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Alan 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 as 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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Uranium-REE-Lithium Proceedings

Opening Address

THE CHALLENGES OF OPERATING A URANIUM MILL IN THE MODERN ERA

By

Dr Brett Moldovan
International Atomic Energy Agency (IAEA), Austria

ABSTRACT

The share of nuclear generation in global electricity supply is currently about 10%, down from a peak of about 17% in 1996. One contributing factor to the decline in the percentage of nuclear power generation globally was response to the 2011 Fukushima Daiichi accident in Japan where all 52 nuclear reactors were shut down. The reduction in nuclear power generation combined with uncertainty regarding the long-term sustainability of the nuclear power industry caused the uranium spot price to fall from about $US22.50/kg U_3O_8 in February 2011 to its current price of about $US10/kg U_3O_8. In addition, the reduction in global nuclear power reduction has resulted in an over-supply scenario with respect to uranium ore concentrate inventories and this has further contributed to the downward pressure on the uranium spot price over the past six years. The sustained low uranium spot price has put significant pressure on primary uranium production operators and several have been operating in a negative cash flow situation. As a result, several of these operators have been forced to place their uranium mines and milling facilities into care and maintenance.

The IAEA has identified that the demand for electricity globally is expected to continue to grow, in particular in developing countries. As a result, the global total electrical generating capacity is forecast to increase from 6,671 GW(e) in 2016 to 9,826 GW(e) by 2030 and to 12,908 GW(e) by 2050. Based on the IAEA forecasts, the share of nuclear generating capacity in the global total electrical capacity will be about 3% in the low scenario and about 6.8% in the high scenario by 2050.

The forecasts indicate positive growth for the nuclear industry for the medium to long term. However, when looking at the historical spot price trends for uranium, the peaks in the spot price have been relatively short lived and the valleys have been unfortunately long-lived. Primary producers of uranium ore concentrate must continuously look for innovation, optimization and collaboration with operational peers and researchers in order to make uranium mills profitable during times of extended low uranium spot pricing. This presentation will focus on key aspects that uranium producers should consider as they look to advance innovation, improve efficiencies and ultimately reduce unit operating costs, whilst maintaining safety performance and high environmental and social standards.

Keywords: Nuclear Power Forecast, Uranium Spot Price, Innovation, Optimization

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Keynote Address

CONSTRUCTIVE DISRUPTION: LEVERAGING KEY INTANGIBLES FOR SMARTER URANIUM PROJECTS

By

Dr Julian Hilton
Chairman
Aleff Group, UK

ABSTRACT

Whether from a policy, market or communications perspective, uranium as an energetic resource is at a decisive, even existential cross-roads. In policy terms the two UN landmark policy statements of late 2015, the 2030 Sustainable Development Goals (UNSDGs), and the Paris Agreement on Climate Change (UNFCCC), have transformed the context within which decisions about uranium use as a nuclear fuel will be made. In market terms, as starkly summarised by a senior Billiton manager in late November 2017, the “tale” of uranium’s future may lie in one of two “tails” - “[the one] a low case world where nuclear generation dwindles in importance, [the other] a green world where nuclear generation increases in importance.” This view is indirectly supported by a 2016 study published by Share Action, a group of major institutional investors, with $5.9 trillion dollars of pension funds under their management. In aligning their future investment strategy explicitly to delivering the UNSDGs the fund managers rank meeting SDG 9 in first place, 13 in second and 7 in third. In that model, uranium’s future will be decided by its capacity for innovation (9), its contribution to climate action (13) and its role as a sustainable energy source (7). From a communications and stakeholder engagement perspective the nature of that role in a post-Fukushima “green world” has still to be constructed in a way that convinces a global audience. As of now the uranium “tale” will, most likely, be of dwindling demand not growth.

This keynote speech explores the case that when the policy, market and communications perspectives converge for the uranium industry and the nuclear power industry it serves the transformative outcome is necessarily disruptive in nature and cannot be technology-led. The change drivers are intangibles. Among these, and in no particular order of significance, are:

- Priority to U recovery as co- and/or by-product based on “all-in sustaining cost” economics
- A “decoupled” energy policy framework with nuclear power integral to base-load provision
- Reworked policies for local content for U projects based on OECD position paper June 2017
- Alignment with SDGs and Climate Action objectives and performance indicators
- Commitment to “comprehensive resource recovery” and “zero waste”
- Investment in new capabilities, e.g. Artificial Intelligence, for higher productivity and resilience
- Delivery by multidisciplinary teams with excellent internal and external communications

A renegotiated social licence to operate based on shared values and a fresh, compelling narrative of uranium as energy source, focused perhaps on small, smart modular reactors.

Keywords: policy, market, communications, intangibles, green-world uranium, zero waste

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Uranium Leaching

TECHNOLOGICAL INNOVATION AND DEVELOPMENT OF IN-SITU LEACHING URANIUM IN CHINA

By

Yahui Tan, Wensheng Liao, Yan Jiang

Beijing Research Institute of Chemical Engineering and Metallurgy (BRICEM), China

Presenter and Corresponding Author

Wensheng Liao

ABSTRACT

In recent years, the rapid development of nuclear power has given rise to an urgent demand for uranium products which enhances the innovation and development of uranium mining and metallurgy in China. This paper introduces the progress of in-situ leaching uranium in China.

