ALTA 2019
18 - 25 May
Perth, Australia

24th Annual Conference Proceedings

Nickel-Cobalt-Copper Conference

Including

Pressure Acid Leaching Forum

Acknowledging the 20-year anniversary of the commissioning of the Bulong, Cawse and Murrin Murrin PAL projects.

Sponsored by

SOLVAY
asking more from chemistry®

24th Annual Nickel-Cobalt-Copper Event

ALTA Metallurgical Services, Melbourne, Australia
www.altamet.com.au

PROCEEDINGS OF
ALTA 2019 NICKEL-COBALT-COPPER SESSIONS

Including

Pressure Acid Leaching Forum

20-22 May 2019

Perth, Australia

ISBN: 978-0-9946425-5-4

Celebrating 33 years of service to the global mining and metallurgical industry.

ALTA Metallurgical Services was established by metallurgical consultant **Alan Taylor** in 1985, to serve the worldwide mining, minerals and metallurgical industries.

Consulting: High level metallurgical and project development consulting.

Conferences: ALTA conferences are established major events on the international metallurgical industry calendar. The event is held annually in Perth, Australia. The event comprises three conferences: Nickel-Cobalt-Copper, Uranium-REE-Lithium and Gold-PM.

Short Courses: Technical Short Courses are presented by Alan Taylor, Managing Director.

Publications: Sales of proceedings from ALTA Conferences, Seminars and Short Courses.

MetBytes: Free technical articles offering metallurgical commentary and insights.

Free Library: Conference proceedings and technical papers. The library is expanded regularly, providing a major ongoing resource to the industry.

ALTA Metallurgical Services PO Box 1211, Blackburn North, Vic, 3130, Australia
T: +61 (0)411 692 442 | www.altamet.com.au


SOLVAY

ALTA Metallurgical Services

Celebrating 33 years of service

ALTA Metallurgical Services (**ALTA**) was established by metallurgical consultant **Alan Taylor** in 1985, to serve the worldwide mining, minerals and metallurgical industries. ALTA offers a wide range of services and resources to the metallurgical industry.

Consulting

High-level metallurgical and project development consulting.

Short Courses

Practically-oriented short courses presented by Alan Taylor. Topics include treatment of nickel laterites, copper ore leaching, uranium ore processing, copper SX-EW, heap leaching and solvent extraction.

Conferences

ALTA 2020 is a world-class annual metallurgical conference, **celebrating its 25th year**, and a leading platform for innovation. The event will be held 23-30 May in Perth, Australia and comprises five technical conferences, three short courses and an international trade exhibition. It features a highly-focused program, topical forums and presentations from key international speakers. What do people say about ALTA? Read our Testimonials

Publications

Proceedings from ALTA conferences and seminars, and technical short courses manuals.

MetBytes

Free technical metallurgical articles offering metallurgical commentary and insights.

Free Library

Includes proceedings from 1995-2017 Nickel-Cobalt-Copper, Uranium-REE and Gold-PM conferences for free download (1460+ papers). A selection of ALTA 2018 papers is also available. The library is expanded regularly, providing a major ongoing resource to the industry.

Alan Tayor 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.

Major Commodities

- Nickel/Cobalt
- Copper
- Uranium
- Gold/Silver
- Base Metals

Areas of Experience

- Metallurgical Testwork Supervision
- Process Development
- Process Design
- Technical & Economic Evaluations
- Feasibility Studies
- Plant Design
- Project Engineering
- Commissioning
- Peer Reviews
- Client Representative for Projects
- New Technology Assessments
- Development & Presentation of Short Courses

Technical & Engineering Expertise

- Leaching – atmospheric tank, heap, pressure, bio, & in-place
- Solid/liquid separation
- Solvent extraction & ion exchange
- Electrowinning & electrorefining
- Precipitation
- Cyanidation & CIP/CIL
- Crushing, grinding & flotation
- Gravity processing

Enquiries: allisontaylor@altamet.com.au www.altamet.com.au

ALTA 2019 18 - 25 May Perth, Australia

Nickel-Cobalt-Copper, Uranium-REE, Gold-PM In Situ Recovery, Lithium Conference and Exhibition

Sharing ideas, innovations, technologies and projects

A special thank you to our sponsors, exhibitors, co-sponsors and partners.

Sponsors

Exhibitors

Partners and Co-Sponsors

CLICK TO NAVIGATE TO PAPERS

CLICK TO NAVIGATE TO PAPERS

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Opening Address

Nickel-Cobalt-Copper Opening Address

THE CHANGING LANDSCAPE OF THE COBALT MARKET

By

David Weight
President
Cobalt Institute, United Kingdom

ABSTRACT

Cobalt is not an obvious metal like copper, aluminium or steel, but it imparts special properties to a wide range of end-use applications from high performance alloys, hard metals, prosthetic joints, ICT, surface treatment etc., to industrial chemical processes (catalysts, driers, adhesives etc) all the way to the subtlety of being essential for medical diagnostics and the production of vaccines - without cobalt there is no pharmaceutical industry. This means that cobalt is virtually essential to most of the products we use in our daily lives such as smartphones, laptops, electric vehicles, ceramics/pigments, tyres, car safety systems, energy storage units, wind turbines, motors, medical treatments, for health and vitality, among many, many others.

However, it is the use of cobalt in rechargeable batteries that has fundamentally changed the dynamics of the market, making it no longer the ‘curiosity’ metal it once was but one of the key ingredients for the highly sought after low-carbon economy. Here, its role in the advancement of electric mobility will be a paradigm shift from the old established market.

Moreover, the cobalt industry faces numerous challenges such as chemical regulation, where its hazard profile is coming under considerable scrutiny from regulators and legislators worldwide; the need to demonstrate a sustainable profile, such as integrating with the circular economic model that is gathering in importance and the focus by civil society on responsible sourcing.

The Cobalt Institute, aims *“to promote the sustainable and responsible use of cobalt in all forms”*, acts as a knowledge centre and represents the voice of the cobalt industry on cobalt related health, safety, and environmental issues together with sustainability, responsible sourcing, global advocacy and general information on this important, technology enabling metal. We also promote co-operation between members, especially on key issues, and provide a mechanism for the development of independent information and support concerning the resources, responsible production and safe use of cobalt.

This presentation will look at the historical changes to the cobalt market, noting specifically the impact that cobalt containing Li-ion battery development has had, while looking at the challenges that cobalt faces in the global market place, from chemical management to responsible sourcing, and the role that cobalt plays in the development of the circular economy.

Keywords: cobalt, Cobalt Institute, lithium-ion, rechargeable battery, responsible sourcing, circular economy

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Keynote Address

THE FUTURE OF NI-CO-CU PROCESSING IN THE AGE OF LITHIUM-ION BATTERIES

By

Dr Bryn Harris
Managing Partner
NMR360 Inc, Canada

ABSTRACT

Batteries were first invented in the mid-1700s, based on the so-called Leiden (or Leyden) Jar capacitor, with the term having been coined by Benjamin Franklin in 1748. However, it was not until the early 1990s that lithium-ion batteries became a commercial reality, with the major components of these batteries being cobalt and, to a lesser extent, nickel. Since then, the advent of electric, battery-powered vehicles has seen an increased demand for both of these metals, to such an extent that some projections indicate a shortfall of cobalt by as soon as 2020. This presents the industry with a unique, and very serious, challenge, especially as far as cobalt is concerned.

