipsed by the losses in other circuits, as mineral processing can be counterintuitive, even for the most experienced plant operator. What should be done when this happens? How about plant benchmarking?

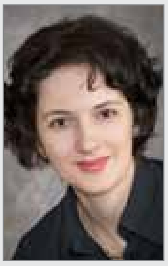
Benchmarking is a good practice designed to detect issues with plant performance and guide the operation in planning improvements. Plant benchmarking may comprise a full plant audit with historical review and process modelling. Systematic sampling across the mill will provide mass, constituent and water balances, and a careful look at plant survey data will help identify bottlenecks and opportunities for process optimisation. A historical review of operational and geological data will add to the understanding of site challenges and help to determine optimisation strategies.

Process modelling can facilitate the evaluation of circuit alternatives for improved overall efficiency. The use of simulation tools will enable the analyses of different scenarios more economically than plant trials, and it can also assist in developing process control strategies and team training in operations. When geological data are combined with mill performance analysis, the information generated can be used to optimise mine scheduling, blend definition, throughput and mill efficiency; thus optimising the overall project profitability.

SRK realises the challenges faced by the mining industry, including a shortage of technical personnel. Quite often, the operations team does not consider the mill as a whole, and plant optimisation efforts end up generating more frustration than positive results. SRK can assist operations in getting the best use of their knowledge and build on it, by offering site support for plant benchmarking, process optimisation, integrated planning and personalised training.

Denise Nunes: dnunes@srk.com

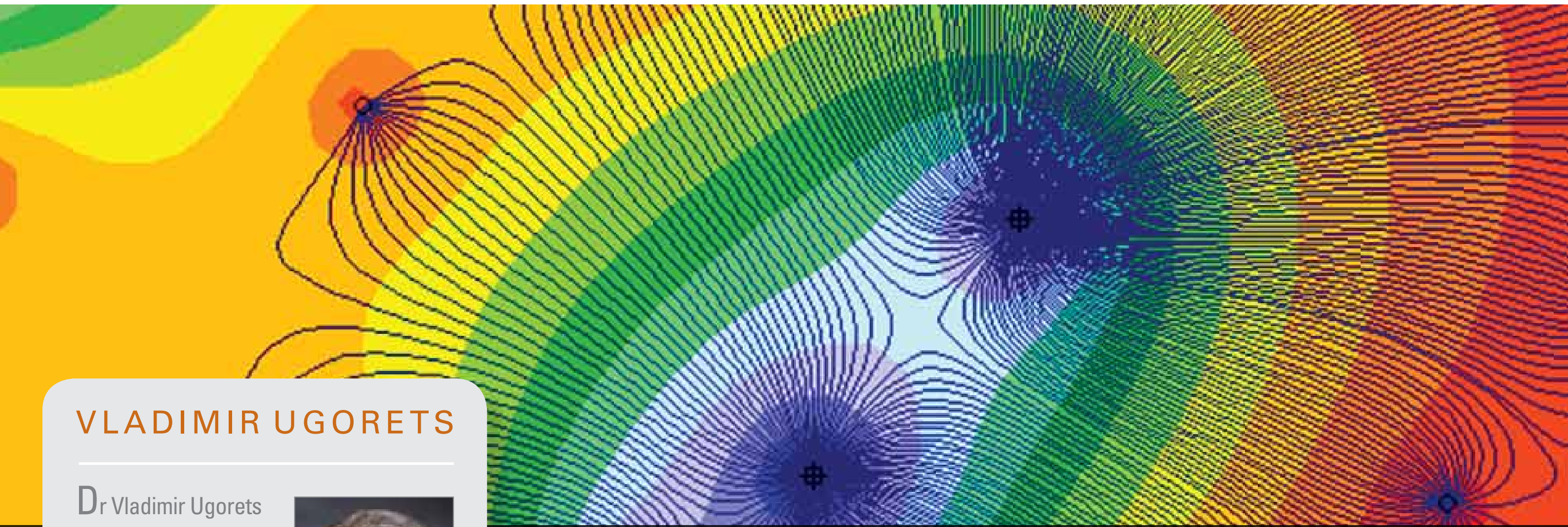
DENISE NUNES



Denise Nunes, Senior Consultant (Metallurgy) with SRK Vancouver is a Mining and Mineral Processing Engineer with over 10 years of experience in geometallurgy programs, flowsheet design and optimisation. She has been involved in projects in South and North America as a consultant, working with research and development and gold operations.. Denise's strengths are based on her solid knowledge of process mineralogy, flotation and gold processing, allowing her to integrate geological information with metallurgical data to better predict mill performance.