After the success of the first in-situ leaching uranium test in 1985, China have conducted extensive research on uranium in-situ leaching of the sandstone type deposits in Xinjiang Uygur and Inner Mongolia autonomous regions. And technologies such as evaluation of sandstone type uranium resources for in-situ leach, well structure and drilling completion, ore underground leaching, control of leaching range, pregnant solution processing and automatic control, have been developed. This paper focuses on the innovative achievements of groundwater seepage field alteration, multilayer ore horizon coordinated and efficient leach, complex orebody leach, leaching solution processing of distributed and small ore blocks, and digitized uranium deposits, according to the complex sandstone uranium deposits in geology, hydrogeology and ore characteristics. Based on the characteristics of the sandstone type uranium deposit and the existing uranium in-situ leaching technology, the developing direction of uranium leaching in China is proposed.

Keywords: Technological Innovation, Process Development, In-situ Leaching of Uranium, China

COLUMN BIOLEACHING IN A VOLCANIC ROCK TYPE URANIUM DEPOSIT，SOUTHEAST-CHINA

By

Gongxin Chen, Zhanxue Sun, Yajie Liu, Jinhui Liu, Weijun Shi, Xuegang Wang and Wenfeng Wang

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Presenter and Corresponding Author

Gongxin Chen

ABSTRACT

The Xiangshan uranium deposit is one of the biggest volcanic rock type uranium mines in China. The ore is complex with a high content of clay minerals. Currently, high-grade uranium ore is leached by conventional agitation hydrometallurgy, but the production is costly and the economic efficiency is poor. Low-grade ore is leached by the percolation leaching method, however fines cause the heap to be compacted and clayey, resulting in distinctly decreased permeability.

In this paper, a heap bioleaching technology is developed for this deposit. Mineralography study using EPMA shows that the dominating uranium minerals are brannerite and pitchblende. Refractory native brannerite accounts for about half the content. These uranium minerals are associated with pyrite and fluorite, and are semi-encapsulated by them or commonly at their edges. There is significant apatite and illite, which can produce mud and clay during heap leaching. The process is carried out in two stages, comprising an acid pre-leaching stage followed by a bioleaching stage. It is found that most of acid is consumed in the pre-leaching acidification stage. The hexavalent uranium is preferentially leached in the initial stage.

The acid consumers existing in the ore have an adverse impact on uranium leaching, and acidification with higher acid in the initial stage can significantly promote uranium leaching. It is shown that the bioleaching of uranium yields better results than acid leaching. Rotating drum technology is one of the important methods to solve the problem of unevenness of the ore in the column during the bioleaching process.

The leaching results show that the acid consumption is low at 6.8% and the leaching rate is high at 90%, with a leaching period of 126 days. Through the study of the change in chemical composition during the leaching process, it is proven that the leaching of uranium is closely related to the leaching of pyrite, so that the leaching of pyrite has a beneficial effect.

Keywords: Uranium Recovery, Bioleaching, Column leaching, two stages leaching, Pilot

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Uranium IX Precipitation

COMPARISON OF WBA AND HIGH CAPACITY SBA RESINS FOR THE RECOVERY OF URANIUM FROM SALINE LEACH LIQUORS

By

[1]James Quinn, [1]Karin Soldenhoff, [1]Tomasz Safinski and [2]Keith Bowles

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[2] BOSS Resources Ltd, Australia

Presenter and Corresponding Author

James Quinn

ABSTRACT

Chloride has a negative impact on the recovery of uranium from sulfuric acid leach liquors using ion exchange (IX). This is relevant to many proposed and operating uranium mines where good quality fresh water is scarce and chloride is present in the ground water. This issue is addressed in practice by strict controls being placed on recirculating liquors to prevent chloride build-up and significant decreases in uranium loading in IX.

ANSTO Minerals has been investigating ion exchange processes for the recovery of uranium from saline liquors for several years. One method that ANSTO examined previously is the use of weak base anion exchange (WBA) resins in place of the conventional strong base (SBA) resins. The WBA resins are more effective at chloride concentrations up to 12 g/L Cl, and can be eluted in a conventional manner using 1 M NaCl. Coupled with nanofiltration for eluate reagent recycle, this process can be quite attractive.

Recently, ANSTO Minerals carried out an extensive testing program for Boss Resources to develop a process for the recovery of uranium from In-Situ Recovery (ISR) leach liquors from the Honeymoon mine site in South Australia. The work program included laboratory and column leach tests, laboratory IX test work for resin screening and investigation of elution options. The process developed was tested in a Field Leach Trial (FLT) that incorporated an IX Pilot Plant constructed at ANSTO and transported to the mine site.

Laboratory resin screening tests identified the potential for this application of a high capacity SBA resin recently released. This resin exhibits considerably elevated loading compared with both WBA and other SBA resins. Chloride elution was also tested and proved successful, although elution was found to be more difficult compared to WBA or SBA resins.

