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ALTA 2020 In-Situ Recovery Conference

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Application of ISR to Copper Forum

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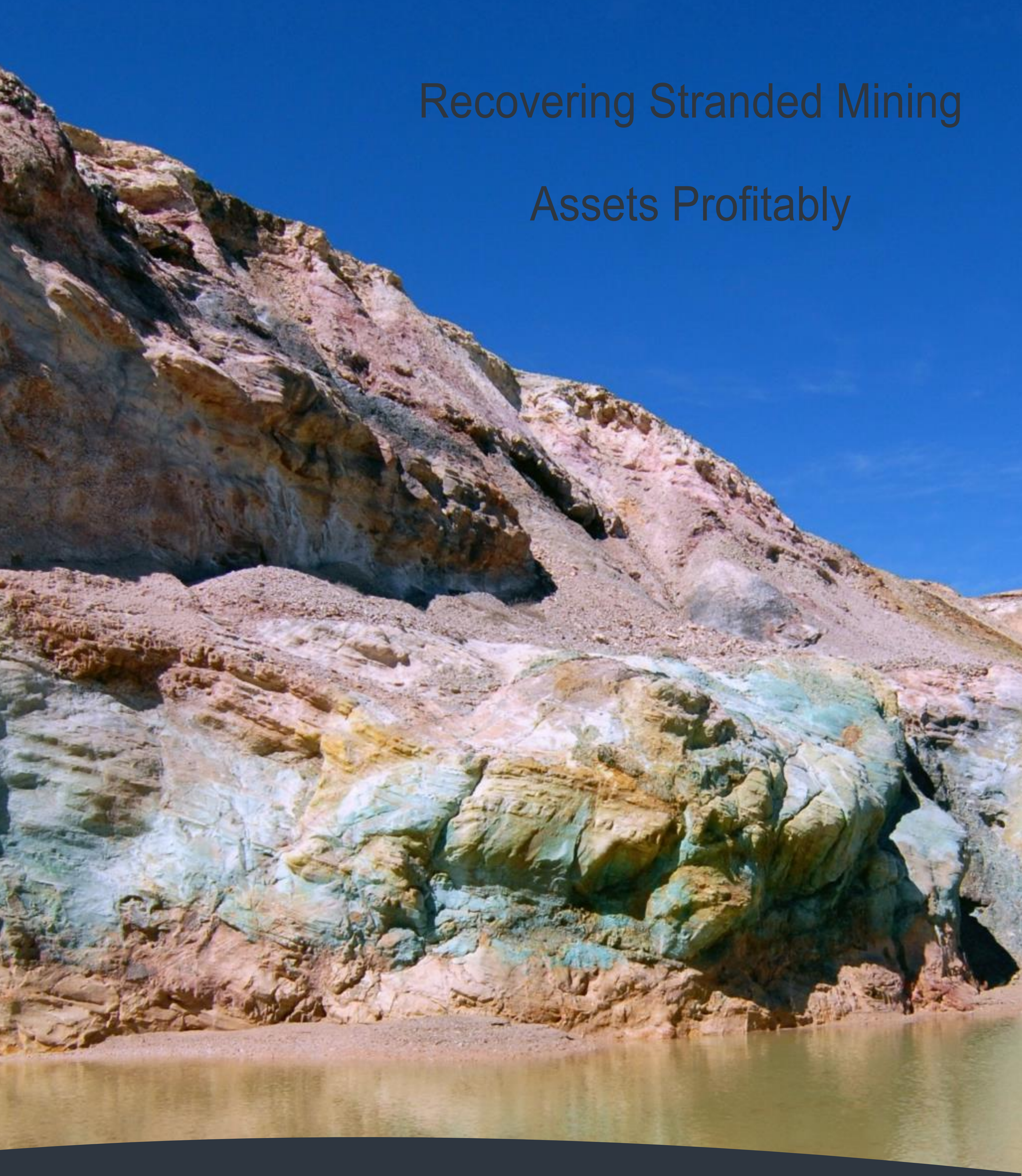

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Alan Taylor has over 40 years' experience in the metallurgical, mineral and chemical processing industries in Australasia, New Zealand, North and South America, Africa, Asia and Europe. He has worked in metallurgical consulting, project development, engineering/construction, plant operations, plant start-up and technology development. Projects and studies have involved copper, gold/silver, nickel/cobalt, uranium and base metals.

Since 1985, as an independent metallurgical consultant, Alan has undertaken feasibility studies, project assessment, project development, supervision of testwork, flowsheet development, basic engineering, supervision of detailed engineering, plant commissioning and peer reviews and audits. Clients have included a variety of major and junior mining, exploration and engineering companies throughout Australia and overseas.

