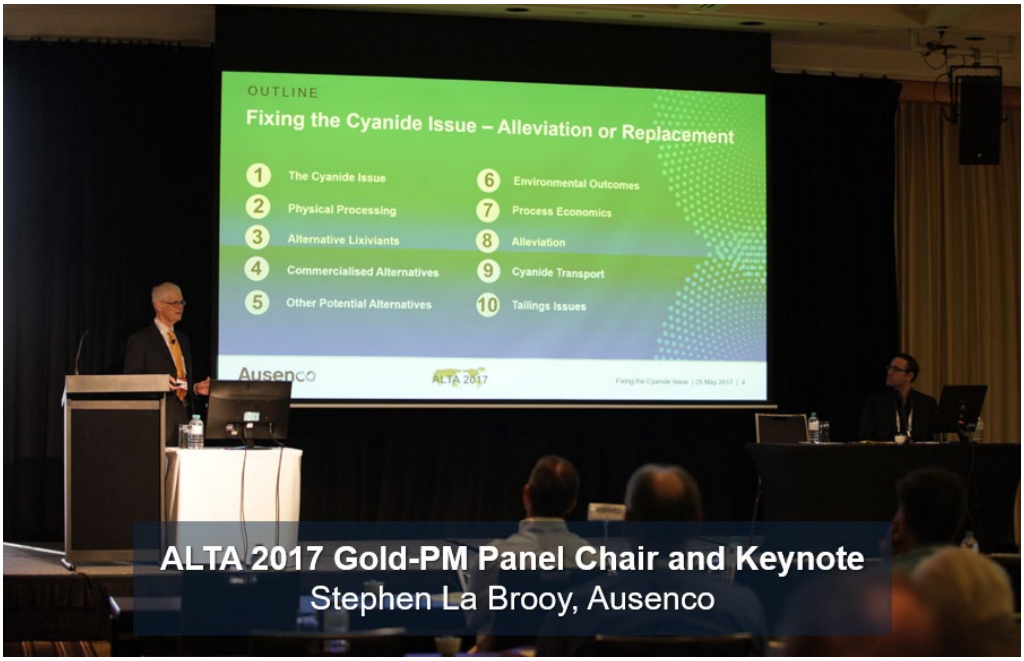

ALTA 2017 CYANIDE ALTERNATIVES/ALLEVIATION PANEL DISCUSSION

May 2017

The panel discussion was held Friday, 26 May, immediately following the Cyanide Alleviation/Alternatives Forum during the Gold-PM Sessions at ALTA 2017 in Perth, Australia.

Panel Chair: Stephen La Brooy (SLB), Ausenco (Australia)

Panel Participants: Elsayed Oraby (EO), Gold Technology Group, Curtin University, (Australia); Xianwen Dai (XD), CSIRO Mineral Resources (Australia); Welhem Lugosi (WD), Mintek (South Africa); Malcolm Paterson (MP), PT Green Gold Engineering (Indonesia); Panayiotis Papacharalmbous (PP), PT Kisangani Boomi (Indonesia)

***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. They are not recorded in order, but are grouped into major topics. 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.*

Cyanide Alleviation

The discussion centred mainly around cyanide recovery/recycle and on-site cyanide manufacture as key issues in satisfying the concerns of regulators and the public and allowing its use to continue.

John O' Callaghan (JOC), Newcrest, (Australia), floor, referred to SLB's Gold-PM Keynote paper that noted that most of the world's cyanide isn't used in the mining industry but in chemical plants. He said that If we manufacture cyanide on site, recycle cyanide such as in the RECYN Process, and apply chemical industry standards to plant design and operation, then cyanide use should be able to continue. If we don't end up with cyanide in the tailings and we are not transporting it to site, then that addresses the two key issues. At the same time, we must continue to look at non-cyanide alternatives, as government regulations may force us in that direction.

MP, panel, said that on-site production of cyanide is an important issue in changing the public perception about cyanide.

SLB, Chair, agreed but pointed out that the first commercial facility is yet to be built. He added that one idea could be to integrate on-site cyanide generation with the RECYN Process and use a common absorption system.

EO, panel, added that reducing the amount of cyanide used in the process would also be beneficial, which is a feature of the glycine technology being developed at Curtin University.

Ralph Hackle (RH) Rio Tinto (Australia), floor, pointed out that there was a panic about cyanide and a push towards alternatives to cyanide in the late 1990s, which perhaps is happening again. It appears to be similar to the sentiment around coal mining and renewable energy. The fact is that cyanide is technically and economically superior to any other lixiviant. We've made some incremental improvements with alternative lixiviants, but cyanide is still "king", and is used for most of the world's gold production. If cyanide is banned, the gold production will decline and the price will go up. He agreed with MP that the best approach is to make cyanide acceptable.

Industry Pressures

XD, panel, reported that the Chinese government has become tougher in approving plants using cyanide, and Chinese companies have become interested in thiosulphate. A cyanide sales tax has been introduced and cyanide is not allowed near population centres and environmental protection zones. The trend is towards the Chinese government becoming increasingly strict on the use of cyanide.