In this presentation we outline some of the key findings relevant to both resin functionalities and present results of the IX Pilot Plant which operated successfully for 10 weeks.

Keywords: Uranium, Ion Exchange, Saline, Weak Base, Strong Base, Anion Exchange.

DEVELOPMENT OF AN EFFICIENT PRECIPITATION PROCESS FOR PRODUCT RECOVERY FROM LEACH LIQUOR OF A LOW-GRADE DOLOSTONE HOSTED URANIUM ORE

By

Ajoy Kumar Singh, T.S. Nikhilesh Iyer, A.K. Sharma, Vivekanand. Kain and Madangopal Krishnan

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Presenter and Corresponding Author

Ajoy Kumar Singh

ABSTRACT

India has a low-grade dolostone hosted stratabound type large uranium ore deposit in Southern Cuddapah basin in Andhra Pradesh. The host rock of this deposit predominately contains dolomite along with quartz, cellophane, chlorite, pyrite etc. Attempts were made for development of an optimized process for efficient recovery of uranium from this ore. A process was developed that has now been adopted on a commercial scale. The process comprising of oxidative alkaline pressure leaching followed by filtration and counter-current washing of leached slurry generates leach liquor of concentration less than 1 gpl of U_3O_8 with a high value of Total Dissolved Solid (TDS). Direct precipitation of Sodium Diuranate (SDU) from leach liquor generates an excessive amount of fine precipitates of morphology not conducive to efficient separation in continuous mode of operation. Ion exchange process for upgradation and purification of leach liquor prior to precipitation was not found effective due to poor loading and poor selectivity of uranium with commercially available ion exchange resins. An innovative process, compatible with the chemistry of alkaline leaching process has been developed after extensive experimental work in continuous mode of operation. Variations in precipitation efficiency were investigated as a function of reagent dosages and precipitation time. The attributes of the products such as their settling characteristic, particle size distribution & morphology, which influence separation of the product, have also been investigated. Under the optimized conditions, it was possible to obtain both precipitation and separation efficiencies of SDU in the order of more than 98%.

This paper outlines the salient experimental results and their implications for SDU precipitation and its separation.

Keywords: uranium, ore, recovery, alkaline pressure leaching, sodium diuranate, particle size distribution, morphology, precipitation efficiency

BIFUNCTIONAL LIGANDS FOR HIGH SELECTIVE EXTRACTION AND RECOVERY OF URANIUM(VI) FROM ACIDIC MEDIA INCLUDING PHOPHORIC SOLUTIONS

By

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[2]Gilles Bernier, [2]Manuel Miguirditchian, [1]Todor Angelov, [1]Georgi Savov and [2]Bas Nauts

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Presenter and Corresponding Author

Guilhem Arrachart

ABSTRACT

Phosphine oxide-phosphonate and carbamoylphosphonate ligands have been synthesized and studied for uranium extraction from phosphates ores. From a structure-selectivity approach, the molecular design of such ligands was optimized leading to a specific one called DEHCNPB which exhibits outstanding results for the selective extraction, and quantitative recovery of uranium in phosphoric acid compared to the URPHOS reference system.

Keywords: Uranium, Phosphoric acid, Solvent extraction, Bifunctional ligands

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REE

ADVANCES ON SCANDIUM RECOVERY BEYOND STATE OF THE ART

By

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Bengi Yagmurlu

ABSTRACT

Scandium (Sc) has attracted a lot of attention in the last decades because of the unique technological applications of this element. It is a key component in solid oxide fuel cells and aluminium alloys, which are especially produced for the aerospace industry. Unfortunately, there exist very few scandium deposits. Thus, scandium is generally recovered from secondary raw materials or by-products from the production of uranium, nickel laterites or titanium dioxide pigment processing.

Recovery of scandium from the leachates has mainly been performed by solvent extraction, ion exchange or a combination of these two techniques. The co-extraction of iron, aluminium and titanium during these hydrometallurgical operations creates problems and extensive purification is required to produce a high-quality product. Therefore, selective and advanced ways to isolate scandium from iron**,** were developed on a laboratory scale.

In highly acidic solutions, scandium can be selectively retained by inorganic metal(IV) phosphate materials via a cation exchange reaction. Amorphous and crystalline layered titanium(IV) and zirconium(IV) phosphates have demonstrated excellent potential for the separation of scandium from bauxite residue leachate. It was found that the selectivity of the inorganic metal phosphates originates from size selection and phosphate coordination. In addition, it was also found that a supported ionic liquid phase (SILP) betainium sulfonyl (trifluoromethanesulfonylimide) poly(styrene-co-divinyl-benzene), prepared by covalent linking of the ionic liquid to the resin, shows an excellent uptake rate of rare-earth elements (REE) from acidic media, in particular of Sc, Y, Nd, Dy. Furthermore, a scandium concentrate can be obtained via successive selective precipitations. The addition of ammonia solution for the removal of iron from the leachate is followed by scandium phosphate precipitation via dibasic phosphates. The purity of the resulting concentrate, containing 20-70% scandium phosphate, depends on the impurity level of the initial solution. The concentrate can be further purified with less effort than by direct processing of the scandium containing solutions.