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In-Situ Recovery Proceedings

Keynote Address

OPPORTUNITIES AND CHALLENGES FOR COPPER ISR - KAPUNDA CRC-P AS AN EXAMPLE

By

Leon Faulkner
Managing Director
EnviroCopper Ltd (Australia)

Philippa Faulkner
Business Manager
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ABSTRACT

EnviroCopper subsidiary, Environmental Copper Recovery Pty Ltd (ECR), commenced research into potentially the first Australian fractured rock Copper ISR project in 2017, 90kms north of Adelaide at the historic mining site of Kapunda in South Australia. Initial investment came from junior Thor Mining PLC then in 2018 ECR received a Cooperative Research Centre Project (CRC-P) Grant from the Commonwealth Government of Australia for $2.85 million to take the project forward.

Presenting at ALTA 2019, ECR introduced the research aims and objectives of primarily advancing ISR as a technique that can be applied to a far wider range of deposits than previously thought, opening up a potentially significant number of previously stranded assets to profitable, low impact recovery. In the last few years ECR have seen a significant increase in interest from all sectors of the mining industry ranging from the juniors to major mining companies in investigating the potential of ISR to work effectively on some of their deposits. It is becoming apparent that there are significant number of potential ISR opportunities both within Australia and throughout the world that might be taken forward, if a suitable path in the technical, regulatory, and social license space can be found.

EnviroCopper understand the significance of this project for the mining industry and the responsibility of establishing a “template” for industry to undertake future projects. The Kapunda project has significantly advanced since last ALTA meeting with many positive technical results, however, like other similar copper projects in the world, it is clear that the path forward for ISR projects in the regulatory, investor and community spaces is currently not quite as smooth as it could be. Most of these issues revolve around education and enabling greater understanding of the ISR process and its potential impact on the environment.

South Australia has 2 permitted Uranium ISR projects, with an established regulatory framework to deal with this technique and commodity, however, the framework for regulation of uranium ISR is not necessarily a perfect fit for copper (or other metal commodities). It is becoming increasingly apparent that there needs to be some consultation on the regulatory framework for ISR of metals other than uranium that involves the different levels of state and local government and the various acts and departments that are involved in approving potential ISR operations. (382 words)

Keywords: Cooperative Research Centre - Project (CRC-P), Stranded assets, Social License to Operate, Environmental mining, Copper ISR, Innovation

In-Situ Recovery Proceedings

Application of ISR to Copper Forum

COMMUNITY PERCEPTIONS OF POTENTIAL NEW COPPER MINING, KAPUNDA, S.A.

By

Tom Measham, Simone Felton and Andrea Walton

CSIRO Land and Water, Australia

Presenter and Corresponding Author

Tom Measham

ABSTRACT

This presentation summarises findings of social research that investigated how residents of Kapunda, South Australia view the mining sector and their town identity and the extent to which a potential renewed mining industry using ISR methods would align to existing values. The research is based on qualitative analysis of focus group data collected in Kapunda in 2019. Using a social licence framework, the research explored the inter-relationships between different factors that contribute to trust in and acceptance of new technology used in the extractive industries.

The framework considers impacts and benefits, procedural fairness, distributional fairness and confidence in governance. The qualitative methods employed in this research enabled a deep understanding of the different issues and dimensions that participants consider when weighing up a potential new technology and development. The research provided a deliberative process for participants to reflect on and share their perspectives on perceived concerns and opportunities related to in-situ recovery (ISR) and the mining industry in general. The research demonstrated that ISR was seen as offering potential for the town's future. Data highlighted several tangible and intangible benefits.

Participants indicated that putting Kapunda 'on the map' as the first Australian ISR copper mine was appealing and resonated strongly with the town's historical identity as the country's first ever copper mine. The study also raised perceived concerns and issues, around visual amenity and disruption to a historic site. The degree to which a new ISR mining operation in Kapunda would be ultimately accepted depends on following a rigorous, evidence-based research and assessment process and maintaining transparent communication to show that any potential environmental impacts were understood and managed effectively.

Keywords: social licence, ISR, regional identity, mining heritage

IN-SITU RECOVERY OF COPPER COMES OF AGE

By

Alan Taylor

ALTA Metallurgical Services, Australia

Presenter and Corresponding Author

Alan Taylor

ABSTRACT

In-Situ Recovery (ISR) is now a mature technology for uranium recovery. Developed in USA and USSR in the 1950-60s, it now accounts for nearly 50% of the world's production. Current project developments indicate that copper ISR is now coming of age.

Copper in-place leaching has a long history. Since the 1950-60s it has been applied to low-grade oxide and sulphide ores on flat terrain, on hillsides, and in pre-existing open cut and underground mines, particularly in the USA. The ore was generally broken by blasting and the solution was allowed to percolate down through the ore and collected at the base with recovery by cementation with scrap iron. A more recent example is the bioleaching system for sulphide ore operated by Gunpowder Copper at their underground Mammoth Mine in Queensland, Australia, in the 1980-90s, with recovery by SX-EW. Large-scale well to well ISR, as practised in the uranium industry, was successfully applied to partially rubblized supergene rock at San Manuel, Arizona in the 1990s – the first application for copper recovery.