PP, panel, commented that in Indonesia it is not just environmental, but also conservation of minerals. So, unless you can show that you are getting good recoveries, it will be difficult to get a permit. The trend is towards looking beyond processes such as heap leaching with 70% recovery to better processes with 95% or higher if possible. Some of these alternative processes still have quite a way to catch up with cyanide.

Alan Taylor, ALTA (Australia), floor, asked whether we are heading for an increasing number of governments banning cyanide, and increasing community and media opposition. If so, is the industry taking it seriously enough in developing alternatives, or is the mining industry burying its head in the sand?

Yeonuk Choi (YC), Barrick (Canada), floor, said the it's not just cyanide that is the problem, but environmental regulations as a whole. NGO's are using the public perception of the danger of cyanide to try to stop mining completely, for example in Montana where cyanide is banned.

Cyanide Alternatives

SLB (Chair) opened the panel and the floor for questions regarding cyanide alternatives. He noted that the main sessions included papers on chloride, bromide, thiosulphate, thiourea, and that several of the world's experts on the application of thiosulfate were present.

JOC, floor, asked whether there are alternatives being worked on which were not covered during the main sessions. He reported that he has looked at chloride extensively, and believes that for high chloride process recycle of the chloride and maintaining the water balance is hard work. Whereas it is okay for anode slimes, for ores and concentrates it is more difficult, though not impossible, and needs a good business case. He said that the industry must come up with something, as the currently feasible alternative to cyanide is leaving the gold in the ground, which is a difficult decision if the deposit is high grade. A higher cost process with lower efficiency compared with cyanide may be preferable under those conditions.

Karel Osten (KO), Amec Foster Wheeler (Australia), floor, commented that it's self-regulating in the sense in that if cyanide is banned it will make our life difficult, but the gold price will increase to compensate.

JOC, floor, said that we need to keep looking at alternative technologies, including revisiting old technologies. We mustn't get bogged down into the way a lixiviant has been used in the past, and think outside the box. We need to encourage academics and researchers to keep working on alternatives as one day it may be beyond our control and we may be forced to do something different.

SLB, Chair, agreed that we must not get stuck in the ruts that people before us have fallen into. An example is all the work done on copper catalysed ammonium thiosulphate, yet the first plant uses calcium thiosulphate.

In-Situ Recovery

Petrus van Staden (PVS), Mintek (South Africa), floor, proposed that there are two "holy grails" the industry is searching for – a cyanide free gold process and an in-situ process which avoids mining. He asked whether we could select a subset of the cyanide free processes as contenders for in-situ application. For in-situ application, a reagent needs to be stable underground and controllable from the surface.

XD, panel, reported that CSIRO are doing work on in-situ leaching, and have done column leach testwork for a gold company with a gold mine in Australia using a particular product. The results are promising and they are waiting for the company to decide to go to the next stage. He considers that thiosulphate could be one of the options for in-situ applications.

PVS, floor, commented that there are a couple of boxes that need to be ticked maybe working against one another. On one hand, we need something stable and controllable, and on the other hand if it escapes into the environment it must biodegrade so that it is not a lasting legacy.

EO, panel, said that glycine covers most of these points and has a wide range metal stability of gold and copper (pH 7-12). It is non-toxic and environmentally benign, and is a good candidate for in-situ leaching.

Paul Breuer (PB) CSIRO (Australia), floor, said that, as pointed out by SLB in his Keynote presentation, for in-situ the issues are very similar to above ground processing for all the alternative lixiviants. The amount of reagent recovery, recycle and re-use that is achievable is probably going to be the biggest driver. It's the complete process, not just having a reagent that can leach gold.

KO, floor, reported that many years ago he worked on in-situ leaching trials with thiourea. It worked pretty well, but the main problem was the loss of solution and reagent. Apart from anything else, for successful in-situ leaching you have to find the right orebody with the appropriate permeability. Many gold orebodies don't fit this criterion.

MP, panel, said that in-situ is a niche process for gold, applicable to a very small percentage of orebodies. Normal mining/leaching applies to a much higher percentage of orebodies and therefore deserves more focus. Also, above ground mining is much easier to control.

PB, floor, responded that CSIRO is looking at in-situ as a game changer, even for hard orebodies. Some of the technologies being looked at for increasing the permeability include hydraulic fracturing, cryogenic cracking, chemical means of creating microfractures, and electro kinetics.

SLB, Chair, pointed out that there comes a point when conventional mining is not economic. He doesn't see in-situ as competition to conventional methods, but is another option in the tool kit.

PVS, floor, reported that from the point of view of the South African gold industry, in-situ is viewed as a possible long-term solution as mines become deeper and to reduce underground fatalities.

Dry Stacking of Tailings

SLB, Chair, agreed with YC that it goes beyond cyanide. We can recover the cyanide but tailings dam failures can do just as much damage even if cyanide free, as at Samarco and Mount Polley.

