ALTA 2019 ENHANCING ISR PERMEABILITY PANEL DISCUSSION

May 2019

The panel discussion was held on Friday 24 May 2019, immediately following the In Situ Recovery sessions at ALTA 2019 in Perth, Australia.

Panel Chair: Laura Kuhar (LK), CSIRO Mineral Resources (Australia)

Panel Participants (left to right): Ewan Sellers (ES), Mining3 (Australia); Peter Dare-Bryan (PDB), Orica (Australia); Kevin Quinlan (KQ), CSIRO Energy (Australia)

Editor's Note*: The contributions of the panel members and delegates are not presented verbatim, but rather have been paraphrased and condensed for clarity and brevity. The topics are presented in the order in which they were discussed. Also, it is not feasible to include all contributions made during the discussions, and they are limited to some that are representative of the key points raised and debated.*

LK (chair) commented that the speakers during the ISR Symposium had provided a good overview and understanding of possible techniques to enhance accessibility in the short term, and ES provided an understanding of what may occur in the future. Existing technologies for access creation were covered in detail, but their advantages and disadvantages, their implementation, and their stages of technological maturity may need clarification. LK mentioned that although it is often difficult to provide cost estimates, it would be useful to obtain insight into what sort of costs are involved in the different techniques. It would also be useful to understand scales of implementation and safety elements that are involved in the techniques. Moving away from traditional access creation, additional permeability enhancers and reducers are expected to affect operation, such as via precipitation, dissolution and swelling, and LK mentioned that it would be interesting to touch on these. The round of questions was then opened.

Social License to Operate Hydraulic Fracturing

LK (chair) stated that LF in his earlier presentation (Environmental Copper Recover Pty Ltd "The potential of in situ recovery for copper, gold and other metals, the Kapunda project as a possible example") had mentioned how important the social licence to operate will become in future in mining in general, and specifically in in situ recovery. Perceptions may exist as a result of insufficient available information and understanding. There is social concern related to "fracking", and LK asked where this concern originates from, how to explain the safety of the technique and what its limitations would be.

KQ (panel) stated that in the mining environment, fracturing is termed preconditioning, which helps to allay concerns and suggested that for ISR, a term such as “forced permeability enhancement” could be used. KQ had not heard of mines that had encountered resistance in terms of social licence to operate. KQ mentioned that they work in areas that have already been approved for mining, at a small scale and not on private land, so this has not been an issue thus far. KQ mentioned that they have done extensive work in New South Wales, Australia, where fracture monitoring is used with regards onshore gas, but that it has not been an issue at the mine sites.

ES (panel) stated that he thought there may be concern from government and the public if chemicals were involved. Regulatory bodies and different states have different rules on chemicals that are allowed onto site. For example, in Queensland, there is a strong emphasis on maintaining registers of different types of chemicals that they have on the operations, and it is difficult to make changes; whereas in South Australia, there is an increased openness to looking at different concepts.

KQ panel) agreed, in that they used mostly water and occasionally, gel, in their applications; if any other chemicals were to be used in ISR, a process would most likely have to be followed for acceptance.

Fracturing of Hard Rock Deposits

Alan Taylor (AT), ALTA Metallurgical Services (Australia), floor picked up from the final presentation in the ISR Symposium (KQ, CSIRO, Hydraulic fracturing in in situ recovery – methods and equipment for field trials), and enquired how possible it may be to apply what was presented to gold and copper hard rock deposits and how far we are from the commercial application of these technologies.

KQ (panel) commented that pumping systems exist and that we can certainly fracture in very high stress environments. He thought that the main issue was to reduce the spacing between fractures. The operational tools exist, and hydraulic fracturing systems operate in mines all over the world. In hard rock mining, fractures can be grown over 50 m, therefore the scale is not a major problem. Thus, it is necessary to understand each case and adapt the approach to the in-situ conditions to achieve the desired outcome . Hydraulic fracturing may provide a large reach rather than closely spaced fractures, to allow for flow and chemical interaction with the rock, and for an increased well spacing, which could be a cost saving.