With the emphasis on scandium recovery in several Horizon2020 EU-funded research projects, i.e. REDMUD, SCALE and REMOVAL, more alternative processes for scandium recovery will become available in the near future.

Keywords: scandium; recovery; secondary resources; hydrometallurgy; bauxite residue

BROWNS RANGE HEAVY RARE EARTHS – DRIVING THE EV EVOLUTION

By

George Bauk

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Presenter and Corresponding Author

George Bauk

ABSTRACT

With global electric vehicle uptake expected to reach 35 million units annually by 2030, the recent focus of the EV sector has been on the development of lithium battery technologies. However, just as important for carmakers in the race for extended range is the development of electric motors that are smaller and operate at higher temperatures.

Dysprosium is a heavy rare earth element used in the permanent magnets inside electric motors. With dysprosium production concentrated in China and global demand already indicating a supply deficit, the rush is on to develop new sources of this critical element.

Northern Minerals is in the process of commissioning the Browns Range heavy rare earth project in the East Kimberley region of WA, which will be the only significant supplier of dysprosium outside China.

Keywords: Dysprosium, rare earths, EV, Browns Range

RECOVERY OF RARE EARTH ELEMENTS FROM A NORWEGIAN DEPOSIT

By

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Norway

Presenter and Corresponding Author

Erik Larsen

ABSTRACT

Rare earth elements (REEs) are commonly divided into light (LREE: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd) and heavy (HREE: Y, Tb, Dy, Ho, Er, Tm, Yb, Lu), based on their atomic weights. LREEs occur in carbonates and phosphates, while HREEs occur in oxides and phosphates, in total about 250 mineral phases. HREEs are less abundant than LREEs, and are strategic elements that have not been exploited in significant quantities. Because of their unique physical and chemical properties, and the ongoing development of new advanced technologies, the demand for REEs is continuously increasing. REEs are amongst Europe's critical raw materials, and in order to strengthen the competitiveness of European industry in line with the renewed industrial strategy for Europe and the development of European resources, it is important to ensure a stable supply of these elements. In line with this there are several interesting REE resources in the southern parts of Norway. Amongst these are the magmatic HREE-bearing microcline-quartz pegmatite deposits of the Evje-Iveland region. The pegmatites contain phosphate minerals among which xenotime (YPO_4) and monazite [(Ce, La, Nd, Th) PO_4] are the main REE-bearing minerals. In addition to characterization studies, various mineral processing test works such as gravity, magnetic and electrostatic separation as well as froth flotation were used in beneficiation of REEs along with other minerals on pegmatite samples from the Tuftane deposit. The mass bulk products from these microcline-quartz type pegmatite deposits would be quartz, feldspars and micas. Based on the initial results a flowsheet for the pegmatite deposit beneficiation was proposed.

Keywords: REE, pegmatite, xenotime, magnetic separation, flotation, mineral liberation, recovery

RARE EARTH AND PRECIOUS METALS RECOVERED WITH CCIX CONTINUOUS COUNTERCURRENT ION EXCHANGE

By

Filip Rochette and Yvan De Busscher

PuriTech Ltd, Belgium

Presenter and Corresponding Author

Yvan De Busscher

ABSTRACT

Specialized resins have been developed for decades to recover or abstract precious metals from acid solutions. Rare Earth and precious metals are too valuable to get lost in the process. Standard ion exchange systems are not performant enough to recover the maximum amount of these metals in an acceptable economic way. New process technology from PuriTech combined with the advantages of CCIX - continuous countercurrent ion exchange - overcomes these downfalls and creates huge savings and gains for mining companies and metal producers.

Recent projects for the recovery of Scandium, Germanium, Gallium and Molybdenum have proven the unique performance of this technology. CCIX ion exchange with PuriTech's patented ION-IXTM system is a game changer in the recovery of Rare Earth and precious metals.

Keywords: Ion Exchange; Rare Earth; Resin; Hydrometallurgy

MOLECULAR SYSTEMS FOR RARE EARTH ELEMENTS EXTRACTION FROM PHOSPHORIC ACID MEDIUM

By

Stéphane Pellet-Rostaing, Guilhem Arrachart and Sandrine Dourdain

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Presenter and Corresponding Author

Stéphane Pellet-Rostaing

ABSTRACT

This work outlines the successful use of new and promising molecular systems for rare earth recovery from phosphoric acid solutions by solvent extraction process.

Extractant formulations were designed on the basis of a combination of a surfactant (AOT) and N,P,O molecular tweezers (DECHNPB and DOGAPA) connecting a phosphonic acid type moiety as cationic exchanger with an amido group as neutral donor chelating site. The extraction has been shown to be very efficient and highly selective over iron without AOT when DOGAPA was used and at a particular molar ratio of AOT of 40% and 60% of DEHCNPB. The mixed-system AOT/DEHCNPB and DOGAPA were tested on a large range of acidities by increasing the phosphoric acid concentration from 2 to 9 M and it was demonstrated that it remains efficient even at high acidity, which is often the case in industrial processes. Moreover, the systems showed a small temperature dependence, which allows for flexible operating conditions.