AT, floor, commented that one of the things discussed in the Nickel-Cobalt-Copper Sessions was the move towards "dry" tailings, for example for nickel laterites, which tends to support the growing concern about tailings dam failures.

SLB, Chair, added that it may be an expensive, and technically unnecessary cost, but cyanide destruction used to be seen as that a few years ago.

MP, panel, responded that a current feasibility shows dry stacking comes with a huge cost due to the large number of filters needed for the high clay ore and the long transport distance for to the disposal area. This has forced a return to wet tailings to make the project economically feasible. The effect of high rainfall on the dry stacked material is another concern.

SLB, Chair, said that dry stacking of tailings is something the industry needs to work towards, as the tailings issue may be one of the reasons why we may have to leave the ore in the ground, especially for low grade which results in proportionally more tailings.

Ben Strong (BS), Ausenco (Australia), floor, reported that some companies are not getting approval for a wet tailings dam.

SLB, Chair, added that stacking on top of an existing tailings dam could avoid the need to permit a new big tailings dam and reduce the cost implications.

AT, floor, reported that the concept of a combination of wet and dry stacking was discussed in the Nickel-Cobalt-Copper Sessions, whereby the cap facilitated the run-off of rain water.

SLB, Chair, added that dry stacking is particularly advantageous in dry areas where water recovery is very important.

Role of Ion Exchange

AT, floor, asked whether ion exchange could play a greater role in gold ore processing.

SLB, Chair, responded that it makes more sense to use carbon due to selectivity. However, there are some opportunities for ion exchange, such as for preg-robbing ores.

BS, floor, reported based on a recent project the capex is similar for CIL and RIL, but the opex is higher for resin due to resin replacement, using a resin loss calculated by using industry standard information.

Technology Development

AT, floor, said that a lot of developers of new processes are technology companies, often very underfunded, and have a tendency to collapse with time. Therefore, wouldn't it be a good thing to have some sort of industry funding so that the technologies will still be available if a cyanide ban does come?

SLB, Chair, followed up by asking whether there benefit in having an industry co-operative where we can send ideas for funding; though he recognized that confidentiality is often a problem.

EO, panel, reported that the Curtin University work on glycine has received good support and encouragement from the big gold producers.

AT, floor, said that Mark Benz' Nickel-Cobalt-Copper keynote paper is well worth reading as it talks about the value of process technology in mining companies and how it should be treated as an investment and not something the accountants cut off when the going gets tough. Mark emphasized the need for mining companies to keep a strong internal technical department, to liaise with universities and engineering companies, and collaborate around the industry. He pointed out that many successful technologies have been developed in this manner, but when innovations become isolated in technology companies, they tend not to get off the ground.

MP, panel, suggested the driving force must come from mining companies. They are the ones that have the problem to be solved.

SLB, Chair, panel, added that it's only when the mining companies become involved in the development process that there is someone with the drive to actually do it. It's only when there is someone who actually needs the solution that the process is commercialized. Barrick put in 15-20 years' work before thiosulfate leaching at Goldstrike was commercialised.

EO, panel, reported that their approach with the glycine program was to look for deficiencies with the available alternative reagents. He believes that the role of the research group or university is to search for what the industry needs, try to solve the problem with some simple low-cost tests, then seek funding. We cannot wait for research money to come to us.

AT, floor, contributed that quite often the big companies don't want to share their technology in order to retain a competitive advantage. Some of the great inventions, which became widely used were developed by non-mining companies. Examples include copper SX developed by reagent supplier General Mills, gold/silver CIP by USBM, and uranium ore treatment processes by US government laboratories. If ideas come from outside the mining companies the resulting innovations are more likely to be disseminated.

JOC, floor, emphasized that innovation always requires a commercial driver. The ideas can come from inside or outside the industry, but there always needs to be a driver. The better the universities understand the industry and its drivers, the better the innovations.

SLB, chair, observed that the gold industry used to be open, but now companies tend to have IP control departments and safeguards. In the aluminium industry, they have gone the other way; they used to be secretive but now are more open. Maybe the cyanide challenge will bring the gold industry together to lower the cyanide profile.

Summary of Key Points:

- The application of a totally closed system with cyanide recycle designed and operated under chemical industry standards, together with on-site cyanide production, may make the use of cyanide acceptable, at least in some jurisdictions.
- It is imperative to continue to work on developing alternative leaching systems in case a widespread cyanide ban should eventuate.
- Alternatives to cyanide could play an important role if research work on improving ore permeability makes it feasible to apply in-situ leaching to gold ores.
- Dry stacking of tailings is more costly but reduces the risk of catastrophic dam failures and maximises water utilization in arid or water restricted areas,

We acknowledge the efforts of the student volunteer from Curtin University, Emma Williams, for providing detailed notes on the discussion.

Refractory and Complex Gold Ores is the featured the topic for the ALTA 2018 Gold-PM Forum and Panel, which will be held 19-26 May in Perth, Australia.

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MetBytes are metallurgical commentary and insights written by Alan Taylor who has 40+ years' experience in the metallurgical, mineral and chemical processing industries. 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, base metals, phosphates and alumina.