Copper ISR is now coming of age with two major well-to-well type projects moving into commercial operation. Excelsior Mining has commenced wet commissioning of their Gunnison ISR-SX-EW project and Taseko Mines are operating the first Phase 1 production ISR-SX-EW facility for their Florence project. Both projects are in Arizona. Environmental Copper Recovery are developing potentially the first Australian first fractured rock copper ISR project in South Australia.

In addition, the application of in-place leaching technology to new hard rock mines, called in-mine recovery (IMR), is being proposed. Drivers include lower cost and alleviation of environmental and social acceptance issues due to significantly reduced surface facilities, tailings, footprint, and energy and water requirements.

Keywords: In-Situ leaching, ISR, in-place leaching, in-mine recovery, IMR, copper

US BUREAU OF MINES SANTA CRUZ IN SITU COPPER MINING PROJECT AND PROGRAM

By

[1]Drummond "Dusty" Earley III and [2]Frank F. Roberto

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Presenter and Corresponding Author

Drummond "Dusty" Earley III

ABSTRACT

The United States Bureau of Mines (USBM) conducted research and development from 1911 to 1996 with the mission to protect the health and safety of miners and ensure the supply of critical and strategic minerals for the US. The USBM was one of several agencies and other organizations that promoted the development and commercialization of in situ recovery (ISR) of uranium which was one of many realizations of its mission. From the 1970s through 1996 the USBM initiated a strategic program to develop and commercialize in situ copper recovery following the commercialization of the in situ uranium mining industry. The primary target for ISR development was copper oxide ore deposits that were uneconomical to mine using conventional mining methods as a result of low grade or deep depth of the deposit. The Santa Cruz ISR copper project became the focus of the USBM's program but also led to ISR technologies for copper sulfides and other base metals, manganese, precious metals and other commodities. The Santa Cruz project was conducted as cooperative research and cost sharing program between the USBM and the Santa Cruz Joint Venture (JV, i.e. ASARCO and Freeport McMoRan). Other government, university, and private entities also contributed important, multidisciplinary research efforts in association with the field project to solve the technical hurdles of ISR. Turnkey technology development thrusts were conducted in the areas of: hydrologic characterization and fracture flow; solution flow and reactive transport modeling; hydrometallurgy, lixiviants and biotechnology; geologic, geochemical and microbiological characterization of ore deposits; rock fragmentation and geomechanics for permeability enhancement; enhanced drilling, wellfield technology, solution containment and neutralization; geophysical tracking of solution movement, plus economic evaluation and cost modeling for ISR. In addition, the USBM worked closely with federal, state, and local officials and stakeholders to develop a permitting framework for copper ISR to ensure the protection of groundwater and other natural and cultural resources. The USBM also launched an outreach program to educate the public on the importance of mining technology research and ISR technology. Attaining social license to operate remains one of the major hurdles to any ISR project.

Prior to its closure in 1996, the USBM conducted a brief pilot test of ISR copper recovery and processing with a pilot scale solvent extraction - electrowinning plant. At the same time another abbreviated, pilot scale in situ copper sulfide mining experiment was conducted successfully at the Mineral Park Mine located in northwestern Arizona. Despite the untimely closure of the USBM and these projects, the resulting data and results contributed: 1) safe, economical and sustainable best practices for ISR copper recovery, 2) technologies for in situ groundwater restoration and remediation, and 3) evidence that ISR can reduce mining wastes and long term pollution potential from metal mines. The eventual exhaustion of shallow and readily processed mineral resources and the need to reduce the associated production of larger and larger volumes of mining wastes has since increased interest in ISR in the past two decades since closure of the USBM. Key results and lessons learned from these projects are presented.

Keywords: In situ Recovery (ISR); copper; Santa Cruz, hydrology, well, hydrometallurgy; geomechanics; permeability enhancement; solution treatment; economics; permitting

HIGH-RESOLUTION X-RAY COMPUTED TOMOGRAPHY STUDY OF COARSE LEACHED PARTICLES FOR IN-SITU RECOVERY APPLICATIONS

By

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Presenter and Corresponding Author

Laura Kuhar

ABSTRACT

In-situ recovery (ISR) refers to the injection of a leach solution into an ore deposit for metal dissolution, and the recovery of the solution at the surface for further processing. To establish the leaching characteristics of samples for conventional processing (such as open pit or underground mining plus tank leaching), finely milled material is often used in laboratory bottle roll leach tests and solid residues and solutions are analysed post-leaching by using techniques such as elemental analysis, (quantitative) X-ray diffractometry and scanning electron microscopy. In ISR, fluid contacts ore at a much coarser scale than may occur, for example, in tank leaching, and as such, initial laboratory experiments to evaluate the ore amenability to ISR and the ideal ISR conditions should be conducted on coarser samples, to simulate the ISR environment. Besides the analytical techniques mentioned previously, an additional valuable tool to understand the three-dimensional morphological and compositional changes that coarse particles experience when leached is high-resolution X-ray computed tomography (which may be used in conjunction with scanning electron microscopy).