Keywords: Rare Earth elements, Phosphoric acid, Solvent Extraction, bifunctional ligands, Synergistic effect

SCALE: AN EMERGING PROJECT FOR EUROPEAN SCANDIUM SUPPLY

By

[1]Carsten Dittrich and [1,2]Bengi Yagmurlu

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Bengi Yagmurlu

ABSTRACT

Scandium (Sc) is one of the highest valued elements in the periodic table and an element which is usually grouped in REEs. The technological applications of this valuable element are unique, as it is a key component in producing solid oxide fuel cells, aluminium alloys especially for aerospace industry and 3D printing applications (SCALMALLOY®). Despite its various technological applications, Sc supply is limited due to its scarcity and the high production costs. Sc producing countries are China (66%), Russia (26%), and Ukraine (7%). Between 2010 and 2014, the European demand was covered from Russia (67%) and Kazakhstan (33%). Additionally, the end-of-life recycling rate of scandium was reported to be 0% (COM/2017/0490: FIN).

There is no production of scandium in Europe, but the region is home to many Sc industrial end-users (Airbus, II-VI, KBM Affilips, etc.). In fact, end-users like Airbus, are not deploying their Sc applications due to the lack of a secure Sc supply. As a member of EU H2020, the SCALE project sets about to develop and secure a European Sc supply chain through the development of technological innovations which will allow the extraction of Sc from European industrial residues (i.e. bauxite residue and TiO_2 production waste), ultimately upgrading it to pure scandium oxide, fluoride, metal and alloy. The industrially driven SCALE consortium covers the entire Sc value chain with 7 major European industries and further features 8 academic and research institutes and 4 engineering companies with track records in RTD.

Keywords: Scandium, Secondary Resources, Recovery, Bauxite Residue, Titanium Production Waste

ALTA 2018

Uranium-REE-Lithium Proceedings

By Product Uranium

OPPORTUNITIES FOR PRODUCING URANIUM WITHOUT DEVELOPING A NEW MINING OPERATION

By

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ABSTRACT

The current low uranium price trend makes it very difficult to justify new conventional uranium mining operations. The most common strategy to avoid conventional mining is to search for deposits amenable to in-situ leaching. However, another approach is to recover uranium as a by-product from existing or future operations producing other commodities.

Uranium has been commercially recovered as a by-product from copper concentrates and tailings, gold ores and tailings, phosphoric acid, polymetallic leach solutions, copper leaching solutions and rare earth leach solutions.

Representative commercial operations are reviewed, and current project developments and future prospects are discussed.

Keywords: Uranium, Low Uranium Price, Avoidance of Mining, By-Product Uranium Opportunities, Commercial Operations

DEPORTMENT OF RADIONUCLIDES DURING COPPER CONCENTRATE METATHESIS REACTIONS

By

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ABSTRACT

Iron oxide copper gold uranium (IOCG-U) ore deposits occur in South Australia. Copper from this ore type is typically extracted by crushing, grinding, sulfide flotation, smelting and electrorefining. South Australian IOCG-U ores also contain highly variable concentrations of uranium along with associated radionuclides such as thorium, radium, lead and polonium. Depending on the concentrations and mineralogical associations of these radionuclides, mineral processing may not be capable of producing a copper concentrate where is saleable into the global smelting pool. In these situations, hydrometallurgical treatment could be considered for separating the radionuclides from the copper. Copper metathesis can potentially be used to leach iron and certain radionuclides into solution while precipitating copper, thereby increasing the concentrate grade and purity.

Copper metathesis reactions can be undertaken at ambient conditions. However, the rate and extent of the reactions are increased with increasing temperature. In this research the influence of key process parameters on the copper concentration and radionuclide deportment are investigated. Solution and solid phases are assayed with the main mineral phases identified by x-ray diffraction. The samples are also characterized by alpha and gamma spectrometry to measure radionuclide deportment during the metathesis reaction. It was found that uranium and thorium are effectively leached, chloride strongly promotes lead and polonium leaching while radium leaching was not effective at the conditions tested.

Keywords: IOCG-U ore, Copper Concentrate, Copper Metathesis, Radionuclide Deportment

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Lithium Processing Forum

DESIGN CONSIDERATIONS FOR LITHIUM PILOT PLANTS

By

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ABSTRACT

The majority of design considerations that engineers, scientists and managers need to understand and investigate when executing a lithium pilot plant project generally encompass the same basic elements considered in the design and fabrication of all pilot plants, particularly hydrometallurgical pilot plants. Methodologies guiding small scale equipment design for processes involving solids and slurry handling, precipitation, filtration, ion exchange, solvent extraction and crystallization, as well as materials of construction selection, are common to both lithium and other hydrometallurgical pilot plants. Furthermore, project teams that apply large scale engineering methods to small scale lithium pilot plants involving highly corrosive solutions and abrasive solid-liquid mixtures will increase the likelihood of project delays, increased costs, poor operability and generally unsuccessful projects. Zeton will leverage its 32 years of experience in the design and fabrication of modular pilot, demonstration and small production plants to explore these general, hydrometallurgical and lithium processing design considerations in more depth and analyze how they affect lithium pilot plant design decisions.