Virtually all cobalt production is as a by-product of copper and nickel processing. Any increase, therefore, necessarily means a much higher (on a tonnage, not percentage, basis) corresponding increase in copper and nickel production. This is further exacerbated by the fact that in 2017, total annual cobalt production was only 110,000 tonnes, compared to 2.1 million tonnes for nickel and 19.7 million tonnes for copper, and that the cobalt to metal ratio in the ore is typically 1:100 for copper, although there are areas of the DRC where it is 1:10, and 1:10 for nickel. Based on current production data, known land-based reserves of cobalt will last for 70 years, and those for copper and nickel for approximately 40 years. Any increase in demand will, therefore, reduce this time frame. Furthermore, 58% of world cobalt production in 2017 emanated from the DRC, most of which was sold into China. This is bringing mining practices in the DRC into focus, and particularly artisanal mining using child miners. The social desire to eliminate such practices has contrasted with the very real economic hardships experienced by these miners in one of the world's poorest, yet, ironically, mineral-richest countries.

As with a previous time when the cobalt price hit US$30/lb in the early 1980s, much effort is now being directed to replacing cobalt in batteries as it was then in super magnets and alloys. Indeed, some battery manufacturers are trying to eliminate its use completely. However, the unique (and far superior) structural properties of cobalt oxides suggest that this will again be as unsuccessful as it was in the 1980s, at least in the near term when cobalt supply is expected to be at breaking point.

The paper briefly reviews the interconnectedness of the cobalt, nickel and copper markets, and presents a basic understanding of the role of cobalt in batteries, and why it seems unlikely, at the present time at least, to be replaced on a large scale. A summary of current, past and proposed cobalt/nickel and cobalt/copper processing flowsheets is given, together with a discussion of where new sources of cobalt might arise from. In this respect, the challenges facing the nickel (and consequently, by-product cobalt) industry are reviewed, where with sulphide reserves becoming depleted, increased focus will be on laterites. Processing of laterites is not easy, and with HPAL laterite plants struggling to be viable, this will likely further distress the supply of both cobalt and nickel. Similarly, the lack of any major new copper discoveries is stressing the copper markets. Finally, it is conjectured that the main short-term source of cobalt supply will be from recycled batteries themselves, since market forces, environmental regulations and simple resource sustainability mandate that this must be so. That being the case, there follows a discussion of battery recycling technology, which is very much more complex than might at first be envisioned, has not been well-managed to date, and is attracting a lot of not necessarily positive attention. In the longer-term, however, it is likely that harvesting of deep-sea manganese nodules and cobalt crusts will become the main source of supply.

Keywords: cobalt, copper, nickel, battery(ies), supply-demand, DRC, Cuba, China, recycling, lithium-ion, laterites, deep-sea nodules.

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Feature Project

THE CLEAN TEQ SUNRISE PROJECT – A ONE STOP SHOP FROM NICKEL LATERITES TO LITHIUM ION BATTERY FEEDSTOCK – PROJECT UPDATE

By

Stephen Grocott, Tim Harrison and Dave McFarlane

Clean TeQ Limited, Australia

Presenter and Corresponding Author

Stephen Grocott

ABSTRACT

The Clean TeQ Sunrise project (formerly known as the Syerston project) is in NSW in a well-established minerals processing region. It has access to nearby and high-quality infrastructure and a skilled workforce. In 2018, it received the last of the necessary Government and regulatory approvals. Having completed a Definitive Feasibility Study in Q3-2018, it commenced front-end engineering design which is due for completion in Q3, 2019. The Metallurgical Corporation of China (MCC) (who built and operate the Ramu nickel laterite pressure acid leach facility in Papua New Guinea) has been appointed as a key project delivery partner. A fixed-price, EPC contract will be finalised with MCC in 2019.

The Clean TeQ Sunrise ore body is one of the largest, high-grade cobalt deposits outside the DRC and is also a significant nickel deposit as well as a very large and high-grade scandium deposit.

The nickel/cobalt world has changed a great deal since the last pressure acid leach project (Ambatovy) was developed. The current, and more importantly the future growth in demand for high-purity lithium ion battery (LIB) cathode feedstocks, especially nickel sulfate, is changing the end-user market for nickel and cobalt. Corresponding changes must be made in the producer processes and technologies.

The Clean TeQ Sunrise project is designed to:

- Supply some of the ballooning demand for high purity nickel/cobalt LIB-cathode feed
- Maximise the value of the accommodating geometallurgical characteristics of the Clean TeQ Sunrise deposit
- Capture the learnings from the past 11 nickel laterite pressure acid leach (PAL) projects
- De-risk some of the problems encountered with past PAL projects by utilising Clean TeQ's continuous resin-in-pulp technology for metal recovery and purification
- Produce a direct feedstock for the manufacture of lithium ion battery cathodes

This presentation will cover

- Background of the Clean TeQ Sunrise project
- Projections for electric vehicle-driven nickel and cobalt demand
- Implications for nickel products (nickel pig iron, ferronickel, Class I metal and nickel sulfate)
- Clean TeQ Sunrise mineralogy and geochemistry
- Incremental process design improvements
- Continuous resin-in-pulp (cRIP) recovery and purification of nickel and cobalt sulfate and how this technology is an enabler for direct production of LIB feedstocks
- Upstream and downstream benefits of a continuous resin-in-pulp metal recovery process
- Capturing the scandium by-product
- How to create a conservative process design – sensors and analysers, process simulation, piloting, hydrometallurgical fundamentals and process modelling

Keywords: Clean TeQ, Nickel, Cobalt, Scandium, Continuous Resin in Pulp, Ion Exchange, Pressure Acid Leach, Impurity Rejection, Pilot Plant, Sunrise, Electric Vehicles, Lithium Ion Battery.

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Battery Metals

THE FUTURE BATTERY INDUSTRIES COOPERATIVE RESEARCH CENTRE (FBICRC) AND ITS ROLE TO CATALYSE GROWTH IN INDUSTRIES ACROSS THE BATTERY VALUE CHAIN

By

J.J. Eksteen

Future Battery Industries Cooperative Research Centre (FBICRC)
Western Australian School of Mines, Curtin University, Australia

Presenter and Corresponding Author

Jacques Eksteen

ABSTRACT

Australia is endowed with all the metals and minerals that is required for modern rechargeable batteries, whether they be conventional lead acid batteries, lithium ion batteries, vanadium redox flow cell batteries or one of the many new generation batteries that seem to make the news headlines on a regular basis. These batteries have become prime enablers to significantly increase the uptake of renewable energy technologies.

The Future Battery Industries Cooperative Research Centre (FBICRC) is a CRC that focusses on the industry growth of all industries related to the battery values chain. This includes battery mineral and metal extraction (e.g. lithium, nickel and cobalt), processing and refining to battery grade intermediates, the manufacture of anode, cathode and electrolyte precursors and the subsequent manufacture of cells and cell assemblies into battery systems. Subsequently, the development of batteries for deployment specific demands are researched, as well as the repurposing and recycling of end-of-life batteries. The FBICRC therefore seeks to catalyse rapid growth in the battery value chain by promoting and funding priority projects that will enable the Australian industry to develop cost effective processes to produce electrochemical precursors, cells and batteries that meet the deployment needs in areas where Australia can be internationally competitive. Essential to the FBICRC is the cost-effective, environmentally responsible and ethical extraction and refining of battery metals/minerals such as lithium, nickel, cobalt, manganese, vanadium and graphite and the promotion of a transparent, auditable production chain to capture Australian provenance from source through manufacturing.

This paper will present an overview of the FBICRC, its programs and project themes and the importance of hydrometallurgy in its research scope.

Keywords: FBICRC, Batteries, Nickel, Cobalt, Lithium, Battery Value Chain

DESIGN OF BATTERY GRADE PURITY NICKEL AND COBALT SULPHATE CRYSTALLISATION PLANTS

By

Nipen M. Shah, Stuart Bradbury, Dave M. Rogans and John J. Warner

JordProxa Pty Ltd, Australia

Presenter and Corresponding Author

Nipen M. Shah

ABSTRACT

The safety and performance of lithium ion batteries is greatly affected by impurities in the chemical precursors. It is imperative that these chemicals are produced to the highest purity, exceeding standards which were previously deemed acceptable.