Denise Nunes:
dnunes@srk.com (Vancouver)

In situ leaching or in situ recovery



ISL model showing streamlines from injection to production wells

VLADIMIR UGORETS

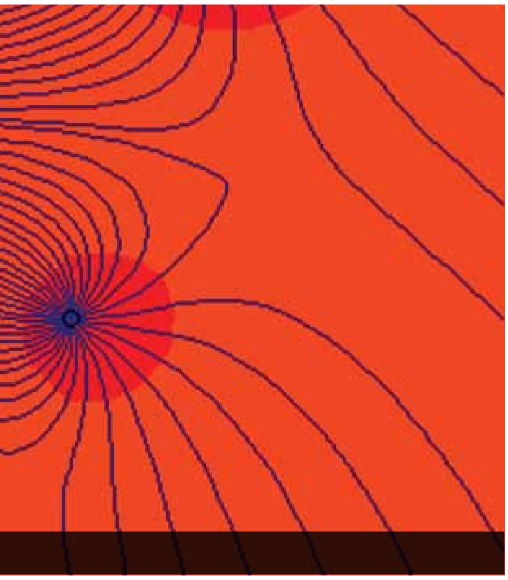
Dr Vladimir Ugorets is a Principal Hydrogeologist in SRK's Denver office, where he has worked since 2007. He has more than 34 years of experience in mining hydrogeology and groundwater flow modelling. Vladimir has been involved in hydrogeological evaluation, groundwater flow, and reactive solute transport modelling for numerous in situ recovery projects in Russia, Kazakhstan, and in Wyoming, Colorado, and South Dakota, USA. These projects are identified as Khiagda, Akbastay, Zarechnoye (Atomredmetzoloto), Smith Range (Cameco), Dewey-Burdock and Centennial (Powertech Uranium Corp.), among others.

Vladimir Ugorets:
vugorets@srk.com (Denver)

In situ leaching (ISL), also known as in situ recovery, is a low capital-cost method of extracting uranium, copper or potash from suitable deposits. A suitable deposit is one where the commodity is located in saturated permeable horizons or distinctive geological areas that are bounded above and below by impermeable strata. Either acid or alkaline solutions can be used to dissolve the metal, depending on the chemical conditions present.

ISL is most commonly used in sandstone roll-front uranium deposits, though it can also be applied to paleochannel deposits and, potentially, to some calcrete hosted deposits as well. In Kazakhstan, the largest uranium producing country, the majority of the mines use ISL techniques with sulfuric acid to dissolve the uranium. Acid is also used in Russia and Australia, but due to higher carbonate content, alkaline sodium carbonate solutions are preferred for ores in the United States. The approach of ISL mining is broadly the same for both acid and alkaline leaching.

At the Khiagda project in Russia, where uranium is found in a series of paleochannels, SRK developed a reactive



transport model coupling hydrogeological and geochemical capabilities to predict the dissolution of uranium with time. This model predicted flow paths and lixiviant or leaching streamlines from injection to recovery wells (see figure above) and used a popular software developed for the US Geological Survey computer program to evaluate the variability in uranium concentration, speciation and attenuation in the flow paths. The model was calibrated against actual field results, then used to evaluate the productivity of different well-field patterns. The results were used to define the production schedule for four paleochannels for the next ten years.

At the Zarechnoye project in Kazakhstan, SRK developed a 3D geological model to define not only the boundaries, thickness and grade of the roll-front deposits, but also the variation in disequilibrium. This helped to explain some of the variability in leaching rates, which would then assist with trials to improve efficiencies.

Vladimir Ugorets: vugorets@srk.com
Dmitry Yermakov: dyermakov@srk.ru.com

Leach circuit design principles

Designing a leach circuit should consider both ore-specific factors as well as factors involving the interaction between the ore and process equipment.

Achieving the optimum leach performance involves combining operating parameters, such as grind size, residence time, chemical conditions (reagent addition levels, temperature, etc.), most of which interact with each other. Determining the optimum process conditions should be the objective of any metallurgical testwork program. Processes that are either relatively straightforward or are well understood, such as cyanide leaching of "free milling" gold, can be characterised on the basis of laboratory scale testwork. However, more complex or novel processes will require progressive stages of testwork, from laboratory to continuous pilot plants, to prove up and optimise the process ahead of plant design.