Keywords: Process Development, Lithium Pilot Plants, Demonstration Plants, Small Scale Design and Fabrication, Slurry Handling, Materials of Construction

A GUIDE FOR ION EXCHANGE RESINS USED IN LITHIUM CONCENTRATE PURIFICATION

By

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ABSTRACT

Traditionally, selective chelating Ion Exchange resins possessing either iminodiacetic acid (IDA) or aminomethylphosphonic acid (AMPA) functional groups have been used for more than three decades in the chloralkali industry. Their superior selectivity characteristics facilitate the removal of trace impurities such as calcium, magnesium and other multivalent cations from a 300 g/L saturated sodium chloride brine solution.

Thus, it became obvious to transfer this established technology to a related technical challenge in hydrometallurgical processes: the hardness from lithium brines. Driven by the surge in demand for high purity battery grade lithium compounds, purification of lithium concentrates to meet the stringent specifications for typical contaminants is a critical step in the production of these chemicals.

There is evidence that conventional purification methods such as precipitation might be insufficient in many cases. Selective chelating ion exchange resins have proven to be a viable and reliable option when it comes to removal of trace levels of earth alkaline metals and other impurities from Li concentrates.

This paper gives a comprehensive overview about the use ion exchange resins in the purification of lithium brines, in particular the removal of residual quantities of contaminants such as calcium, magnesium, boron and other metals. Key aspects of ion exchange resins such as selection criteria, their physical and chemical characteristics, and the process and operating parameters which have an influence on the overall performance of the Ion Exchange resin purification systems shall be discussed.

Keywords: Ion Exchange, Impurity Removal, Lithium Brine Purification, Calcium and Magnesium Removal

WHAT IS BATTERY GRADE LITHIUM CARBONATE?

By

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Grant Harman

ABSTRACT

Currently there is no universal standard for the reporting of battery grade lithium carbonate analysis. It is common to hear that a lithium carbonate has been produced with a purity of > 99.5% but no clear understanding how this was determined or really what this means.

It is proposed in this paper to consider that a lithium carbonate sample could be described as having a lithium content or alternatively has a lithium carbonate purity. In the case of lithium carbonate content, the proposed formula is:

> *Lithium Carbonate Content = 100% – Water Content – Loss on Ignition – Acid Insolubles – Impurities.*

In the case of lithium carbonate purity, it is proposed that the formula is:

> *Lithium Carbonate Purity =100% – Acid Insolubles – Impurities*

This helps to explain why a bicarbonated lithium carbonate, can have a lower lithium content while having higher purity. This is due to some bicarbonated lithium carbonates having a higher percentage of lithium bicarbonate.

It is also proposed that a standard suit of impurities be included the reporting lithium carbonate purity and that the detection limits, stated in this paper, using ICP and or AA, be used as a standard.

Regardless of the Lithium Carbonate Content and or the Purity, the purchasers of battery grade lithium carbonate will use their own maximum acceptable concentrations for key impurities. There is only one published standard by the Chinese (YS/T582-2006).

There is considerable difference in opinion amongst battery component fabricators as to what impurities in the lithium carbonate are harmful. The paper presents some commonly stated key impurities and their reported influence on battery performance.

Keywords: Lithium Carbonate, Battery Grade, Lithium Carbonate Purity, lithium battery performance, detection limits, Battery Impurities.

REMOVAL OF MINOR AND TRACE IMPURITIES FROM LITHIUM LEACH LIQUORS

By

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Stephen La Brooy

ABSTRACT

It is relatively straightforward to extract lithium from minerals and clays. However, the number and amount of impurities that are co-leached can vary significantly. Limiting lithium losses during removal of impurities can pose significant challenges in the production of battery grade lithium chemicals.

Typically leach liquors from lithium mica ores and clays contain higher levels of impurities than from spodumene. Sighter testwork is required to identify the best technology to remove each impurity. This then needs to be followed by locked cycle testwork. It is necessary to simulate as many of the recycle loops as possible to determine the effect of each loop, to understand what level of impurity removal is possible and how impurities will build up in the circuit. In most cases a process bleed is required to limit the build-up to be able to produce battery grade lithium chemicals.

This paper presents the typical impurities found in the extraction of lithium from various ores and reviews some of the issues with removal of minor and trace impurities from leach liquors such as: boron, fluoride, caesium, rubidium, calcium and magnesium. Techniques discussed are chemical precipitation, crystallisation, adsorption, selective ion exchange and solvent extraction for the production of battery grade lithium carbonate.