Novel flowsheets are being developed incorporating purification steps (solvent extraction & ion exchange) to produce liquors which are sufficiently pure that the crystals which may be recovered from them will meet the current stringent specifications. Historically crystallisation has at times been regarded as a unit operation which recovers a product of a purity which matches the feed solution. This assumption overlooks the potential of the crystallisation process to selectively recover a species with minimal entrainment of impure mother liquor. Consequently, the importance of crystallisation as a final purification step in producing highly pure crystals has often been understated.

A properly designed crystalliser producing large, well-formed crystals enables less entrainment of liquor on the crystal surface and allows for improved washing to enable the achievement of the highest purities possible. The lower levels of moisture entering the dryer that are achieved significantly reduces the overall energy requirements of the plant. A further technical innovation is the incorporation of mechanical vapour recompression (MVR) technology into nickel sulphate crystallisers, a manifestation of the wholesale improvements in the design and development of the turbo fan. This halves the energy input per ton of nickel sulphate produced.

This paper describes novel crystalliser design features for the production of battery grade nickel sulphate hexahydrate and cobalt sulphate heptahydrate products at minimum energy consumption. It will compare the operating conditions, crystalliser types, product dryer types, preferred energy source and the control of product purity.

Keywords: nickel sulphate, cobalt sulphate, crystallisation, MVR, TVR, purity

PROCESS MODELING AND SIMULATION IN THE BATTERY ERA

By

[1]James Groutsch, [2]Kevin Charlesworth, and [3]Sargon Lovkis

[1]MetEng Pty Ltd, Australia
[2]METSIM International LLC, Australia
[3]Sargon Engineering Pty Ltd, Australia

Presenter and Corresponding Author

James Groutsch

ABSTRACT

Process modeling and simulation has been the basis for process development, plant design, and operations optimisation for centuries. The earliest models were built as thought experiments, later models were developed by hand-written calculations and use of graph paper, and we now use computers.

Georg Bauer's (Agricola) "De Re Metallica", published in 1556, provided a solid basis for thinking about the development of processes to produce the metals required of that era. Arthur Taggart's "Handbook of Mineral Processing" copyright 1927 provides a wealth of information on crushing, grinding, screening, and flotation that is still one of the best sources of plant data on mineral processing today.

Many of the mathematical modelling methods for crushing, screening and grinding - that are still the basis for many models used today - were developed in the 1960's. The general use of these methods, and their integration to processes with recycles became possible in the 1970's. Integration of mineral processing and chemical processes with control strategies became available in the 1980's.

We are now in a new era of metallurgical pursuit – driven by the transition from the consumption of fossil fuels to the harnessing of renewable energy sources. Processes are now required for production of high-quality metal-based materials, often from low grade sources, and in some cases by re-processing old tailings materials.

This paper looks at the history of process modelling and simulation software, a few of the key people who have made significant contributions to this field - and shows how METSIM provides a complete tool-kit for the development of processes and plant designs in the Battery Era and beyond.

The Battery Era provides many business opportunities, but there are many "rabbit holes" of technical complexity with "money and time traps" set along many of the paths. This paper aims to help understand the requirements and make good decisions about process development, modelling and simulation.

Keywords: Batteries, Copper, Nickel, Cobalt, Lithium, Thorium, Cesium, Alumina, Mineral Processing, Flotation, Hydrometallurgy, Pyrometallurgy, Process Economics, Plant Design

ENVIRONMENTAL EVALUATION OF MAKING NICKEL SULPHATE

By

[1]Mike Dry, [2]James Vaughan and [3]Will Hawker

[1]Arithmetek Inc., Canada
[2]University of Queensland, Australia
[3]Pure Battery Technologies, Australia

Presenter and Corresponding Author

Mike Dry

ABSTRACT

Nickel sulphate, conventionally made from pure nickel metal, is a major input in the manufacture of lithium ion batteries. This paper presents a study of the manufacture of nickel sulphate for the manufacture of lithium ion batteries via a number of routes, examining the environmental aspects, i.e. water consumption and the carbon emissions, associated with a number of processing options.

The routes selected for processing limonite to intermediate products are:

- HPAL, making MHP;
- Caron, making BNC;
- Goro, making NiO;
- RKEF, making NPI.

The routes selected for producing nickel sulphate hexahydrate from the intermediate products are:

- MHP leaching, Co SX-EW, Ni EW and redissolution, crystallization of $NiSO_4{\bullet}6H_2O$;
- MHP leaching, Co SX-precipitation, Ni EW and redissolution, crystallization of $NiSO_4{\bullet}6H_2O$;
- MHP leaching, Co SX-precipitation, crystallization of $NiSO_4{\bullet}6H_2O$
- Selective acid leaching (SAL) of MHP, purification, crystallization of $NiSO_4{\bullet}6H_2O$;
- Dissolution of NiO and recrystallisation of $NiSO_4{\bullet}6H_2O$;
- Dissolution of BNC and recrystallisation of $NiSO_4{\bullet}6H_2O$;
- Oxidative leaching of NPI with iron rejection, Co SX-precipitation, Ni EW and re-dissolution, crystallization of $NiSO_4{\bullet}6H_2O$;

Calculated CO_2 and water footprints are presented for each route examined. The route found to have the lowest CO_2 footprint overall is the HPAL primary circuit coupled with the SAL route to $NiSO_4$. The HPAL-SAL and the Goro-NiO routes have very nearly the same overall water footprint. The Caron route was found to have substantially higher CO_2 and water footprints than HPAL and Goro. The RKEF circuit has a CO_2 footprint almost triple that of the Caron circuit.

Keywords: Nickel sulphate, Batteries, Economics, Emissions, CO_2, Water

DEVELOPMENT OF SELECTIVE NICKEL LEACHING TECHNOLOGY FOR REFINING MIXED NICKEL-COBALT HYDROXIDE PRECIPITATE

By

[1]James Vaughan, [1]Stefan Lakemond, [1,2]William Hawker, [2]Stephen Wilmot, [2]Richard Wittig, and [2]Bjorn Zikarsky

[1]The University of Queensland, Australia
[2]Pure Battery Technologies, Australia

Presenters and Corresponding Authors

James Vaughan and Bjorn Zikarsky

ABSTRACT

Conventional refining of mixed nickel-cobalt hydroxide precipitate targets high leaching extractions of both nickel and cobalt. Nickel-cobalt separation is subsequently achieved using solvent extraction. An alternative approach is to largely separate nickel from cobalt in a selective leaching step which takes place in strongly oxidising but mildly acidic conditions. This provides a streamlined route to obtain a range of nickel products as well as a leach residue which is an upgraded cobalt concentrate. The process economics were previously shown to be favourable for an electroplated nickel product scenario. The economics are even more promising for high purity nickel sulphate salts for the emerging battery market. The selective leaching technology has now been licensed from UniQuest to Pure Battery Technologies, a company that will demonstrate the technology at a commercially viable scale. This paper describes aspects of the process development, demonstration plans along with a discussion of the commercialisation feasibility development process.

Keywords: mixed nickel-cobalt hydroxide, nickel sulphate, leaching, crystallisation, process development, demonstration plant, commercialisation, feasibility study, financial model, risk, capital cost, operating cost, safety in design

Nickel-Cobalt-Copper Proceedings

Laterite Processing

THE PLATINA SCANDIUM PROJECT – ONE STEP CLOSER TO PRODUCTION

By

[1]Boyd Willis, [2]Corey Nolan and [3]John Horton

[1]Boyd Willis Hydromet Consulting, Australia
[2]Platina Resources Limited, Australia
[3]ResEval Pty Ltd, Australia

Presenter and Corresponding Author

Boyd Willis

ABSTRACT

A definitive feasibility study (DFS) was completed for the Platina Scandium Project (PSP), previously known as Owendale, in 2018. The DFS demonstrates very robust financials. Based on a mine life of 30 years, the project generates an after-tax NPV in real terms (8% discount rate) of USD 166 million (AUD 234 million), post-tax IRR of 29% and a payback period of 5.3 years. The DFS is based on a processing plant designed to initially produce 20 t/a of scandium oxide at a capital cost of USD 48.1 million (Stage 1), expanding in Year 4 to 40 t/a of scandium oxide for a very low incremental capital cost of USD 11.1 million (Stage 2). The life-of-mine cash operating cost is USD 525/kg of scandium oxide.