In this work, two unrelated samples sets were studied pre- and post-leaching to understand the behaviour of coarse particle leaching as may occur in an in-situ leach. First, (i) sulfuric-acid leach tests were conducted on individual sub-6.3-mm particles from a vanadium–titanium deposit to understand the mechanism by which the leaching occurs. Second, leach tests were conducted on (ii) cubes (4-mm sides) that contained copper sulfides (chalcopyrite, bornite and chalcocite) under anoxic conditions in ferric chloride/hydrochloric acid solutions for 5 and 30 days between 90°C and 110°C. The individual vanadium–titanium particles or copper sulfide cubes were characterised pre- and post-leaching by using high-resolution X-ray computed tomography with quantitative scanning electron microscopy to understand the extent of leaching of different minerals in individual grains and changes to the particles or cubes.

Leaching results from the vanadium–titanium samples showed that titano-magnetite was more affected by leaching than ilmenite and, as expected, those minerals that were located closest to the outer particle boundary were leached most. Leaching occurred by a shrinking-core mechanism or by access via cracks or grain boundaries. Adjacent grain boundaries did not necessarily leach to the same extent, which implies that the crystal boundaries may affect the leaching.

The copper-containing cubes showed a replacement of the initial solid by copper-enriched secondary sulfides and sulfur as a final product. The solids showed an increase in void space and changes in the textural characteristics of the transformation products. Replacements also followed access zones, and the number of fractures and their size increased after the reaction.

The outcomes from this work show the value of combined high-resolution X-ray computed tomography and quantitative scanning electron microscopy to understand the leaching behaviour of coarse materials. More broadly, results from this study may be relevant to other processing applications, including heap and vat leaching.

Keywords: in-situ recovery; coarse particle leaching; high-resolution X-ray computed tomography; vanadium–titanium ore; copper-containing ore; three-dimensional morphological change

In-Situ Recovery Proceedings

Environmental

IN SITU RECOVERY (ISR) – THE PERMITTING CHALLENGE

By

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Presenter and Corresponding Author

Doris Hiam-Galvez

ABSTRACT

In situ recovery (ISR) offers many potential benefits over conventional surface and underground mining methods for some ore bodies, including improved economics and reduced social and environmental impacts.

ISR recovers valuable minerals via leaching with lixiviants, leaving the host rock in place. This avoids the capital and energy intensive recovery methods of conventional mining and reduces surface disturbances associated with waste rock piles and tailings facilities. The technology has been applied successfully for commercial mining of uranium and potash over the last several decades, as well as a few copper operations in the 1980's and 1990's, with ongoing research to commercialize its application to copper and gold deposits, where less permeable host rock creates challenges.

The commercial success of ISR has been supported by advances in the technologies that allow its safe and environmentally responsible implementation, including techniques for hydrological modelling and mapping of the ore body, containment of fugitive lixiviant, monitoring ground water quality, and other risk mitigation methods. Despite these advances ISR is sometimes viewed with suspicion by the general public and regulators alike, possibly due to the relative novelty of ISR and its associated risk mitigation technologies compared to conventional mining.

This paper discusses the permitting challenges of ISR by providing an overview of risk mitigation methods for key areas to demonstrate how the technical challenges can be addressed to facilitate permitting of an ISR project.

Keywords: In situ Recovery, Permitting, Licensing, Regulations

ASSESSING THE IMPACTS OF HYDRAULIC FRACTURING ON WATER QUALITY IN THE VICINITY OF WELL SITES IN THE SURAT BASIN, QUEENSLAND

By

Simon C. Apte, Mike Williams, Brad M. Angel, Rai S. Kookana, Josh King and Adelle Craig

CSIRO Land and Water, Australia

Presenter and Corresponding Author

Simon Apte

ABSTRACT

Coal seam gas (CSG) production has grown exponentially in Australia over the last two decades. CSG extraction involves installing a network of wells across a gas field to depths that intersect the target coal seams. In order to increase methane yields, some wells undergo hydraulic fracturing (HF). HF involves the controlled high pressure injection of a large volume of fluids containing chemical additives into a well in order to fracture the coal seams and thereby increase gas flow.

Despite significant monitoring by industry and strict regulatory oversight, there is still widespread public concern about the impacts of HF, in particular the threats posed by the use of chemicals. CSIRO has recently undertaken a comprehensive investigation of the impacts of HF on air, soil and water quality at two locations in the Surat Basin, Qld. The study targeted six wells which were sampled periodically for up to 6 months from the time of HF. The concentrations of a comprehensive range of chemicals in flowback waters, produced waters generated during gas production, nearby surface waters and groundwater bores in close proximity to the wells undergoing HF were measured. A total of 113 water samples were analysed for over 150 potential contaminants including organics, inorganics and radionuclides. To the best of our knowledge this is the most extensive study conducted in the world to date on this topic. The findings of the study will be reported and their relevance to *in situ* recovery discussed.