Keywords: lithium carbonate, battery grade, impurities, boron, fluoride caesium, rubidium, calcium, magnesium, leach liquor, lithium chemistry, precipitation, crystallisation, adsorption, ion exchange and solvent extraction

MITIGATING INNOVATIVE PLANT START-UP RISK

By

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Andrea Langridge

ABSTRACT

The risk to on-time, on-budget ramp-up of new flow sheets and technologies is well known. Percentage of design throughput vs time curves as classified by McNulty are one way of representing how risk affects ramp-up. A mature flow sheet using proven equipment will reach name plate capacity within a year (McNulty - Type 1). Poorly defined projects applying a new flow sheet and new equipment and technology with minimal testwork, will NEVER reach nameplate throughput without significant capital injection (McNulty Type 4,5).

A review of plant ramp-up curves for flotation concentrators, HPAL nickel laterite, rare earth and lithium plants suggests the industry has not grasped how to mitigate these risks.

By their very nature, low head grade clay type ore deposits must be characterized as a McNulty Type 4 or worse. The more complicated the back end processing (for instance, the removal of trace contaminants for battery grade lithium carbonate) the more entrenched the project is with risk. However, with foreknowledge and well-conceived studies, a project may be raised to at least a McNulty Type 2 level of risk, suitable for investment.

This paper presents historical ramp-up curves for clay ore and other high-risk projects, as well as how risks can be identified and mitigated in the study phase.

Keywords: lithium carbonate, McNulty curve, risk mitigation, ramp-up, start-up, failure factors

THE SONORA LITHIUM PROJECT – MOLDING SUCCESS FROM CLAY

By

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ABSTRACT

Ausenco completed the feasibility study for the Bacanora Minerals, Sonora Lithium Project in early 2018 having spent the best part of three years performing studies to refine the process and mitigate project risks. This presentation will describe the project background, technical challenges and innovative engineering solutions that have made the Sonora Lithium project a world-class investment opportunity.

The Sonora Lithium project is located in the state of Sonora in north-west Mexico. The lithium is mineralised as polylithionite (clay). The measured and indicated resource is 291 Mt at 3.250 ppm lithium. The project consists of an open-pit mine with a mine plan for 19 years and a mineral conversion plant (MCP) to produce lithium carbonate.

The design output for the project will commence at 17,500 t/y of battery-grade lithium carbonate (Stage 1) for the first four years of the project, followed by a proposed expansion, by duplicating the plant, to produce a target minimum design output of 35,000 t/y (Stage 2). The Sonora Lithium Project is designed to produce up to 28,800 t/y of potassium sulfate per stage as a by product, for sale to the fertiliser industry.

Significant testwork was undertaken to define the flowsheet. Beneficiation was found to enable economic processing of the orebody. Roast chemistry was studied in detail to optimise lithium recovery and reduce reagent consumption and overcome limitations of conventional roasting equipment. The final flowsheet employs novel uses of established technology to achieve lithium recovery and impurity removal.

Variability test work was done to verify robustness of the flowsheet for both the beneficiation and extraction sections of the process. Locked cycle testwork was also completed to test flow sheet stability.

The study has resulted in an economic project worthy of investment. The economic analysis indicates a pretax net present value, discounted at 8%, of approximately $1,253M and an Internal Rate of Return of approximately 26%.

Keywords: Clay Ore Beneficiation, Roasting, Lithium Recovery, Mineral Conversion Plant, Crystalisation, Process Development, Test Work, Pilot Plant

AQUEOUS CHEMISTRY OF LITHIUM PRODUCTION

By

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Mike Dry

ABSTRACT

This paper presents an overview of the aqueous chemistry found in lithium processing. The sulphate and chloride systems are examined via modelling of the relevant chemistry. Examples used are the purification and extraction of lithium from sulphate solutions arising from processing spodumene and clay, as well as concentrating, purifying and precipitating lithium carbonate from a generic salar brine.

The recovery of lithium from brine entails the solar evaporation of large volumes of chloride brine, with various salts crystallizing as evaporation proceeds. However, it is also necessary to pump the concentrated brine, and pumping a solution saturated in any given salt can suffer from scaling that blocks lines and foul pumps. For that reason, the saturated brine is usually diluted with fresh water before being pumped. This partially undoes the evaporation, so the amount of water added is important. This paper includes a study of scaling tendencies versus dilution at the various stages of solar evaporation.

Concentrated chloride brines are corrosive, and this paper presents a brief look at the effect of pH on the rates of corrosion on carbon steel and duplex stainless steel in chloride brine.

Keywords: Lithium, potassium, brine, aqueous chemistry, scaling, corrosion, potash.

LEPIDOLITE PROCESSING USING SULPHATION BAKING: A COMPARISON AGAINST CONVENTIONAL PROCESSING FLOWSHEETS

By

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Adam J. Roper

ABSTRACT

Processing of hardrock Li-bearing minerals other than spodumene and petalite are challenging due to the reduced grades of Li and increased reagent costs associated with impurity rejection prior to production of a saleable lithium chemical concentrate. In the current climate however, Li-bearing micas such as lepidolite and zinnwaldite have attracted significant commercial attention as potential development targets.

A number of extraction processes for Li-bearing micas have been outlined in the public domain. Many of these processes have been reported for mineral concentrates, although some have examined the direct use of ore. Whether involving a mineral concentrate or ore, the unit processes employed to ‘crack’ the Li-bearing micas have typically involved air roasting, suphation roasting or acid leaching. A number of less common approaches such as sodium sulfide mechanochemical activation, chlorination and carbonate pressure leaching do not appear to have attracted any commercial interest.