The strength of the PSP is the very large and high-grade scandium resource, which is amenable to simple, low-cost, open-cut mining techniques at a low waste to ore ratio (1.9:1). The processing facility will utilise an existing industrial site in Condobolin, Central New South Wales, 70 km by road south-west of the mine site. This unique site provides access to existing infrastructure – labour, water, power, rail, and sealed roads – which results in lower capital costs and simplifies the permitting and approvals process. A key focus of the process plant design and equipment selection was to facilitate the transition from Stage 1 to Stage 2 in such a way that the combined capital costs after the Stage 2 expansion are competitive with projects aiming to commence at similar or higher production rates. This paper summarises the key facets of the DFS and discusses some unique opportunities that the small scale of the project presented for HPAL circuit design and equipment selection, as well as design initiatives that facilitated the Stage 2 doubling of capacity at a very low incremental capital cost.

Keywords: Platina, scandium, scandium oxide, feasibility study, resource, Owendale, financials, NPV, IRR, capital cost, operating cost, HPAL, plant design, equipment selection, small scale, expansion.

PRODUCING FERRONICKEL AS A PROCESS ALTERNATIVE FOR NICKEL LATERITE PROCESSING

By

Damian Connelly

METS Engineering Group Pty Ltd (METS), Australia

Presenter and Corresponding Author

Damian Connelly

ABSTRACT

Pyro metallurgical and hydrometallurgical processing for nickel laterites has been implemented on a commercial scale for many deposits. High pressure acid leaching (HPAL) has experienced many issues since its development and suffers from issues such as operability, high acid consumption, environmental complexities, low availabilities and high maintenance requirements.

The production of ferronickel by reduction smelting (RKEF) is an attractive alternative to this process which also produces a highly desirable product in ferronickel. Ferronickel has a minimum nickel content of 15% and contains considerably less phosphor and sulfur per tonne of nickel than nickel pig iron (NPI). The production of ferronickel from nickel laterites is reviewed and compared to alternative nickel laterite processing options.

Nickel-Cobalt-Copper Proceedings

Project Risk

IS YOUR CLASS 1 NICKEL DEVELOPMENT BIASED FOR SUCCESS OR FAILURE?

By

Grant Wellwood

Jenike & Johanson Pty Ltd, Australia

Presenter and Corresponding Author

Grant Wellwood

ABSTRACT

Driven by explosive demand for electric vehicle (EV)'s, the dynamics of the nickel market are changing with battery grade nickel poised to become the second-largest end-use application. The high purity form required for batteries ("Class 1") attracts a premium (nom. 35% over LME reference), which combined with increased demand has resulted in a rush to develop the operations that can capitalise on the opportunity.

Rushes are an exciting time in the Mining and Mineral Processing (M&MP) sector, where expectations and sentiments are high and there are many exhilarating projects being proposed. Developments in pursuit of the Class 1 nickel prize generally share common attributes including the need to the process higher volumes of lower grate laterite ore and more complex beneficiation flowsheet to produce battery grade chemicals.

Regrettably the most likely outcomes are disappointment and loss, as it is a historical fact that only 5% of sanctioned M&MP projects meet their self-proclaimed criteria for success, especially if they require multi-step processing and chemical transformation(s) to achieve high purity. Extensive research into this systemic underperformance over the last 50 years continually flags the quality and completeness of the front-end loading or "study–phase" that precedes project sanctioning, as the most telling factor in terms of the success or failure of M&MP projects.

Despite this very consistent conclusion, study–phase is still often seen as a waste of time and effort that would be better spent just "getting on with it". While this posture is untenable and pure folly in the context of the huge investments involved, it sometimes prevails or leads to a reduction in the quality and integrity of this important development step. To help ensure minimum standards are maintained, the Stage-Gate (S-G) project management framework is frequently mandated. Although universally acknowledged as the best way to manage the risks of M&MP projects and maintain study–phase quality, S-G is not infallible straight out of the box and application experience is essential if the process is to be anything more than tokenism.

The main weakness is not the S-G framework per-se, but it does occur in-process during the gating step(s). In the majority of application disappointments, researchers trace the primary failure point back to a deviation from intention due to Gatekeeper misjudgement. This common cause is independent of the country, company or seniority of the individual(s) involved and can be linked to a universal human trait; cognitive biases. As the extent and impact of these biases is related to project pressure, the risk profile is heightened during rushes.

On the basis that a bias recognised, is a bias neutralised, this paper reveals the most common and impactful Gatekeeper biases associated with M&MP development projects. Each S-G judgement bias exposed is described in detail, illustrated in the context of personal anecdotes and accompanied by suggested counter measures. A worked example featuring a mega M&MP project failure due to Gatekeeper bias is also presented, with a view to putting the presented insights into a more familiar process context, aiding danger sign recognition and therefore avoidance in your own Class 1 nickel development project context.

Keywords: Bias, Stage-Gate, study–phase, failure, nickel, Ravensthorpe, EV

FIRE AND EXPLOSION RISKS IN COMPLEX HYDROMETALLURGY FACILITIES

By

Larry J Moore

FM Global, USA

Presenter and Corresponding Author

Larry Moore

ABSTRACT

Complex hydrometallurgical processing such as pressure leaching of platinum group metals (PGM), gold, nickel laterites, bauxite, hydrogen reductions of metals, and solvent extraction of copper, uranium, nickel and other metals present high risks. These processes have unique and difficult-to-understand and quantify hazards. Fire, explosion and mechanical breakdown incidents present significant physical property asset exposures as well as the potential to shut down a facility indefinitely, causing major business interruption exposures. The shutdown of a major production facility can impact both market share and global metal prices and, in some cases, have caused a facility to never regain pre-loss production. Pressure leaching autoclaves have experienced internal fires due to reaction of oxygen with titanium and internal combustion explosions due to unanticipated formation of hydrogen by the reaction of acids with fresh metals. Overpressure of an autoclave with resultant explosion damage to surrounding structures can occur should acid enter an annular space between the liner and the shell, causing thinning and a reduction in mechanical integrity. Abrasive slurry solutions have also eroded and failed pipes – notably at elbows - causing rapid release of vapor clouds of corrosive acid into the atmosphere damaging the plant and the environment. If these types of hazards are not detected by modern and systematic inspection techniques such as non-destructive examination (NDE) they could go unnoticed until an event suddenly happens, often without warning.

Potential risk incidents are reviewed in this paper with loss case studies to demonstrate the impact and causes of real-world events. Solutions to prevent or protect against episodic risk incidents in hydrometallurgical processing plants are presented, focusing on pressure leaching. The use of process safety management – including vigorous and routine process hazard analyses and management of change programs – to better understand and manage these risks is also explored.

Keywords: hydrometallurgy risks, pressure leaching processes, fires and explosions, property risk management, process safety management, process hazard analysis, non-destructive examination.