Keywords: coal seam gas, hydraulic fracturing, contaminants, water quality

TRIALS AT DEPTH WITH VESI™ – A NEW GROUND WATER MONITORING TECHNOLOGY FOR ISR OPERATIONS

By

[1]Daniella Caruso, [1]Mikko Vepsalainen, [1]Kathie McGregor, [1]Miao Chen, [1]Dylan Marley, [1]David Macedo, [1]Tony Kilpatrick, [1]Avi Bendavid, [1]Luda Malishev, [2]Kathryn Levingstone, [2]Rohan Calley, [2]Nathan Hoskins and [3]Tim Duff

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Presenter and Corresponding Author

Daniella Caruso

ABSTRACT

Responsible management of surface water and groundwater is a key challenge facing most mining companies. Nearly every mine has an impact on groundwater and needs to monitor and manage it. In many countries, the regulatory environment in place to monitor and protect water resources is tightening, which has driven the need for better environmental sensing systems. The testing of many crucial water quality parameters (e.g., pH, redox potential, conductivity, ion concentration, etc.) still involves taking separate samples from the water body or effluent stream and transporting these to a laboratory for analysis. Moving to more efficient, continuous, on-line monitoring systems requires sensors for water chemistry that can stay calibrated for long periods of time (months to years), and give stable, reliable data. Such sensors are not presently available and represent a significant gap in the market.

To address this challenge, CSIRO has developed an innovative sensing system – Vesi™ – that allows automated monitoring of water quality for groundwater and surface water resources, even in harsh chemical environments and remote locations. The key differentiator between Vesi™ and other market offerings is CSIRO's patented solid-state pH and reference electrodes that require no on-going calibration and little maintenance over many months.

In partnership with Heathgate Resources Pty Ltd, NERA (National Energy Resources Australia) and Boss Resources Pty Ltd, CSIRO is conducting a groundwater field trial of sensor prototype units at Heathgate's Four Mile ISR uranium mine in South Australia. The results for phase 1 of the trial have been mostly positive – all above-ground architecture (integrated system design, electronics, software, remote energy storage, and communications) has performed well, in a remote outback area where daytime temperatures can reach 40-48 degrees Celsius. Challenges have been encountered with the sensor seals and preventing water ingress in groundwater wells of up to 180m at depth. New packaging for the electrodes has been developed and tested in CSIRO laboratories including elevated pressure and high sulphide concentration. The new packaging solves the leakage issues encountered during the first stage of the field trials and the new electrode material enables stable potential readings in a high sulphide environment. The new versions will be trialled in in-situ groundwater monitoring wells in 2021.

Once the groundwater monitoring system has been successfully developed through comprehensive testing then additional applications for the sensors will be trialled and developed including surface water, acid mine drainage monitoring and monitoring of tailings facilities.

Keywords: Sensors, Groundwater monitoring, Real-time

In-Situ Recovery Proceedings

Modelling

INFORMATISATION SYSTEMS FOR ISR MINES

By

Maxim Seredkin

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Presenter and Corresponding Author

Maxim Seredkin

ABSTRACT

In-situ recovery (ISR) transfers hydrometallurgical processing of mineralised bodies to the subsurface to directly obtain solutions of commodities. As a result, there is little surface disturbance. For ISR to be successful, however, deposits need to be permeable. Furthermore, commodities need to be readily amenable to dissolution by leaching solutions over a reasonable period, with an acceptable consumption of leaching reagents.

ISR is a “hidden” extraction process and development of an informatisation system allows the process to be more predictable and controlled. Informatisation systems are used at various ISR mines, including Beverley, Kazatomprom and others.

In 2010, the Strategic Conceptual Project was developed for informatisation of all ARMZ Holding mines, including the Dalur and Khiagda ISR uranium mines. The strategic directions were developed by two teams over the last nine years (Seredkin, Solodov, Boytsov, 2016).

The methodology for geological / resource modelling of sandstone-type deposits for extraction by ISR was developed by CSA Global (Seredkin, 2018). The methodology was based on modelling morphological elements of roll front mineralisation (noses, wings, residual parts), horizons / interbeds of impermeable sediments, the variability of permeability, and estimation of grade-thickness parameters for mineralised bodies. The resulting geological / resource models allow the preparation of the mine schedule and cash flow model for the ISR project, in addition to an assessment of the economic sensitivities.

Software for modelling hydrodynamic, physico-chemical and operation models/parameters was developed by the National Research Nuclear University with methodological support from ARMZ Holding (Seredkin, Solodov, Boytsov, 2016). This software includes the following modules: geological modelling based on operation wells, collection of initial operational data, hydrodynamic and physico-chemical modelling (core module), and economic analysis and forecast.

The module for geological modelling allows a quick update of the geological model based on the exploration grid after obtaining data from operation wells.