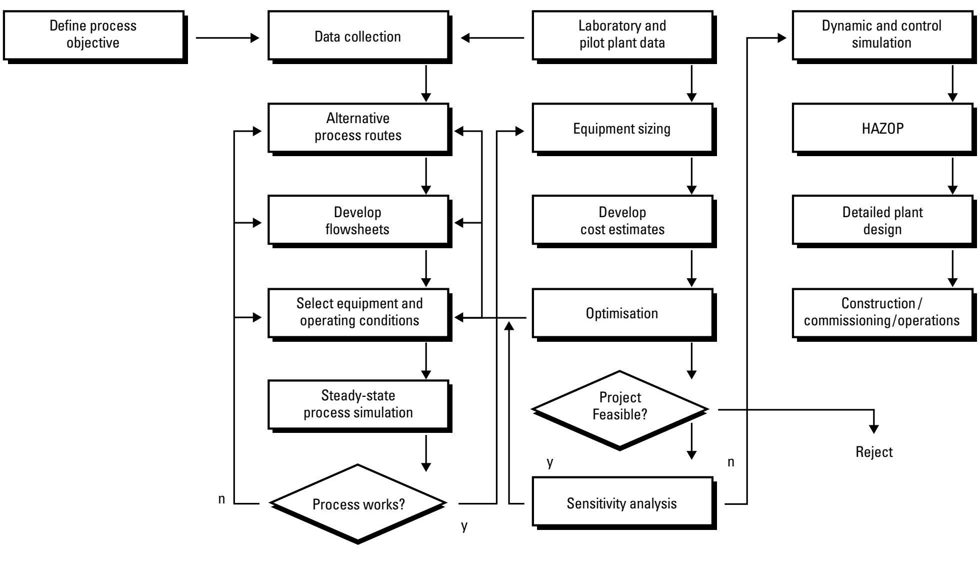
Grind size is usually the key process parameter in a leach plant, as grinding represents the highest energy input and cost element in the overall process. Sufficient grinding is required to expose the target minerals to the leach solution; the optimum grind size can range from the order of 1mm for minerals such as potash down to less than 10 microns for refractory sulfide minerals. There is some scope to offset grind size against residence time and/or reagent levels; the grind size also has impacts on material handling, such as agitator power for coarse grind sizes, and downstream thickening and filtration for fine grind sizes.

The tank material of construction (e.g., carbon steel, stainless steel, other metal alloy or non-metallic) is a function of the chemical and physical interaction between the ore and the process equipment. Agitator design is determined by whether the aim of the agitator is to simply keep the material suspended or the need for efficient introduction of air/oxygen for the leach reaction.

The technical aspects of designing the leach circuit fall within the overall project design activities, as shown in the diagram below. Key aspects of the overall design picture include the initial definition process, process selection through testwork and simulation, cost estimation and financial analysis, leading to the final design, construction and commissioning.

John Willis: jwillis@srk.co.uk

Typical process design flowchart



Yellowknife gold project

Tyhee Gold Corp., through its 100% owned subsidiary, Tyhee NWT Corp., commissioned a feasibility study for its Yellowknife Gold Project located in the Northwest Territories, Canada. The feasibility study was prepared by a team of consultants that included SRK Consulting (U.S.), Inc, Lyntek Incorporated, Knight Piésold and Co. and EBA, a Tetra Tech Company. The feasibility study and NI 43-101 technical report were issued on schedule during September 2012 and demonstrated proven and probable ore reserves of 20 million tonnes at an average grade of 2 g/t Au.

As part of this study, SRK designed and supervised a feasibility-level metallurgical development program that was conducted on master composites and variability composites from the Ormsby, Nicholas Lake and Clan Lake ore deposits. Based on these studies, SRK recommended a process flowsheet that includes:

- three-stage crushing
- ball mill grinding
- gravity concentration of the coarse gold
- gold flotation from the gravity tailings
- cyanide leaching of gold flotation concentrate
- cyanide detoxification of the cyanidation residue
- tailings thickening

In the SRK-recommended process flowsheet, gravity concentration of coarse gold values followed by flotation of the remaining gold values into a flotation concentrate results in a very compact process plant in which only five weight percent of the initial ore is subjected to cyanidation.

Gold recoveries for Ormsby, Nicholas Lake and Clan Lake have been developed from the results of both locked-cycle testwork and from bulk gravity/flotation tests that were conducted on each of the test composites to produce flotation concentrates for regrind and cyanidation testwork. Gold recoveries for the Ormsby and Clan Lake deposits are projected at 92% and gold recovery for the Nicholas Lake deposit is projected at 82%. Additional testing is planned for the Nicholas Lake deposit to further assess ore character and process parameters that could potentially increase gold recoveries for the Nicholas Lake deposit.