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Feature Project

FIRST COMMERCIALISATION OF THE ALBION PROCESS™ FOR COPPER

By

Paul Voigt, Glenn Stieper and Mike Hourn

Glencore Technology, Australia

Presenter and Corresponding Author

Mike Hourn

ABSTRACT

Sable Zinc Kabwe Limited ("**Sable**") is a base metal processing plant two kilometres south of Kabwe Town in Central Province, Zambia. The region has a rich history in mining and minerals production, being a major lead and zinc producer from the 1900's up to the mid-1990s. In 2006, a copper plant was built at the Sable processing site to treat third-party copper and cobalt oxide ores and concentrates. The oxide leaching plant included whole ore leaching, solvent extraction and production of 8,000 tpa LME Grade A copper cathode. The plant was placed on care and maintenance in 2014, and Glencore Plc ("**Glencore**") took the opportunity to convert the plant using a minimal budget, to an Albion Process™ plant to treat local refractory copper concentrates unsuitable or uneconomic for smelting.

The Albion Process™ plant comprises an M100 IsaMill™ operating in acidic conditions such that raffinate from the downstream process is recycled back to slurry the concentrate delivered to site thus maximising copper tenor in solution and reducing water consumption. The finely ground concentrate feeds an oxidative leaching plant using the existing stainless steel oxide leach reactors converted to Albion Process™ duty by fitting HyperSparge™ supersonic oxygen injectors and gas dispersing agitators. The leached slurry is then directed to the existing solid/liquid separation equipment and the PLS is then sent to the existing SX/EW plant. The plant also allows for cobalt recovery from the raffinate.

The plant was designed based on testwork on regional copper concentrates. The plant was designed to toll treat a range of concentrates and so the design was flexible with the flexibility of the Albion Process™ being one of its distinct advantages, the plant was ideally suited for tolling regional concentrates.

The plant was commissioned and ramped up in six weeks using low grade Zambian copper concentrate, and produced exclusively LME Grade A copper with over 99% leach recovery in the Albion Process™ circuit.

Keywords: Albion Process, IsaMill, Oxidative Leaching, Copper Concentrates

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Extraction & Purification

ACORGA™ CR60 CRUD MITIGATION REAGENT - COMMERCIAL TRIALS IN NORTH AMERICA AND AFRICA

By

[1]Bravo Mbao, [2]Adam J. Fischmann, [2]Laurent Cohen, [2]Luis Moya, [2]Michael Moser, [2]Tyler Mccallum and [2]Owen Tinkler

[1]Solvay EMEA, Zambia
[2]Solvay USA

Presenter and Corresponding Author

Bravo Mbao

ABSTRACT

Crud is a ubiquitous challenge for copper solvent extraction (SX) plants around the world. This solid-stabilized emulsion forms when aqueous leaching solutions containing fine suspended solids are mixed with an immiscible organic phase. Without intervention, crud builds up in the settler and can eventually spread throughout the SX plant, causing higher rates of organic loss, higher aqueous in organic entrainment (leading to cathode quality issues or increased electrolyte bleeds) and downtime for the operation. Many current techniques for handling crud in SX plants are reactive (i.e., periodically, the crud is physically removed and treated via different mechanical techniques). Some operations endure periodic shutdowns to drain and clean the settler.

Taking a radically different approach, Solvay developed a new additive (ACORGA™ CR60) to dose directly in the PLS prior to the extract stage and, which, under certain conditions, will inactivate the crud formation process. While this development is still in progress, the results from laboratory-scale and larger-scale on-site tests have demonstrated that crud formation can be dramatically reduced while maintaining SX plant performance. The solids that formerly accumulated in the settler instead report to the raffinate pond, anticipated to greatly decrease costly downtime and organic losses associated with settler cleanout. During the tests, no adverse effects on physical or metallurgical SX plant performance were seen, and laboratory testing specifically demonstrated that ACORGA™ CR60 does not affect oxime stability or cathode quality.

Keywords: Solvent Extraction, Crud Formation, Copper, Emulsion, ACORGA™ CR60

FURTHER DEVELOPMENT OF THE CONTINUOUS ION EXCHANGE PROCESS FOR COPPER RECOVERY FROM FINES

By

[1]Pavel Spiridonov, [2]William Skinner, [2]Jonas Addai-Mensah, [3]Hans Hein and [3]Ricardo Hein

[1]InnovEco Australia, Australia
[2]University of South Australia, Australia
[3]Oryxeio Ingeniería, Chile

Presenter and Corresponding Author

Pavel Spiridonov

ABSTRACT

The presence of large amounts of fines in mineral feed ores presents significant issues for their processing. In particular, clays and other fines may form impermeable layers in the heaps which significantly reduce lixiviant percolation and, hence, the target metal recovery rate. To eliminate such an issue, InnovEco Australia has developed a new method for processing fine minerals based on ion exchange technology. The recovery of copper from fine ores achieved in preliminary bench top tests and mini pilot plant trials was high, in the range 90-96%.

This paper demonstrates the results of the technology validation via building a plant prototype. The prototype simulates a continuous ion exchange process that enables the processing of fine minerals (up to 300 microns). Mineral ore sample from a South Australian copper mine was used in the tests. Continuous operation test trials confirmed high copper recovery rates, short residence time and lower acid consumption in comparison with traditional technologies.

The plant prototype trials have been validated independently by the research team of the University of South Australia by process observation and analyses of the solid and liquid samples before and after processing.

This project has been supported by the Australian Government through Accelerating Commercialisation, an element of the Entrepreneurs' Programme.

Keywords: Copper Recovery, Ion Exchange, Resin in Pulp, Resin in Moist Mix, Fine Ore Processing

APPLICATION OF SOLVENT-IMPREGNATED RESINS FOR PRODUCTION OF HIGH-PURITY NICKEL AND COBALT LIQUORS

By

Johanna van Deventer and William McDevitt

Purolite, South Africa

Presenter and Corresponding Author

Johanna van Deventer

ABSTRACT

The growth of the electric vehicle industry has resulted in an increased demand for metals used in the production of batteries, most notably nickel, cobalt and lithium. The mandate from battery producers is for metal salts of high purity, with the majority of impurities required to be at levels of less than 5 mg/kg. Conventional precipitation and solvent-extraction methods are not always able to produce liquors of the desired purity, while ion-exchange resins are highly suitable for the task.

Although the current available ranges of ion-exchange resins lack the appropriate selectivity for certain target impurities in a background of highly concentrated nickel or cobalt sulphate, suitable solvents do exist. The use of solvent-impregnated resins combines the best of both worlds, i.e., the selectivity of the solvents with the ease of engineering of ion-exchange resins.

This paper discusses the application of two new solvent-impregnated resins for the removal of specific impurities from nickel and cobalt sulphate liquors.

Keywords: solvent-impregnated resins, ion exchange, nickel, cobalt

MEMBRANE TECHNOLOGY: ADVANCES IN BASE METAL PROCESSING

By

[1]Ilya Krougly, [1]Johannes Herrmann and [2]Les-Lee Thompson

[1]AMS Technologies, Israel
[2]Chimerical Technology, South Africa

Presenter and Corresponding Author

Ilya Krougly

ABSTRACT

The hydrometallurgical extraction of base metals from various host ores is a reagent intensive process resulting in continuously decreasing metals concentrations and large processing volumes. Nanofiltration membranes have been proven across copper, cobalt, nickel and zinc applications to concentrate the target metals and simultaneously recover the reagents (acid or alkali).

Recently developed low MWCO (100 Da) nanofiltration membrane enables recovery of acid and further purification of the stream for reuse as high-grade acid in the process. The membrane is chemically stable across the entire pH range as well as at elevated temperatures up to 80 °C.

This paper contains a summary of case studies based on low-MWCO membrane used in the base metal applications individually as well as in combination with other NF membranes. The case studies include:

- Concentration of zinc from a PLS solution;
- Concentration of cobalt in electrolyte;
- Acid recovery prior to neutralization in copper leaching;
- Nickel concentration from tailings pond water.

Keywords: Membranes, Nanofiltration, Acid recovery, Metals concentration, Copper, Cobalt, Nickel, Zinc.