The module for the collection of initial operational data allows the creation of a database for the primary data at regular periods from wells, pipes and the plant. The data includes the volume of leaching and pregnant solutions, concentration and consumption of leaching reagents, and concentration of uranium and other components.

The module for physico-chemical modelling allows the preparation of an operating model for each period of the ISR process based on the geological model and operational data database.

The economic analysis and forecast modules are focused on forecasting the ISR process and making informed decisions to optimise injection/pumping solutions, and concentrations of leaching reagents.

In summary, an informatisation system has been developed for modelling and optimisation of the ISR process, which includes emerging technologies similar to big data and artificial intelligence.

Keywords: *in-situ recovery, informatisation, hydrodynamic modelling, physico-chemical modelling, forecast, big data, artificial intelligence.*

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In-Situ Recovery Proceedings

Economics

ECONOMIC MODELLING AND APPLICATION OF IN-SITU RECOVERY IN HARD ROCK MINING

By

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ABSTRACT

With the trend of declining ore grades and increasing costs in the mineral resources sector arises the challenge of finding new ways to target low-grade deposits. An alternative mining method that could overcome the current challenges of the industry is In Situ Recovery. However, its application is limited because of its restriction to highly porous and permeable deposits. Aiming to overcome this major concern, a new concept, called In Mine Recovery is proposed and evaluated in this study. The purpose is to induce and increase permeability by drilling and blasting, in order to apply an underground leach process in a hard rock environment. Therefore, a generic economic model of the approach is developed which calculates the net present value of the projected In Mine Recovery operations, to assess a first value indication of the concept and its potential benefits.

The focus lies in analysing its key performance indicators in order to understand its critical processes and dependencies, to enable its application to the mining industry. Due to still prevailing technical and general challenges of In Mine Recovery's implementation, a hybrid approach is proposed in which the higher-grade zones are mined conventionally and the lower-grade zones are mined by In Mine Recovery. Therefore, the model is applied to evaluate an existing mining operations, illustrating the challenges in real life conditions and emphasising the potential economic advantage of the supplementation of an In Mine Recovery approach to increase mineral ore reserves. Additionally, the case study is analysed to stress the economic similarities and differences between In Mine Recovery and conventional mining methods, showing how both approaches can be combined to increase and optimize mineral reserves.

Keywords: In-Situ Recovery, In-Mine Recovery, Economic Model, Copper Extraction, Gold Extraction, Ore Reserves

EXPANDING THE VALUE CASE FOR INSITU MINING

By

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ABSTRACT

Insitu mining has been considered for many years though technology is now improving to a level that encourages practical implementation. Insitu mining provides three opportunities to mine differently. Insitu recovery (ISR) involves drilling from surface into permeable strata to recover metal. In mine recovery (IMR) extends conventional open stoping to fragment then leach impermeable ore. In line mining (ILM) involves selective underground excavation followed immediately by processing.

The novelty of the approaches implies that the technology may appear to be uncompetitive. However, these insitu options create a new potential to overcome the present challenges of initiating mining operations that include the cost and availability of energy and water, and social acceptance by reducing tailings and footprints. However, new economic calculations are required to present the true value of these operations. Conventional NPV rewards high grade extraction in the shortest possible time leaving significant lower grade material behind while claiming full recovery.

New economic measures need to be developed to value the reduced capital expenditure providing cash flow over a longer period, recovery of metals with minimal tailings without deleterious elements, reduced exposure to diesel and other fumes as well as saving of the energy and carbon footprint of comminution for flotation. Similarly, economic cut-off grade and cost per ton mined become less meaningful measures of success in a diffuse operation so alternatives are investigated for insitu operations using case studies of realistic orebodies.

Keywords: Insitu mining, Insitu recovery (ISR), In mine recovery (IMR), In line mining (ILM), social acceptance, Conventional NPV, high grade extraction, deleterious elements, comminution, realistic orebodies.

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Permeability

DIRECTIONAL DRILLING AND HYDRAULIC FRACTURING FOR ISR APPLICATIONS

By

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ABSTRACT

Novel mining technologies such as in-situ recovery (ISR) have enabled minerals extraction from low-grade ore deposits, which otherwise would be deemed uneconomic to exploit. However, ISR applications for mineral extraction can be limited due to the low permeability of the host rock. Hydraulic fracturing technique has been proven as an efficient method to enhance permeability in hard impervious rock formations. Hydraulic fractures commonly propagate in a direction perpendicular to the minimum in-situ stress, which may not be the optimum direction for ISR applications. In addition, local variations in in-situ stresses, rock material properties, layering, or existence of natural fractures can affect the propagation direction of hydraulic fractures, making it difficult for the operator to control the direction just by adjusting the injection rate and pressure.

Alternatively, a new technology based on Radial Jet Drilling (RJD) has been widely used in petroleum and geothermal industries for improving injectivity/productivity of wells. In this technique, small-diameter holes (namely laterals or radials) are drilled out from the wellbore into the rock formation using a high-pressure fluid jet. Provided that the formation is jettable, the RJD laterals can enhance the utility of a single vertical well by increasing its lateral reach by tens of meters.

