ALTA 2018 REFRACTORY AND COMPLEX GOLD ORES PANEL DISCUSSION

May 2018

The panel discussion was held Friday 25 May, immediately following the Refractory and Complex Gold Ores Panel Discussion Forum during the Gold-PM Sessions at ALTA 2018 in Perth, Australia.

Panel Chair: Alan Taylor (AT), ALTA Metallurgical Services (Australia)

Panel Participants (left to right): Miao Chen (MC), CSIRO Minerals (Australia); Cleophace Mpinga (CM), Curtin University (Australia); Karel Osten (KO), Wood plc (Australia); Jan van Niekerk (JVN), Outotec Biomin (South Africa); James Wang (JW), Zijin Mining Group (China); John O'Callaghan (JOC), Newcrest Mining (Australia); John Neale (JN), Mintek (South Africa); Mark Martin (MM), Koch Knight (USA)

***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 necessarily 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.*

Is There a Need for New Processes for Refractory Gold ores?

AT (chair) commenced by noting that the established processes for refractory ores are roasting, POX, bio-oxidation and Albion, then asked the panel whether we have taken these processes as far as we can go given the trend to an increase in impurities such arsenic, decrease in grade, tighter environmental regulations and increase in social concerns. Alternatively, is there a need for new processes or step changes to current processes?

JOC (panel) responded that ultimately the cyanide process for final gold recovery needs to be reviewed by the industry moving forward. Less intensive low temperature refractory treatment technology of some form, such as bio-oxidation, e.g. BIOX, or ferric oxidation, e.g. Albion, will eventually dominate and be more successful due to capital and maintenance cost considerations. With the drop in grade and increase of sulphur and arsenic, there is need to pursue lower temperature less intensive reactors, even though retention time is longer and there will be a trade-off in gold recovery. All processes, even POX and roasting, are evolving, but the lower temperature less intensive processes will probably eventually succeed, and there is definitely an incentive to look into new technology, particularly for lower grade ores.

JW (panel) said that the trend in China in the next 5-10 years will be small modifications to current processes

to improve efficiency and decrease operating cost rather than a turnover of technology. In China, there is very strong government regulation of cyanide use, so the industry needs to find an alternative reagent, in particular, for acidified oxidised slurry after POX. There is a potential market in China if a solution is found. Another challenge in China is the safe handling of arsenic oxide from roaster off-gas to meet government regulations. This increases operating cost and is a major area needed to be studied. Arsenic handling is easier with POX as it can be readily oxidised with ferric iron to form scorodite for safe disposal in the tailings dam. Industry needs to do some detailed studies to understand the fundamental mechanisms in order to reduce capital and operating costs. Ore characteristics vary, so studies have to be carried out to find the best process for each project. For example, during the first year of commissioning of a POX plant, there were problems with sodium and chlorine in solution which significantly impacted gold recovery .

JN (panel) commented that James Wang's keynote paper shows that the take-up of bio-oxidation in China has been amazing, with a total of about 11 plants. This tends to support JOC's view that adoption of milder technology has some advantages, and the Outotec BIOX presentation shows that there are ways to reduce costs. For a long time, the Achilles heel of bio-oxidation has been cyanide consumption, and the indicated capex savings of 5% and opex savings of 10% in the paper are significant in making it feasible to treat lower Au:S ratio material.

JOC (panel) agreed that there is a need to look at all options. Once a company gets used to a technology it is hard to "divorce" them from it. For example, if a company builds POX plants they tend to continue building more POX plants. Due to the grade, limited free gold, and more refractory deposits with higher arsenic, there is definitely a need to look at other technology, specifically for arsenic.

KO (panel) stated that if the gold to sulphur ratio is good, he would not be too pessimistic about lower grades and more arsenic. POX technology, and maybe others, are certainly capable of handling them, and the gold will pay for the sulphur. Vitrification may be the ultimate, but it is a niche technology and hard to justify economically. He doesn't see why responsible operation of POX plants with the right chemistry and feed and proper tailings management won't be acceptable, unless regulations change significantly.

Alternatives to Cyanide

AT (chair) asked what would the difference be if more governments ban cyanide? Politics can change rapidly, and we can't always wait for it to happen. We need to have some ideas on how we will respond.