SRK would like to thank Tyhee for their permission to discuss the Yellowknife Gold Project in this edition of SRK News.

Eric Olin: eolin@srk.com

OXIDATION
Remediation Process
Bio-oxidation (Bacteria)
Catalysis
Electro-Oxidation
Electro-Chlorination
Alkaline-Chlorination
Oxygen
Ozone
Hydrogen Peroxide
Hydrogen Peroxide/Cupric
Hydrogen Peroxide/Kastone
Caro's Acid
Sulfur Dioxide (INCO)
Direct Photolysis
Photolytic Ozonation
Photolytic Peroxidation
TiO_2 Photocatalysis

The environmental impacts of mining operations are currently a major focus of attention. The traditional flowchart of gold ore processing involves the use of cyanide solutions, and generates cyanide-containing tailings.

There are many methods which achieve the destruction of cyanide in tailings. In many countries, the limits of environmental impact are established for industries. In addition, international conventions such as the Cyanide Code impose limitations. Post-USSR standards known as the Maximum Allowable Concentrations are still valid within many CIS countries including Russia, and are among the most stringent standards in the world.

Along with free cyanide, current Russian standards establish criteria for thiocyanates, which are not regulated in most countries. These rules apply rigorous requirements to the cyanide destruction cycle. Some methods commonly used all over the world are rarely used in Russia.

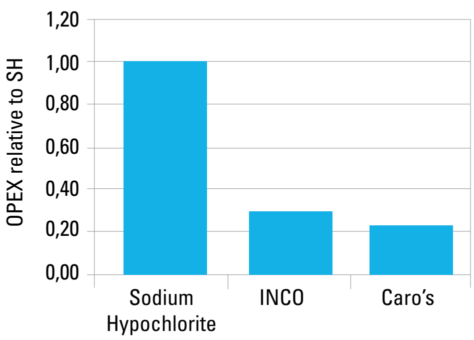
Cyanide destruction

OXIDATION EFFECTIVENESS						
Free Cyanide	**Thiocyanate**	**WAD Metal Complex (weak acid-dissociable)**		**SAD Metal Complex (strong acid-dissociable)**		**Need Further Treatment**
		Cd/Zn	**Cu/Ni**	**Fe**	**others**	
yes	yes	most	most	yes	yes	little
yes		yes	yes	no	some	yes
most	yes	most	most	no	no	yes
yes	yes	yes	yes	no	no	yes
yes	yes	yes	yes	no	no	yes
yes	some	some	no	no	no	yes
yes	yes	yes	yes	no	no	yes
yes	no	yes	some	some	no	yes
yes	no	yes	yes	yes	no	some
yes	no	yes	yes	yes (ppt)	no	some
yes	yes	yes	yes	yes	no	little
yes	some	yes	yes	yes (ppt)	most	little
no	no	no	some	yes	some	yes
yes	yes	yes	yes	yes	yes	no
yes	yes	yes	yes	yes	yes	no
yes	yes	yes	yes	yes	yes	no

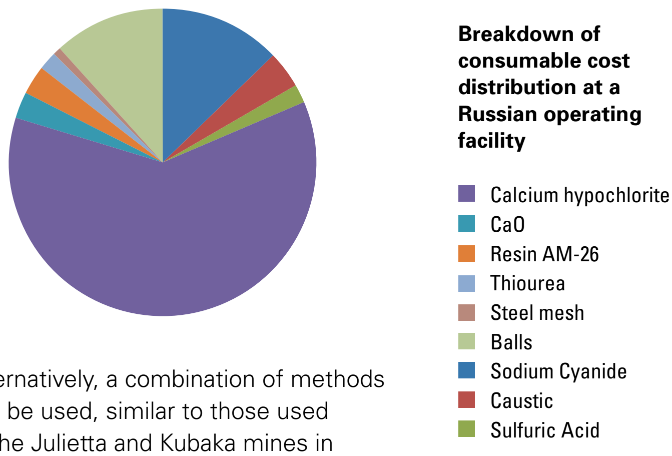
Cyanide destruction methods

(Source: Cyanide remediation: Current and past technologies. C.A. Young and T.S. Jordan, Department of Metallurgical Engineering, Montana Tech, Butte, MT 59701) May 1995

One such method is the INCO process (shown in the list of cyanide destruction methods in the table above), which does not decompose thiocyanates completely. Extreme climate and complicated logistics limit the use of the method based on Caro's acid. Practically all operating and planned production facilities in Russia use the method based on sodium hypochlorite, but this method imposes significantly higher operating costs (see graph below for comparative costs).