UANIUM RECOVERY FROM COBALT LEACH SOLUTION IN THE DRC

By

Willem Vriesendorp

Clean TeQ Water, China

Presenter and Corresponding Author

Willem Vriesendorp

ABSTRACT

Clean TeQ water designs and supplies equipment for waste and process water treatment, impurity removal and metal recovery from process streams.

One of Clean TeQ Water core technology relies on Continuous Ionic Filtration (CIF). CIF provide both ion exchange and filtration equipment in which a packed bed of resins move downwards in counter flow to the liquid moving upwards. In such systems loaded resins are removed from the bottom and moved to the next column through airlifts.

The technology has been successfully applied for different types of water and process treatment throughout the world. This specific case focuses on the recent results from a large scale IX-CIF plant in the DRC for removal of Uranium impurities from a Cobalt stream. This Uranium polishing plant was designed and supplied by Clean TeQ Water in cooperation with Multotec, Clean TeQ's partner in Africa. The results from site show the Uranium concentration reduced from around 40 to around 4 ppm from a 20,000 m3 per day 1.5 pH raffinate stream. The next step is for the end-user to increase the pH of the incoming raffinate (as per design) such that the outgoing Uranium concentration will reach below 1 ppm.

Using such ion exchange CIF system provides a number of benefits compared to regular resin exchange systems including

- The ability to accept up to around 150 mg/l solids which is continuously filtered out and removed by the moving packed bed. This is substantially higher than would be acceptable for any fixed packed bed system which would require expensive pre-treatment.
- Limited space requirements and capex due to the combination of packed beds and counterflow. This is in contrast to fluidized or stirred reactors that require more space and potentially require long series of vessels to create similar counter flow results.
- Low output impurity levels and a highly concentrated waste stream (uranium strip liquor), making disposal or further processing easier.
- The ability to quickly adjust to changing feed flow or concentration conditions by adjusting the speed of resin flow.

Clean TeQ Water applies this technology not only for Uranium removal, but also for the recovery from process water and tailings of valuable metals (e.g., Ni, Co, Cu, Au), for the removal of other pollutants (e.g., Se, As, Sb) and for nutrient removal (P, N)

Keywords: Uranium, Ion Exchange, Cobalt, Impurity removal, polishing, Waste water treatment, Clean TeQ, Sunrise, DRC

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Filtration

REAGENT AND PRODUCT RECOVERY FROM LEACHED ORE SLURRIES USING FILTER PRESSES

By

[1]Andrew Hawkey, [2]Francesco Kaswalder, [2]Davide Cavalli

[1]Diemme Filtration (Aqseptence Group), Australia
[2]Diemme Filtration (Aqseptence Group), Italy

Presenter and Corresponding Author

Andrew Hawkey

ABSTRACT

The paper focuses on the application of in-filter cake washing and, where appropriate, the filter-repulp-filter process for recovering valuable products (dissolved metals) and expensive leaching reagents from leach residues. The concept was introduced in a paper by the same authors at ALTA 2018. This paper expands on the details of the process and presents laboratory results of tests conducted over the last couple of years. The configuration of the plate pack and the operation of the filter press in order to achieve good results at full scale is also discussed. Wash water (or solvent) consumption is compared with the extent of product and reagent recovery to demonstrate the efficiency of the process.

In situations where the resulting filter cake is not sufficiently permeable to wash in the filter, the filter-repulp-filter process is a suitable alternative. The details of the process are presented together with the results of laboratory tests. A third option using a combination of the filter-repulp-filter process and final in-filter cake washing is also suggested. In some cases this combination is the most cost-effective solution. If there is no further processing of the leach residue required, an obvious advantage of using this technology is that the resulting filter cake is usually suitable for dry stacking as tailings.

Keywords: Ore Leaching, Tailings, Product Recovery, Reagent Recovery, Filtration, Dry Stacking, Cake Washing

TAILINGS MANAGEMENT: AN OVERVIEW AND TECHONOLGY IMPLEMENTATION WITHIN ACIDIC PROCESS ENVIRONMENTS

By

[1]Edoardo Sommacal, [2]Martin Vieira

[1]Matec Pacific, Australia
[2]Matec S.r.l, Italy

Presenter and Corresponding Author

Edoardo Sommacal

ABSTRACT

The first section of this paper presents and discusses the benefits of using a high-pressure filtration filter press for tailings management, after examining the typical alternative technologies currently being used for solid/liquid separation equipment.

The second section of the paper briefly introduces filter press technologies within the acidic process environment and its auxiliaries that play a major role in the performance of the filter press and its process.

A brief case study on copper concentrate process as well as a feasibility study for lithium is used to demonstrate the success of this technology, as an attractive alternative solution to current tailings dams' operation and tailing storage facilities (TSF). The paper proposes that the installation and use of specialized high-pressure tailings management systems can result in significant process optimization with capital and operational cost savings. Similarly, the paper recommends the consideration of the replacement of "old" technology and removal of tailings dams to be considered due to its effects long term even after mine closure.

The paper concludes with the suggestion that this approach will be beneficial for new and existing process applications and shows the flexibility of integration of the technology in new and existing mining infrastructure regardless the sophistication and process environment implemented.

Keywords: Tailings, Concentrate, Filter Press, Silt Management, Dewatering, Separation, Acidic Environment, Risk Mitigation

Nickel-Cobalt-Copper Proceedings

Leaching Process Development

FUTURE OF THE GLYLEACH^{TM} PROCESS TREATING KOMATIITE NICKEL DEPOSITS IN WA

By

[1]Frank Trask and [2]Elsayed Oraby

[1]Mining and Process Solutions (MPS), Australia
[2]Curtin University, Australia

Presenter and Corresponding Author

Frank Trask

ABSTRACT

The used of GlyLeach^{TM} process for the extraction of Ni, Co, and Cu from predominantly Type 1 but also from Type 2 Komatiite Deposits is now being explored. Type 1, the most common category in number of occurrences, consists of massive and net textured Ni sulphides. Type 2 consists of low-grade disseminated Ni sulphides. MPS and Curtin now have substantial experience in leaching these variable ores and have identified conditions that yield GlyLeach^{TM} recoveries between 75% and 90% on ores tested to date. Leaching at lower pH's (pH 9-10) was much better than high pH (pH >11). This is advantageous when processing in high salinity water as you reduce the lime consumption from solution buffering. It was discovered that Ni and Co leach congruently, while copper extraction was variable. Another big advantage is leach solutions form a simple PLS, essentially free of contaminates such as Fe, Si, Mn, Al, and appear suitable for direct extraction by various combinations of solvent extraction (SX), or Ion exchange (IX) followed by acid stripping for either organics or resins. Leaching with glycine barren/recycle solutions shows high efficiency to continuously leach Ni and Co. Saleable products such as metal sulphate salts, carbonate salts, metal sulphides, and EW metals are possible.

The paper explores the used heap and agitated leach schemes with GlyLeach^{TM} to directly leach Komatiite ores.

Keywords: Glyleach^{TM}, Komatiite Deposits, Nickel, Cobalt

UNDERSTANDING THE ARSENIC IN-SITU PRECIPITATION DURING THE AF 5-CATALYZED ATMOSPHERIC SULFIDE LEACHING PROCESS

By

Fazel Jahromi and Ahmad Ghahreman

Mining Department, Queen's University, Canada

Presenter and Corresponding Author

Ahmad Ghahreman

ABSTRACT

Copper recovery from primary copper sulfides via the atmospheric leaching processes has been studied significantly in the past few years. Nonetheless, when it comes to the treatment of the arsenical copper sulfides, the chemistry of arsenic plays a significant role in the process development. This is an even more important subject in atmospheric oxidation processes for copper recovery; under atmospheric leaching conditions most often the arsenic is solubilized into the pregnant leach solution (PLS) as arsenite species, As(III), and the arsenic immobilization processes are mostly designed to immobilize arsenate species, As(V).