ES (panel) mentioned that PDB indicated that is possible to work at large scales when using caving preconditioning. ES believes that the main challenge with hydraulic fracturing will be related to the ore body shape. For example, when veins exist in the ore, a hydraulic fracture will be driven in the direction of high stresses, so if the stress direction does not lie in the same direction as the ore body, fracturing will not be possible in that particular operation. However, in a large operation, such as a large low-grade copper deposit, a large area needs to be fractured, and this then becomes very similar to what is being done in caving preconditioning.

PDB (panel) asked whether slurry pumping has changed the game, about the possible chemical hazards that may have to be considered in terms of slurry pumping, and whether it is possible to generate hard rock fractures and keep them open. He asked whether local stresses are changed and whether the possibility of generating another series of fractures is affected or made easier.

KQ (panel) mentioned that he thinks they evidenced changes in local stress when they tried to put sand into hydraulic fractures, when trying to place fractures with a close spacing in a short period of time. Sometimes the only requirement is to increase existing natural fractures. When only short periods of time are available, increased planning is required. It is possible to conduct multiple passes using widely spaces fractures with additional fracturing thereafter between the initial fractures after a stabilisation time. Larger pumps are available, and some mines are now using ultra-preconditioning. Operators are looking at using higher pressures to produce larger fractures. It is an engineering problem: with a large enough pump, it is possible to break any rock mass; the only limitation to the size of the pump is the pressurising injection line and the engines.

LK (chair) asked a follow-up question to AT’s query of how far we are from implementing permeability enhancing technology. KQ had mentioned in his presentation that the closest fracture spacing is ~2.5 m currently and that we could potentially expect to reach fracture spacings of as close as 100 mm. She asked how much work is required to reach that goal, and whether it will be years before this is achieved or if the option exists now but that there is a lack of demand in current environments for close spacing.

KQ (panel) suggested that the main challenge may be the field in which fracturing is applied. If the stresses are closely aligned it is difficult to control fracture placement. If the fractures are too closely aligned, fractures are more likely to grow into each other, and they may separate again at some point, but this effect is variable and would probably require a trial field-scale test. Laboratory tests are possible, for example, using a polyaxial cell, and should be the first approach, as this is probably the most cost-effective, followed by a field test. Field trials are important because the effect of scale is difficult to understand in a laboratory test on a 400-mm block, as the borehole notches will be proportionally much larger than in a field environment. In a field-scale trial, the fracture can be monitored and measured as it grows.

Application of Blasting to Enhance Permeability and Create In-Ground Leaching "Silos"

AT (floor) agreed that the term "conditioning" or enhancing permeability is positive. He then asked PDB a question on the use of explosives (based on PDB's presentation, PDB and Stephen Boyce, Orica, Potential use of blasting to enhance permeability) for creating leaching silos, as to whether the concept can be applied at depth without proceeding all the way to the surface; is it possible to prepare a deep cavity, inject solution to depth and then back to the surface without creating surface disturbance?

PDB (panel) responded that it is possible, that the surface can be reinforced with break up underneath and there would be no surface disruption.

AT (floor) asked what would happen at the surface and if there would be a push on the surface.

PDB (panel) responded that there must be a stable structure at the surface because lixiviant is introduced at the top.

AT (floor) stated that there would be a number of stranded deposits at depth that cannot be accessed by open pit, and that are too small for underground processing, that may be a target for this type of application.

PDB (panel) responded that there may be some development costs associated with such an implementation or drives would be required, which would need to be determined during planning.

AT (floor) imagined that there could be difficulties in implementing the technology, but maybe these could be overcome by instrumentation and using pumping to achieve circulation, and envisaged that this could be possible. He commented that in heap leaching, up to 70% recovery is possible for low-grade material and up to 80% recovery is achievable for finely crushed materials. AT asked whether higher recoveries could be achieved by using the silo method and if it would be possible to perform a small test to predict the achievable recovery.

PDB (panel) agreed that it was absolutely possible and that aggressive blasting could be applied to yield smaller particle sizes, which would eliminate the requirement for downstream process equipment such as thickeners.

AT (floor) mentioned that preferential flow can result in heap leaching, and it can be difficult to predict the percolation pattern. He asked if it would be possible to tailor the structure of the ore body to prevent such issues.

ES (panel) mentioned that each rock type has a radius of stability and that it is possible to calculate how big this radius is (20 or 30 meters). The rock support can act like an arch bridge to support lots of smaller rocks. In caving mining, the radius is tailored so that the rock starts to fall in.