Jacques Eksteen (JE), Curtin University (Australia), floor said that cyanide has a lot of benefits, and is such a robust chemical that it is hard to find an alternative. One possible solution is to find a system using a synergistic reagent running with 5 ppm residual cyanide which would not be dangerous to animals. (It would be for fish, though it would be alleviated by water dilution.) Ferrocyanide is used in food but people look at the word cyanide and tend to link it with free cyanide. The gold industry needs to get together in terms of conversation with the government to say that we are working towards an acceptable solution, but zero cyanide is not possible. Alternatives can be found to reduce cyanide but not eliminate it completely, which is not always necessary. For example, the Synergen Met paper presented a site-based cyanide production process using plasma that eliminates one very big risk from the cyanide equation - transport to site. This could be combined with the GlyCat synergistic leaching system which reduces cyanide use in the plant by 95%.

JOC (panel) advised if you can get a permit for cyanide - use it. It's truly an amazing chemical and, if well managed, it is safe from environmental and O&H points of view. Unfortunately, there have been several incidents around the world where the industry has failed. This has precipitated the research being done on alternatives. It could be too late, but the argument for cyanide is very strong, and as an industry we should keep trying to put it forward. However, the world is turning against cyanide and it is not going to be up to the industry anymore, unfortunately. We can maybe delay the process, but the writing is on the wall.

Sazini Makamu (SM), Mintek (South Africa), floor asked since researchers are moving to find an alternative to cyanide, should we focus on modifying existing projects or on new projects? And how do we convince companies to use a new lixiviant instead of cyanide when nobody else uses it, especially if it is not as effective as cyanide?

AT (chair) followed up by asking whether you could justify spending a billion dollars on a project based on cyanide when it may not last long due to the cyanide issue? Isn't it an investment issue as well as technical?

JOC (panel) responded that it is not going to happen quickly. Some jurisdictions will be slow, and it is hard to believe that Australia, for example, will stop using cyanide, though it is possible. However, there are jurisdictions in the world which are very sensitive to even the mention of cyanide. A new project should look at all technologies. Researchers are developing some very interesting information, but cyanide is a very difficult chemical to compete with as it is extraordinarily efficient.

Etienne Kiss-Borlase (EKB), MetOxs (Singapore), floor said that he tends to disagree. There are many mines that are closed today due to the proximity to towns which still have high grade ore but are unable to operate. So it is definitely time to find an alternative to cyanide. His company is developing the MetOxs Process which is probably the only truly clean gold leaching process. It is based on novel technology which he is unable to disclose at this time. It doesn't use cyanide or any toxic chemicals. There is no pollution to air, water or ground. The process is at the development stage. Laboratory scale tests have attained 80% recovery for 100 g refractory ore samples, and 95% is now being achieved with 1 kg samples. The proof of concept has been certified by an independent company and achieved 95%. It is a very simple process which promises to be much cheaper than existing technologies, though CAPEX and OPEX have not yet been quantified. It is a one cycle 2 hr process. It uses large particles of about 250 micr. which will have an impact on grinding and flotation. The first pilot scale plant is planned for 2019.

Ben Bissonnette (BB), Barrick Gold (Canada) floor said that Barrick has a lot of refractory ore. Cyanide doesn't work that well for everything. For example, when the ore is really refractory, with a lot of carbon, cyanide doesn't work, but calcium thiosulphate, which Barrick has developed, does work.

JE (floor) said that acidic ferric thiourea, with or without additives, is a possible option, particularly with bio-oxidation and POX where the acid and ferric levels are at pH 2 or lower. It is not cheap, however it does not require neutralisation and doesn't form gypsum or muck, so the lixiviant can be contacted with the gold bearing material without the presence of hematite, jarosite, gypsum, etc.

Extensive work has been done on alternative lixiviants by individual organizations such as CSIRO and Barrick on thiosulphate, Outotec on chloride, and others on iodine and bromine. Chloride leaching is particularly useful as it is readily available in seawater and saline ground water. The main challenge is that the region of stability is on the high oxidation high acidity side, so that the area of application is very small, and in that area chloride tends to attack everything else as well. Interaction with gangue material is intensive, and acid consuming silicates form gels. Also chlorides preg-rob very badly onto carbon and fine silicates. Other halides, bromide and iodide, are expensive.

A key issue is for the industry to recognize is that some processes are applicable to concentrate and others to ores, so that a "fit-for-purpose" approach is required which is the topic for the ALTA 2019 Gold-PM Forum and Panel. In other words, there are specific solutions to specific problems. For example, glycine cannot be used for carbonaceous pen-robbing ore because the gold-glycine complex is adsorbed more onto carbon than is cyanide. There are many things that determine fit-for-purpose, including site terrain, proximity of ports, water availability, meteorological conditions, ore grade, metallurgical characteristics, legislation issues, etc.