This paper pertains to the atmospheric oxidation of enargite (Cu_3AsS_4) in acidic ferric chloride solutions and the chemistry of arsenic during the oxidation stage. It is shown that the solubilized arsenic into the PLS is arsenite species in the absence of a catalyst, however in the presence of AF 5 catalyst it is possible to oxidize arsenic to arsenate in the PLS (in-situ process) and generate scorodite ($FeAsO_4.2H_2O$) in the leach PLS. The chemistry of the in-situ scorodite precipitation process can be altered by different factors such as the catalyst to concentrate ratio in the leach reactor, temperature, acidity of the PLS, and the pulp density of the leach slurry.

The scorodite precipitate can be produced at optimum leach conditions of 80 °C, free acid of 10 to 15 g/L, and concentrate to catalyst mass ratio of 1:1. Under optimum leach conditions most of the arsenic precipitates as scorodite, leaving behind only about 50 mg/L arsenic in the PLS. From the experiments it was concluded that a minimum of 5 g/L ferric is required in the background solution to facilitate scorodite precipitation. The scorodite product is a crystalline scorodite with well-defined structure, and the toxicity characteristic leaching procedure (TCLP) tests have confirmed that the scorodite precipitates are stable, with arsenic solubilization of about 0.2 to 0.7 mg/L.

Keywords: Arsenic, Arsenic oxidation, Scorodite, Enargite, Leaching, Oxidative in-situ precipitation

HYDROMETALLURGICAL RECOVERY OF COBALT AND COPPER FROM CEMENTATION RESIDUE AT THE TRAIL ZINC REFINERY

By

Tom Robinson and Tyler Seaman

Teck Resources, Canada

Presenter and Corresponding Author

Tom Robinson

ABSTRACT

Teck's zinc refinery in Trail selectively removes impurities from solution prior to zinc electrolysis utilizing two stages of zinc cementation. The first stage removes copper and cadmium and the second stage removes cobalt and some additional copper. The second stage cementation residue is recycled to the slag furnace where contained zinc and lead are recovered and copper and cobalt deport to the slag. The following paper reviews bench testing results utilizing selective hydrometallurgical leaching of cobalt and copper from the residue, and proposes a hydrometallurgical flowsheet to recover the copper as copper sulphate and the cobalt as a hydroxide for marketing. The paper also provides results from an economic assessment of the proposed flowsheet and discusses challenges and opportunities surrounding value drivers for the project.

Keywords: Teck, cobalt, copper, cementation, trail zinc refinery, hydrometallurgy

THE IMPACTS OF CHLORIDE UPON THE LEACHING OF CHALCOPYRITE

By

Robbie McDonald, Denis Shiers, David Collinson, Tania Hidalgo and Laura Kuhar

CSIRO Mineral Resources, Australia

Presenter and Corresponding Author

Robbie McDonald

ABSTRACT

The leaching of chalcopyrite in saline water is topical given the declining availability of good quality process water. This paper examines the impacts of salinity, and more specifically, the impacts of chloride on the leaching of chalcopyrite. An overview of this topic is presented along with examples taken from studies conducted within CSIRO. These studies range from bioleaching with halotolerant microorganisms, to atmospheric leaching at sub-boiling temperatures through to pressure oxidation at temperatures up to 245°C.

Keywords: Chalcopyrite, Chloride, Bioleaching, Atmospheric Leaching, Pressure Oxidation

INVESTIGATION OF THE RESIN IN MOIST MIX PROCESS FOR THE NICKEL AND COBALT RECOVERY FROM LATERITES

By

[1]Pavel Spiridonov, [2]William Skinner, [2]Jonas Addai-Mensah, [3]Hans Hein and [3]Ricardo Hein

[1]InnovEco Australia, Australia
[2]University of South Australia, Australia
[3]Oryxeio Ingeniería, Chile

Presenter and Corresponding Author

Pavel Spiridonov

ABSTRACT

Nickel laterites represent a large resource for nickel and cobalt worldwide and in Australia in particular. The majority of laterites are characterised by rather low nickel and cobalt content (~1.0% Ni and ~0.04% Co). Finding a cost-effective way to recover nickel and cobalt from laterites is a great challenge for the mining industry.

This paper outlines the findings of the research conducted in collaboration between InnovEco Australia and the University of South Australia. InnovEco, in partnership with Oryxeio Ingeniería, Chile, has developed the resin in moist mix (RIMM) process for the recovery of valuable metals from various types of minerals based on ion exchange technology. The present research has been devoted to nickel and cobalt recovery from Ni laterites using the RIMM principles. The initial results show that the new RIMM method may provide significant advantages from the point of view of process time and acid consumption in comparison with the traditional technologies such as heap leaching.

The research team of the University of South Australia has previously studied nickel and cobalt recovery from different types of Australian laterite ores using the laboratory scale column leaching technique. The influence of ore mineralogy, particle size distribution, agglomerate characteristics and leaching process parameters (e.g. leaching time, acid consumption) have been reported, and it is with this conventional process data with which the present study is compared.

This research project has been supported by the Future Industry Institute of the University of South Australia in the form of the Mobility and Infrastructure grants.

Keywords: Nickel and Cobalt Recovery, Ion Exchange, Resin in Moist Mix, Laterite Ores

ALTA 2019

Nickel-Cobalt-Copper Proceedings

Heap Leaching

BIOHEAPLEACHING IN BOREAL CONDITIONS - TEMPERATURE PROFILE INSIDE THE HEAPS AND MICROBIOLOGY IN ELEVATED TEMPERATURES

By

Ville Heikkinen and Mikael Korte

Terrafame, Finland

Presenter and Corresponding Author

Ville Heikkinen, Mikael Korte

ABSTRACT

Terrafame operates bioleaching in two phases: In primary leaching the ore is leached in 8,5 – 9,5 m high 6,5 Mt heaps. After the primary phase the ore is reclaimed and stacked into secondary leaching.

The feed ore contains 5-15 % of pyrrhotite mineral which acts as an energy source when leached in the heap conditions. The pyrrhotite leaching dominates the beginning of the primary leaching. The oxidizing reaction is promoted by aeration and acidification of the ore. The reaction is vigorous and heats the heap shortly after the startup. Terrafame has utilized temperature sensing cables (DTS), which have been installed inside the heap along the stacking front. The cables have been in two or three layers and the cable measures the temperature in every 1 m. Results from different heaps are presented in the report. Temperatures up to 100 °C inside the heap are normal and in some areas also higher temperatures have been observed.

Microbial cell count and population structure have+ been analyzed in primary and secondary heaps. Samples have been taken from the discharge solutions of primary and secondary heaps. Sulfur and iron oxidizing bacteria were enumerated with the MPN-method. The cell count of iron oxidizing bacteria ranges between 0 and 10^3 cfu/ml. Sulfur oxidizing bacteria tend to have higher numbers, staying mostly around 10^3 and 10^4 cfu/ml. In the secondary heap the corresponding numbers are $10^3…10^4$ cfu/ml for both, iron and sulfur oxidizing bacteria. The microbial population was analyzed with DNA-fragment analysis and capillary electrophoresis. *A. ferrooxidans* was the only species that was consistently observed in both areas, whereas other species appear to prefer either location.

Therefore, it would appear that the secondary heap is more favorable for microbial growth in general. Temperature range and rapid changes in the conditions in primary leaching are the most probable reasons for the observed discrepancy.