AT (floor) commented that the design could be tailored to the structure of the ore body.

ES (panel) remarked that laboratory testing can identify some of the challenges. It is important to identify challenges such as short-circuiting in columns, because these are the same challenges that will occur at a larger scale. We do not know if we will only have a very broad size distribution from blasting, because blasting does create fines.

AT (floor) commented that it may be possible to place holes at the sides of the silo to allow flow down the outsides and the achievement of coverage.

LK (chair) asked what is holding us back from using silo technology and whether there were any available candidate sites willing to try the technique for the first time.

PDB (panel) agreed that it is often difficult to implement new technologies, ideas and processes at mines.

LK (chair) followed up querying whether there are any technical limitations that need to be developed further.

Stephen Boyce (SB), Orica (Australia), floor commented that the ROES (Remote Ore Extraction System) technology was first proposed by the CSIRO more than 10 years ago to mine large-scale rock at Olympic Dam in a sublevel open stoping method and to get rid of mid sublevels. At that time, automatic drilling was new to the industry and therefore, it was impossible to automatically charge explosives by getting the wires down to the detonators. Nowadays, we have wireless blasting technologies, new pumping systems, and automatic drilling as standard industry technologies. So, it becomes an engineering solution that can be pulled together and a new mining method can be made from an old mining method. SB did not envisage any technically limiting aspect; the application requires a mine and company that wants to invest.

Brigitte Seaman (BS), Newcrest Mining (Australia), floor commented that from a processing perspective it would be ideal to operate in a saturated environment, because that is one way of maximising chemical stability. Brigitte enquired whether it would be possible to flood the silos in the ROES application, almost like a vat, or whether this would create an unstable environment.

PDB (panel) commented that it depends on the local geology and the condition of the siloes.

SB (floor) added that such an approach can essentially be achieved now where fluid can be controlled, or back flow in a stock can be controlled by building walls and metering and draining using drain holes to contain the liquid inside the silo. This approach is achieved currently in different mining methods.

LK (chair) stated that in a hard rock environment, it is unlikely that much fluid will be present to start, but if channels with liquid flowing were present, would that place a limitation on implementing underground reactors, and could such an approach be used in an already saturated environment?

PDB (panel) stated that the approach would be most suited to an unsaturated environment and that the other situations would be undesirable.

Ivor Bryan (IB), MPS (Australia), floor added that the ROES feasibility study was attractive and that the main limitation previously was automating explosives, but the mining method was certainly viable. He commented that there are certain risk factors associated with ROES/silos, such as mud rushes and possible oxidant introduction in flooded stopes.

LK (Chair) clarified whether IB intended oxidant introduction in the form of a gas.

IB (floor) responded that if the underground reactor were flooded, then the challenge may be to ensure that the oxidant could get into the solution and percolate the rock mass.

Alternative Techniques to Enhance Permeability

John O'Callaghan (JOC), Newcrest (Australia), floor commented that he liked the idea of using a lixiviant that dissolves the minerals and creates space, while under pressure. He stated that it may be possible by convection to get the solution moving in a macro sense up and down holes, but asked how we will achieve mass transfer, where diffusion is going to be the dominant mass transfer mechanism. He thought that if we can get that mechanism working faster from a chemical engineering approach, and keep the system pressurised, we could create space naturally. He mentioned that in comminution, fracturing tends to occur along mineral boundaries where rock mineral weakness exists, and this could occur in a similar way with chemical dissolution of minerals. He thought this may be slower, but that somehow such an approach could be an improvement over diffusion mass transfer.

LK (chair) commented that Tania Hidalgo (TH) in her presentation (Tania Hidalgo, Curtin University/CSIRO; Robbie McDonald, Laura Kuhar, CSIRO; Andreas Beinlich, Andrew Putnis, Curtin University; Staged leaching of bornite with acidic solutions at moderate temperature in an in-situ recovery environment) had mentioned that she had achieved changes in mineral surface texture of 7 microns in 7 days, which may be slow. She commented that one of the new Murdoch University/CSIRO PhD students (Elahe Karami) would be focusing on the enhancement of mass transfer by ultrasound, electrokinetics and pulsed fluid flow, and BASF has produced a reagent, LixTRA™, to enhance mass transfer. So there are challenges in terms of scale and time, but hopefully further research will help to make progress in this area.