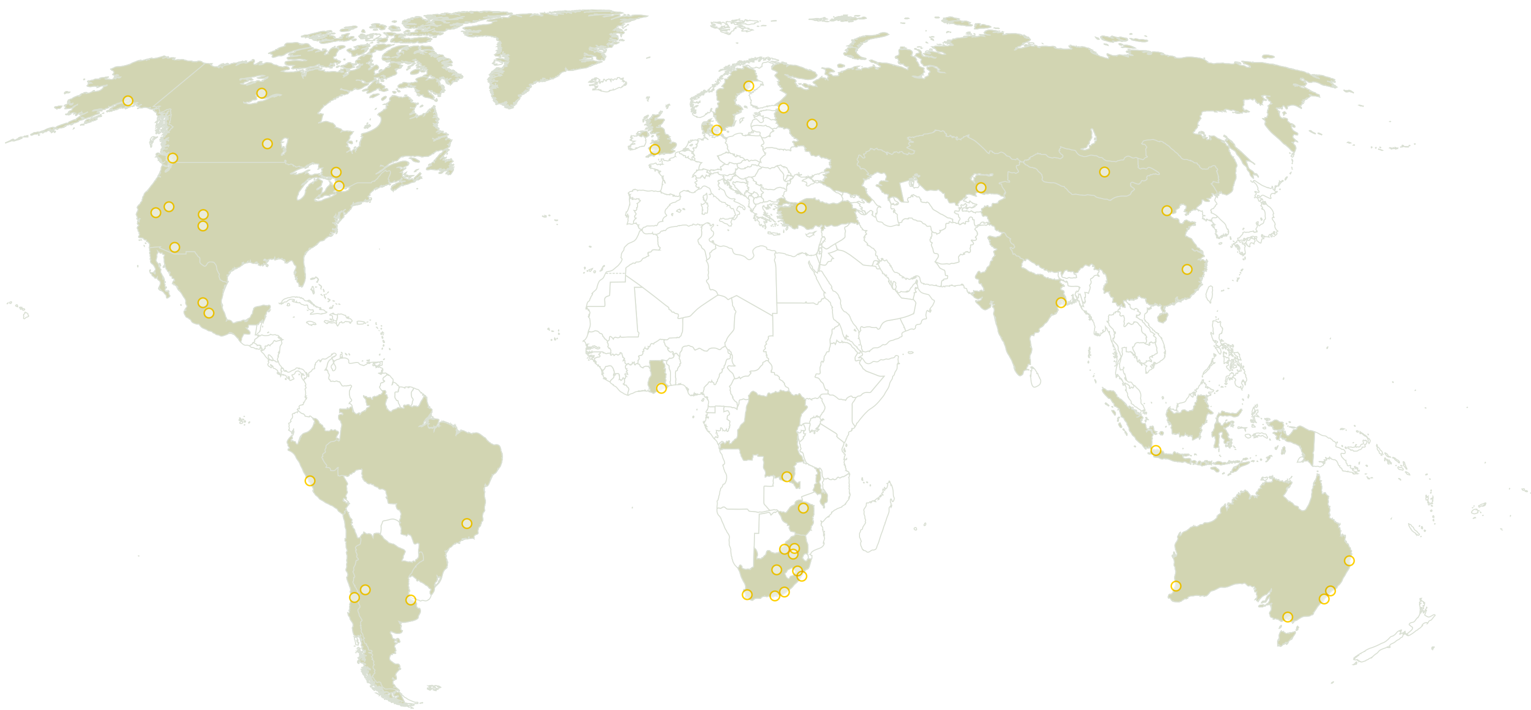
Comparative operating costs for different methods of cyanide destruction



Breakdown of consumable cost distribution at a Russian operating facility

Alternatively, a combination of methods can be used, similar to those used at the Julietta and Kubaka mines in Russia. Using closed water circulation at the processing plant reduces the cost of dewatering. This approach can also help reduce operating costs (see breakdown of consumable costs in figure above). SRK performs audits of operating facilities and facilities still under construction for compliance with the International Cyanide Management Code requirements, and plays an active role in promoting alternative methods of cyanide destruction.

Dmitry Yermakov: dyermakov@srk.ru.com



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