JOC (panel) advised that a few years ago Newcrest found that gold can be leached with sea water, and a high chloride environment is not needed. Advantage can be taken of the instability of the gold chloride complex in the presence of the seawater at pH 2-2.5 in which the gold will reduce onto carbon.

Newcrest is also working on the concept of "sustainable cyanide" with CSIRO. When there is no transportation of cyanide and no discharge there is no problem. There are many chemical plants around the world using a very high cyanide concentration in their process without discharging any. So why can't this be done for gold processing by recycling all the cyanide?

AT (chair) pointed out that the Green Gold technology that was presented and discussed at ALTA 2017 uses IX to recover and recycle cyanide. This, in combination with on-site cyanide production, as presented this year by Synergen Met, could be a big step forward.

Caroline Olson (CO), COREM (Canada), floor said that COREM is a private research centre with members from around the world, which continues to do cyanide work for interested parties. They have a new project to convert cyanidation by-products such as thiocyanide and WAD to free cyanide for re-injection into the pulp. This has reached small-scale demonstration, and they are waiting for funds for a full pilot-scale demonstration to develop data for a preliminary economic evaluation.

She believes that it is important to continue to consider the safety aspect of cyanide use and reduce the risk of transportation. COREM continues to investigate opportunities to use new lixiviants and new ways to use past lixiviants, and are interested in collaboration. Their view is not to banish cyanide forever, but to keep an open mind and work for the best outcome.

Stability of Arsenic Residues

Tony Parry (TP), OreSort Solutions (Australia), floor noted that roasting is not viable for high arsenic ores, while with POX/bio-oxidation arsenic is believed to be permanently fixed as ferric arsenate in the tailings. The question is, do we know conclusively from long-term tailing dam studies that there is no arsenic dissolution from the tailings? This is an important issue for environmental approvals.

JE (floor) said that calcium arsenate and scorodite are not as stable as we think as they exist in a range of forms, and asked JW to comment on the arsenic vitrification process developed by Dundee Precious Metals in Canada, whereby arsenic is vitrified in glass to make it non-leachable.

JW (panel) responded that that scholars in China are studying glassifying technology. However, the plants produce about 2000 tons of arsenic per year and it is challenging to handle all this environmentally safely with low OPEX.

JVN (panel) reported that there has been work on 39-year-old tailings which found that no arsenic was released. This was also found in a study of 15-year-old tailings.

JN (panel) added that he was involved in a long-term lab-scale stability study on bio-leach residue, where site conditions were duplicated, and found that the residues actually became more stable over time.

KO (panel) added as a qualification that that stability is predicated on the process being operated correctly. As with anything, if it is mis-operated it will not work as advertised.

Heap Leaching of Refractory Gold Ores

AT (chair) noted that in copper, there is a focus on heap leaching for treating low grade chalcopyrite ores. Two processes currently making progress are bio and chloride heap leaching. He asked whether there an opportunity to apply these processes to low-grade refractory gold ores?

MC (panel) responded that heap leaching is very cost effective and is a possible process for recovering a number of elements from sulphide ores. Also, heap leaching technology is advancing, for example with new agglomeration technology.

JE (floor) added that heap leaching is great, but relies on a number of conditions being favourable, such as terrain. A point to note is that alkaline technology has an advantage over acidic systems in that it is easier to agglomerate.

Collaboration and the Need for Industry Research

AT (chair) invited comments on the need for industry-wide collaboration in R&D on the issues of cyanide and alternative lixiviants, and how to bring it about?

JE (floor) responded that Curtin is involved in collaboration in gold research and that it is not always easy because some companies want to optimize cyanide use and developing new lixiviants is not a priority for them. About two thirds of current sponsors are in that category, while the other third is more proactive. As mentioned by JOC, many companies have a permit to use cyanide so there is no great incentive to change, especially in remote areas. However, a collaborative effort with a pre-competitive approach is needed as the cost is more than one company can afford. The AMIRA P420 project, which has been in progress at Curtin for many years, is an example of one approach to collaboration.