BS (floor) commented that TH's work has been very encouraging in showing changes in microcracking that result from mineral leaching.

Tania Hidalgo (TH), Curtin University/CSIRO (Australia) floor mentioned that it is possible to use the in situ deposit temperature to enhance mineral transformation. Furthermore, chemical reactions result in changes in the texture of the formed product phase. The new phase that forms after chemical interaction is porous and allows the fluid to enter the original phase, e.g., chalcocite that is formed after the acidic leaching of bornite showed surface cracks and porosity in the rim. It may be necessary to scale this effect to larger particles to achieve relevant information for an ISR environment. TH found in all her leach tests that fluid enters cracks and that chemical reactions increase the cracks (slowly). TH suggested that an ideal approach would be to use the enhanced permeability provided by blasting combined with fractures and porosity that result from the chemical interaction.

LK (chair) supported TH's comment that it is a good idea to have a combination of techniques, where, for example, hydraulic fractures create the super highways that are spaced approximately one metre apart, and blasting or some other alternative is used to induce smaller fractures; and during leaching, additional cracks are generated to promote further leaching to access the minerals of interest. As a final question, LK stated that ES had presented on a number of blue-sky options in his talk (Ewan Sellers, Sevda Dehkhoda, Ebrahim Fathi Salmi, Ruslan Puscasu; Mining3; Innovations in Rock Fragmentation and Fracturing - Creating Access for Leaching) and asked which of these technologies he believed to be most promising, after fracturing and blasting.

ES (Panel) said they were looking at different ways to introduce microwave technology, and not only using conventional heating but heating rock in different places to generate a differential and crack the rock.

LK (Chair) closed the panel discussion and thanked everybody for their participation. LK stated that at the inaugural ALTA ISR Symposium she had spoken about Prof Brian Cox's comments on getting humans to Mars and how it felt that in some ways achieving ISR in hard rock was more ambitious. However, the progress made in technologies, such as those discussed in the panel to enhance permeability help to bring us closer to the goal, and provides optimism in moving towards achieving ISR processing.

Summary of Key Points

- Social licence to operate is becoming more important in the future in mining in general, and specifically in in situ recovery. Perceptions may exist as a result of insufficient available information and understanding. Regulations may differ between states and regulatory bodies.
- Hydraulic fracturing technology is available for use in an in-situ recovery environment. Pumping systems exist to apply hydraulic fracturing to gold and copper hard rock deposits as does the capacity to fracture in high stress environments. The main issues that require further attention are the reduction in spacing between fractures (which is dependent on the stresses in the field in which the fracturing is to be applied) and the relationship to the ore body shape and structure. The operational tools exist, hydraulic fracturing systems operate in mines all over the world, and in hard rock mining, fractures can be grown over 50 m, therefore scale is not a major problem. Thus, it is necessary to understand each case and adapt the approach to the in-situ conditions to achieve the desired outcome. Laboratory tests are possible to understand the fracture behaviour, and field trials are important because the effect of scale is difficult to understand in a laboratory test.
- Deep stranded deposits or other unsaturated hard rock deposits may be a target for the creation of a fractured cavity by blasting, with solution injection and/or flooding (with natural sealing by surrounding rock) and pumping back to the surface. The technologies exist nowadays to achieve such underground reactors ("silos"), and wireless blasting technologies, new pumping systems, and automatic drilling are mainstream technologies that can be used in such applications; such an implementation requires a company interested in trialling the technology.

- It is possible to use lixiviants to create access via microcracking, dissolution and porosity creation. Furthermore, techniques are being studied to enhance mass transfer (e.g., surfactants, ultrasound, electrokinetics and pulsed fluid flow). These approaches to increased permeability enhancement can supplement techniques such as hydraulic fracturing and blasting.
- Alternative novel approaches are being considered for enhancing permeability, such as by microwave application and preferential heating.

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Application of ISR to Copper is the featured topic for the ALTA 2020 In Situ Recovery Forum and Panel, which will be held 29 May in Perth, Australia.

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ALTA Panel Notes