In this study, we investigate a directional hydraulic fracturing technique by combining the RJD technology with the hydraulic fracturing technique to optimise the hydraulic fracture geometries. The utilisation of directing hydraulic fractures along horizontal wells has already been applied successfully in a hydrocarbon field. In the proposed method, multiple RJD laterals, drilled in the desirable depth and direction in the host formation, are used to initiate hydraulic fractures. The RJD laterals are pressurised to initiate hydraulic fractures. The hydraulic fractures initiated from RJD laterals are expected to connect to each other and create a single fracture in a desirable optimum direction.

Keywords: Hydraulic fractures, Radial Jet Drilling, Directional Drilling, In-situ Recovery

DESIGN OPTIONS FOR UNDERGROUND LEACH SYSTEMS

By

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ABSTRACT

In traditional underground mining, significant underground development is required to extract the ore and transport it to the surface, and a large surface footprint is required for mineral processing, particularly if leach pads are used to extract the metal from the ore. In situ Recovery (ISR) systems use boreholes that are drilled from the surface to circulate a lixiviant through the ore body underground. The metal in the ore body is dissolved into solution and the metal is recovered from the pregnant solution at the surface. However, with ISR in hard rock environments achieving sufficient porosity for fluid flow through the ore body can be problematic due to the confined environment. As an interim step a system of developing porous leach piles in situ is discussed.

The underground leach reactors are developed over a series of blasts. A small amount of blasted material is extracted at the production level between blasts to provide sufficient space (void) for material in the next blast to fragment and swell, forming porous broken stock. Automated loading systems employing wireless initiation systems allow for the complete explosive charging of the stope and the subsequent series of blasts, for the safe and efficient staged development of each reactor. This process develops individual silos of broken porous ore that can act as underground leach pads with lixiviant introduced at the top and pregnant solution recovered from the bottom and pumped to the surface. Consequently, providing the potential for substantial capital savings as well as a smaller surface footprint compared to traditional underground mining techniques.

Examples are presented for the design and development of leach reactors to suit different ore body shapes and geological conditions.

Keywords: underground, in situ, leach, blasting, stope

FLUID FLOW PERFORMANCE THROUGH DEEP HARD FRACTURED ROCK MASSES IN A POTENTIAL IN-SITU LEACHING MINE SITE IN WESTERN AUSTRALIA

By

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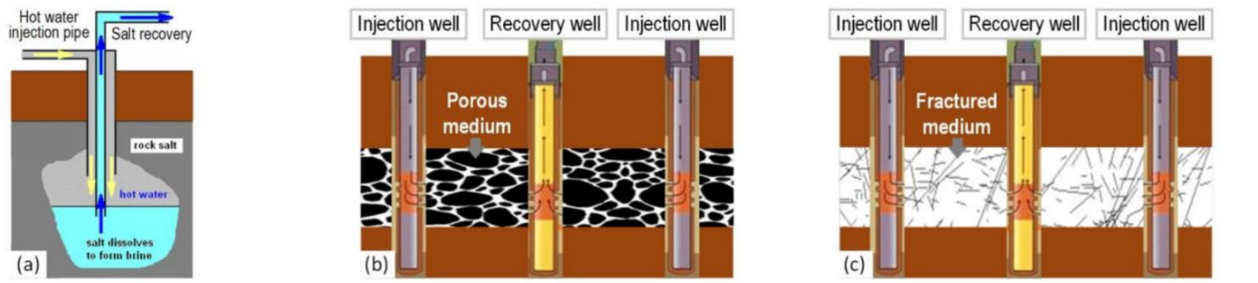
ABSTRACT

In-situ leaching is a promising mining method to extract minerals from fractured rock mass, such as nickel, gold, copper, and uranium. The in-situ leaching performance is constrained by several factors, especially the low hydraulic conductivity of rock at depth, because the pre-existing discrete fracture networks (DFNs) play a critical role in in-situ leaching. The natural fractures characteristics such as aperture, orientation, persistence, density, and transmissivity contribute profoundly to conductivity. In this research, subsurface fractures from a depth of 1500 m to 2500 m were mapped using a DFN, and then a numerical model was calibrated using well test permeability for this case. The fluid flow through fractured rock mass with ranges of fracture characteristics was analysed and illustrated. The simulation results indicate that for the fracture orientation, the flow rate first decreased and then increased. As another critical factor that contributes to the fluid flow in natural fractures, the fracture transmissivity has a direct relationship with the flow rate. Sensitivity studies show that natural fracture characteristics play a critical role in in-situ leaching performance. The simulation results indicate that the flow rate has a direct relationship with the natural fracture transmissivity. A parametric study on the effect of fracture characteristics on in-situ leaching showed that pre-existing natural fractures play a critical role in production.