Paul Breuer (PB), CSIRO (Australia), floor added that CSIRO as an organization took a step back a number of years ago and looked at the issue of an alternative to cyanide and concluded that, despite extensive research over a long time period, the industry is not going to find a single solution. Instead, we need to look for niche fit-for-purpose opportunities. Although it is difficult to put together collaboration packages for fit-for-

purpose applications, there are opportunities where developing new technology is better than trying to improve cyanidation.

SM (floor) noted that there is an industry trend to close down research facilities, and asked whether in view of this the gold industry is doing enough research? For example, if Mintek were to shut down, there would basically not be any gold research in Africa. So, what can be done to encourage the industry to invest more money in further gold research and change the current situation?

JOC (panel) responded that it is sad to see what is happening around the world with research organizations. He does not know the answer except to say that it is up to operating companies to support research organizations like Mintek and CSIRO as much as possible. There is no doubt that research is needed, but unfortunately companies tend to be run by non-technical people who haven't fully appreciated the value of the contributions research institutions have made to the industry over decades. Certainly Newcrest is very keen to support fundamental research.

CM (panel) added that in his country, when there is a plant problem it has to be sent to the outside, which results in a reluctance for the plant to spend money on-site.

EKB (floor) added a final thought. The mining industry is known to be extremely conservative in the adoption of new technology. The reaction tends to be "I will use it when my neighbour uses it". Entrepreneurs are willing to take a risk and may win or lose, but the feeling is that the mining industry is not open yet for new things and new discoveries. We need to bring the mining industry into a new age.

Summary of Key Points

- There is an industry trend towards lower ore grades, and refractory ore types with higher arsenic level which is driving research and development into improvements to existing processes as well as the application of new technology. While all processes are evolving, the trends are likely to favour increased application of less intensive lower temperature processes such as bio-oxidation, e.g. BIOX, or ferric oxidation, e.g. Albion, due to capital and maintenance cost considerations.

- Increasingly stringent government regulations including outright banning in some countries, aggravated by high profile incidents, have precipitated research and development into finding an alternative to cyanide. So far it has proven difficult to find a complete replacement with sufficiently favourable process and economic properties, and the current trend is towards developing niche fit-for-purpose applications such as Barrick's thiosulphate process for carbonaceous refractory ores. Significant work has also been done with halide lixiviants, particularly chloride.

- There are many mines that are closed today due to the proximity to towns which still have high grade gold ore but are unable to operate with cyanide, which offers a current opportunity for new technology. These are being targeted by MetOxs, Singapore/USA, who are developing a non-cyanide non-toxic system.

- An alternative approach is to demonstrate that cyanide can be used safely by avoiding any loss from the plant circuit, as in the chemical industry. This can be achieved by recycling all of the cyanide from the leach residue as in the Green Gold process, Indonesia, which was featured at ALTA 2017. The adoption of on-site cyanide production, as presented this year by Synergen Met, Australia, would eliminate the risk of cyanide spillage during transport to site, which is the other significant risk.

- COREM, Canada, are developing technology for converting cyanidation by-products such as thiocyanide and WAD to free cyanide for re-injection into the pulp.

- Disposal of arsenic as scorodite is widely regarded as an environmentally safe disposal method for arsenic, which has been supported by studies on actual tailings. However, the reliability is dependent on the correct operation of the process.

- Dundee Precious Metals, Canada, are developing an arsenic stabilization process whereby arsenic is vitrified in glass to make it non-leachable. Vitrification technology is also being studied in China.

- It was noted that chloride leaching is being developed for heap leaching of low-grade chalcopyrite copper ores, and may have potential for low-grade refractory gold ores.

- Setting up a collaborative group would make the development of alternative lixiviants more affordable. It was recognized that while many companies do not see the development of an alternative to cyanide as a priority, there are niche fit-for-purpose opportunities which could attract support.

- It was noted that there is an industry trend to close down research facilities reflecting a lack of appreciation of the valuable contribution made by research over the years, particularly by non-technical management. Efforts are needed to encourage operating companies to support the still existing research organizations. There is a need for the mining industry to be more open to new technology.

The Editor acknowledges the excellent work of the student volunteer from Curtin University, Jessica Tedja, for providing detailed and comprehensive notes on the discussion.

Fit-for-Purpose Leaching Systems is the featured topic for the ALTA 2019 Gold-PM Forum and Panel, which will be held 24 May in Perth, Australia. The Gold-PM sessions are organized in partnership with the Gold Technology Group, Curtin WA School of Mines.

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