Energy cost sensitivity is arguably the most important economic factor affecting the use of roasting and sulphation roasting process flowsheets. Moreover, despite reasonable rejection up-front of the major gangue elements, significant effort is still required to manage alkali elements (Na, K, Rb and Cs) in the downstream circuit, plus rejection of a extended suite of minor and trace impurities.

ANSTO Minerals has had significant exposure to both brine and hardrock Li projects for the last six years, providing us with a unique breadth of Li processing experience. From our perspective, aside from the energy cost sensitivity, a key risk to realising the value of Li-bearing micas via roasting and sulphation roasting process flowsheets is the need to remove alkali sulphates (Na and K) via crystallisation steps (evaporative and / or cooling) and the lack of specific impurity removal steps from the downstream hydrometallurgical processing steps.

As a possible alternative processing approach, we have examined a hybrid approach involving sulphation baking up-front and downstream processing specifically aimed at readily and cost effectively rejecting the major gangue elements, along with problematic minor and trace impurities. The development of a simple reagent-free, impurity rejection method early in the flowsheet has significantly simplified the overall process flowsheet. This presentation will outline and discuss this approach and its application to lepidolite ore.

Keywords: Lithium, Hardrock Processing, Lepidolite, Sulphation Baking, Process Development

THE MINERALOGY OF A PEGMATITE ORE – IMPLICATIONS FOR PROCESSING

By

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Mark Aylmore

ABSTRACT

A combination of analytical microscopy and mass spectrometry techniques have been used to detect and characterise different lithium minerals in a LCT-Complex spodumene-type pegmatite from the Pilbara region of Western Australia. Information collated by these techniques can be used to predict processing amenability. The mineralogy and liberation characteristics of samples were characterised using automated mineralogy techniques and the Li content and elemental distribution within minerals defined using instrumentation with secondary mass spectrometry capabilities. The majority of lithium is associated with spodumene particles with minor amounts of lithium bearing micas and beryl. A proportion of spodumene particles have undergone alteration with spodumene replaced by micaceous minerals of muscovite, lepidolite and trilithionite, as well as calcite. Some minor intergrowths of quartz, feldspar and spodumene were also evident in the coarser fractions.

Based on mineralogical observations in the current study, the majority of the main gangue minerals quartz, K feldspar and albite can be rejected at a coarse grind size of -4mm, to recover 90% of the spodumene with Li upgrade from 0.99-1.5 wt% Li to 3.0-3.5 wt% (6.5-7.5 Li2O). The iron content (81-1475ppm) in the spodumene is low and therefore make these spodumene concentrates suitable for use in ceramic and glass applications.

The high content of Rb (1 wt%) and the abundance of free grains makes K feldspar a source of rubidium, particularly in sample which has K feldspar in high abundance (21 wt%) and can potentially be recovered by reverse flotation technique.

The low concentrations of the Ta, Nb and Sn minerals identified in samples were found to be fairly well liberated and could be recovered by conventional gravity separation techniques

Keywords: Lithium, Mineralogy, pegmatite, liberation

FROM MANTLE TO MOTOR VEHICLE – THE QUEST FOR SUSTAINABILITY

By

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Adrian Griffin

ABSTRACT

The use of battery or so-called 'energy metals' is critical to the sustainability of the power storage systems that will drive our society into the future. And the sustainability of those power storage systems, particularly in electric vehicles ('EVs'), is directly linked to the sustainable delivery of their critical components into the supply chain.

At present, a number of metals – including lithium, nickel and cobalt in particular – are crucial to the production of lithium-ion batteries ('LIBs'). On the supply side, a common thread is their magmatic origins. With the cycling of basic magmas and basaltic crust, nickel and cobalt are recycled, whereas it's the recycling of sialic crust, subduction of sedimentary materials and re-melting that provide the geological inputs to concentrate lithium.

The first concentrations of both the base metals and lithium that created orebodies are recorded in the Archaean, and many survive today, having not been subjected to a second cycle in more than two billion years. Lithium in the orogenic zones, including the area termed the 'Lithium Triangle', located within Chile, Argentina and Bolivia, has been subjected to much more recent recycling/ concentration events, to the extent that lithium deposits are still actively forming in those zones today. The emanations of 'black smokers', which cause base-metal sulphides to appear on still- forming oceanic rifts and ridges, represent the base-metals counterpart.

At present, burgeoning demand for energy metals is creating supply shortages of lithium and cobalt and, if measures to create a sustainable cycle for these critical commodities are not implemented, nickel and copper may follow suit. Both the recovery of lithium from unconventional (and hitherto unconsidered) sources and the recycling of battery materials are becoming imperative. As the power storage industry matures, and the production of new batteries balances the quantities being decommissioned, recycling of the latter – over a period of far less than two billion years – could support a sustainable future. Some options for achieving that sustainability are examined in this paper.

Keywords: lithium, battery, SiLeach$^{®}$, VSPC, sustainability, cobalt.