(a) Solution mining in the past (b) Porous medium leaching in the present (c) Fractured rock mass leaching in future

Fig. In-situ leaching trend (Sharifzadeh *et al.* 2018)

Keywords: In-situ leaching; Rock mass permeability; Discrete fracture network; Fracture characteristics

APPLICABILITY OF PERMEABILITY ENHANCEMENT FOR IN-SITU RECOVERY

By

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ABSTRACT

A major factor dictating the applicability of in-situ recovery (ISR) is the permeability and associated hydraulic conductivity (K) of the deposit. Typically, ISR of uranium deposits is performed in sedimentary formations with K > 0.1 m/d and the interrelated effective porosity (typically > 15%). These influence the potential pore volume exchange rate and ore-lixiviant contact, as well as the subsequent recovery concentrations and rates. Recent advancements in innovative ISR technology have extended its applicability to more challenging deposits. For ore bodies where K < 0.1 m/d, permeability enhancement (PE) improving the mass transfer (leachability) may be a viable option to obtain economic recoveries.

PE is a common practice in the oil and gas industry to increase extraction and flow rates. Various techniques (or combinations of those) are available, including:

- Hydraulic fracturing
- Acidizing
- Thermal fracturing
- Acoustic or electrical stimulation
- Drilling and blasting
- Non-stationary flow regimes, including pulsed injection and others (mostly „conceptual“)

The applicability of different PE methods depends on the specific deposit characteristics and is constrained by the incompressibility of the rock. However, ISR poses additional challenges that have yet made PE inapplicable for ISR projects. PE generates preferential flow paths and it must be ensured that either:

- Adequate reaction space is available
- PE sufficiently connects the existing pore spaces
- PE method creates additional porosity

Changing the flow direction via non-stationary flow regimes (including pulsed pumping method (PPM), wellfield (WF) role reversals) may be a promising PE method for ISR applications, whereby new flow paths are generated (pushing the flow into poorly connected pores) and acidification through leaching increases the total area of ore-lix contact.

PPM is tested at lab-scale by dynamic column leach tests (DCLTs) in triaxial cells using intact core containing the target metal mineralization. Resulting recoveries and permeabilities using pulsed and continuous flows are compared. PPM should reduce the impact of preferential flow, and thus increase the ore contacted by the lix and the subsequent recovery concentrations. Numerical WF simulations indicate that WF role-reversals successfully increase the total ore-lix contact by increasing flow into WF ‘dead zones’. Broadening the flow range connects more of the fractures/pore spaces or preferential flow paths created through PE.

To evaluate the feasibility of such methods for ISR applications, the PE and associated porosity increase must be simulated. In addition to full-scale 3D reactive transport simulations (e.g. by FEFLOW), a simplified mass balance model (KiLea - UIT in-house software) is used to model potential recoveries and determine ISR WF design criteria considering PE through fracturing and acidification in parallel to leaching.

Keywords: in-situ recovery, permeability enhancement, column leach tests, non-stationary flow regimes, pulsed pumping,

INVESTIGATION OF COAL CLEAT NETWORK STIMULATION THROUGH LIQUID NITROGEN FRACTURING

By

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ABSTRACT

Extraction of methane from coalbed typically requires enhanced recovery techniques due to coal's low permeability measure coupled with its unique gas storage mechanism. Since hydraulic fracturing has lost its popularity due to its associated technical as well as environmental drawbacks, anhydrous techniques as enhanced recovery stimulation approaches have attracted attention of unconventional reservoirs producers. Amongst anhydrous techniques, liquid nitrogen fracturing has been proven to be an efficient fracturing approach via thermally shocking the reservoir rock. Therefore, this work is aimed at investigating liquid nitrogen fracturing in a coal at microscale via X-ray micro-computed topography.

The in-situ visualization results suggest the promising performance of liquid nitrogen fracturing technique in coals. The images illustrate generation of fracture planes originated form the cleat network, as a result of which the porosity evolution is 11%. The images also highlight the interconnection of isolated pores and cracks with the original cleat network. This phenomenon in turn implies that the porosity evolution has further boosted the connectivity of the original cleat network. The surface visualization through SEM reveals similar results, appearance of continuous conductive fractures with the aperture size of 9 µm. Moreover, the mechanical analysis of the experiment shows a 25% decrease in the indentation modulus of the frozen sample, implying the degree of damage to the rock.

The final parameter of investigation, coal permeability, is investigated through experimental and numerical approaches. The fluid dynamics analysis via Lattice Boltzmann simulations suggest a two-fold permeability evolution, a finding which matches the experimental permeability measurement through flooding. Therefore, the results clearly illustrate that liquid nitrogen fracturing is an encouraging stimulation approach in coals, and enhances the porosity and connectivity of the cleat network, thereby increases the coal permeability.

Keywords: Coalbed methane, enhanced recovery, liquid nitrogen fracturing, SEM, Computed Tomography, Mechanical Properties.