Keywords: Terrafame, Nickel, Cobalt, bioheapleaching, pyrrhotite, temperature, DTS, microbiology, population, cell count, MPN, DNA fragment analysis, *Acidithiobacillus ferrooxidans, iron, sulfur*

FIELD RESULTS FROM LEACHING AID TRIALS USING BASF'S LixTRA™ REAGENT

By

[1]Jack Bender and [2]Peter Haig

[1]BASF Corp, USA
[2]BASF, Australia

Presenter and Corresponding Author

Jack Bender

ABSTRACT

BASF has developed an effective leaching aid for heap and dump leaching systems. The first leaching systems tested have been copper secondary sulfide and oxide ores. Several LixTRA™ field trials at customer sites have been completed and include column and mini heap scale work. Results have far exceeded expectations with the majority of ores having 20-35% more copper leached at a given time.

Particle size has the largest effect on the effectiveness of the leaching aid, where the use of large rocks in the test charges gave the most dramatic leaching improvements. While copper leaching was greatly affected, the acid and iron concentrations were not appreciably affected and full compatibility with CuSX circuits confirmed. The review of the field trials as well as the analytical results will be covered in the article.

Keywords: Copper Recovery, Heap Leach, Dump Leach, Leaching Aid, LixTRA, Leaching Columns

Nickel-Cobalt-Copper Proceedings

Pressure Acid Leaching Forum

Acknowledging the 20-year anniversary of the commissioning of the Bulong, Cawse and Murrin Murrin PAL projects.

20Th ANNIVERSARY OF THE ANACONDA, BULONG, CAWSE NICKEL-COBALT HPAL PROJECTS DESIGN AND COMMISSIONING EXPERIENCES LESSONS LEARNED

By

Paul Tucker

Bantrel Co., Canada

Presenter and Corresponding Author

Paul Tucker

ABSTRACT

The decade of the 1990's was perhaps the most significant time for Nickel, and its companion metal Cobalt, since the wartime era. The decade began with the break-up of the Soviet Union in 1991 followed closely by the discovery of the Voisey's Bay Ni-Co-Cu deposit in Canada, the last major nickel sulphide deposit found in the world. In 1995, WMC committed to a Simon-Carves Monsanto® sulphuric acid plant to be constructed at their Kalgoorlie Nickel Smelter. This enabler allowed the smaller of the so-called ABC Projects (Anaconda, Bulong, Cawse) to become feasible given a source of sulphuric acid. Anaconda, backed by exclusive use of Sherritt technology, chose to construct their own Monsanto® acid plant. These were the first plants to use HPAL technology since Freeport Sulphur Company built their Moa Bay operation in the late 1950's and the first to employ horizontal mechanically agitated autoclaves for the process.

The paper will discuss the design of each HPAL circuit, specifically what was similar and what was different. It will segue into the commissioning stage which occurred 20 years ago and discuss what worked, what didn't and what should never be tried again. The mature technology that exists today was based upon the hard lessons learned during 1999. The future of Ni-Co is with laterites that exist in abundance, as sulphide hard rock mines become deeper and more costly to operate.

This paper offers the unique perspective of the author who was employed by all three of the EPC/M companies that undertook groundbreaking design and implementation of these three projects as well as a role as Commissioning Engineer at Anaconda Nickel NL's Murrin Murrin Operations.

Keywords: Laterites, High Pressure Acid Leaching, HPAL, Autoclave Technology, Pressure Hydrometallurgy, Corrosion Resistant Materials, Acid Resistant Membranes & Refractory Brick, Severe Service Valves, Sulphuric Acid

20 YEARS OF TI CLAD IN HYDROMETALLURGY

By

Warren Salt

NobelClad, USA

Presenter and Corresponding Author

Warren Salt

ABSTRACT

The processing of nickel ore bodies using a High Pressure Acid Leaching (HPAL) hydrometallurgy process is a high temperature and very corrosive environment providing many unique material and processing challenges. Titanium was identified early in the process development as the ideal material to resist the corrosive process. The challenge with titanium is that it is an expensive material and the process temperatures and pressures require a heavy wall pressure vessel. Titanium cladding reduces the cost of vessel construction through optimizing the titanium thickness for corrosion protection and using low-cost carbon steel for pressure containment such that titanium protection becomes a financially viable option.

For the past 20 years, titanium cladding has been the material of choice for HPAL vessel construction. Recently titanium is also being evaluated as an option for POX autoclaves as newer processes are using higher pressures and temperatures. The first titanium clad POX autoclave is now being manufactured using NobelClad titanium clad metal.

Keywords: Laterites, High Pressure Acid Leaching, Titanium, Cladding, Explosion Welding, HPAL, Autoclave Technology, Pressure Hydrometallurgy, Corrosion Resistant Materials, Acid Resistant Membranes & Refractory Brick, Service Valves, Sulphuric Acid, Pressure Oxidation, POX

REVIEW OF ARTIFICIAL INTELLIGENCE USE IN HIGH PRESSURE ACID LEACH (HPAL)

By

[1]Cory Kosinski, [1]Alain Tshilombo, [1]Vijay Reddy, [1]Kelvin Buban, [2]Chowdary Meenavilli, [2]Siddhartha Tirumalaraju and [2]Sriraj Meenavilli

[1]Sherritt Technologies, Canada
[2]NTWIST, Canada

Presenter and Corresponding Author

Cory Kosinski

ABSTRACT

Application of artificial intelligence (AI) techniques to optimize the High Pressure Acid Leach (HPAL) autoclave operation at the Ambatovy facility were evaluated by Sherritt Technologies in conjunction with NTWIST.

Historical operating data obtained from the Ambatovy HPAL circuit were used to develop models to predict autoclave discharge parameters based on operating conditions and ore composition. A second set of models (AI model) was developed based on the prediction models, input costs and operating constraints for the Ambatovy operation; this was done with the aim of identifying optimal autoclave sulphuric acid and steam dosages to optimize plant operation with respect to reagent consumption and metals recovery.

For the six-month evaluation period, the AI model identified operating conditions that could have had a positive economic impact in approximately 42% of the total operating hours; even with the limited operating data available to build and train the models. The AI model was able to suggest changes to operating parameters to bring adverse operating conditions to within their target limits in approximately 17% of the total operating hours. Further refinement of the model parameters, through increasing the size of the training data set and optimizing the AI model's search parameters is expected to improve the model's ability to identify optimal operating conditions leading to further economic benefit and process stability.

In addition to the economic benefit, the use of AI has the potential to improve the overall operation of a facility through providing tools to assist with training and improving process stability, process optimization and troubleshooting.

Keywords: High Pressure Acid Leach, Artificial Intelligence, Laterites, Nickel Extraction, Cobalt Extraction, Acid Consumption, Process Optimization

THE CLEAN TEQ SUNRISE PROJECT FLOWSHEET RHEOLOGY AND PRACTICAL IMPLICATIONS ON PROCESS DESIGN

By

[1]Fiona Sofra, [1]Raul Cavalida and [2]Tim Harrison

[1]Rheological Consulting Services Pty Ltd, Australia
[2]Clean TeQ Limited, Australia

Presenter and Corresponding Author

Fiona Sofra

ABSTRACT

The Clean TeQ Sunrise Project in New South Wales is one of the largest and highest-grade cobalt-nickel deposits outside Africa. It also contains one of the largest and highest-grade scandium deposits in the world. The Clean TeQ Sunrise Project will utilise conventional pressure acid leaching (PAL) for metal dissolution and Clean-iX® continuous Resin-in-Pulp (cRIP) ion-exchange technology to recover target metals from leach slurry. Subsequent purification and processing are undertaken to produce battery grade nickel and cobalt sulfate and 99.9% scandium oxide products.

Fundamental to the successful design and operation of the project is a thorough understanding of the rheology, or material flow characteristics, throughout the entire flowsheet. In particular, the PAL feed solids concentration must be optimised to maintain flow characteristics amenable to optimal heat transfer and reaction kinetics. Likewise, the rheology in the pre-reduction and neutralisation processes are key factors in optimising pipe flow, vessel agitation and reaction rates. Lastly, characterisation of tailings rheology guides thickening and pipeline transport, water recovery, tailings management facility design and depositional properties.

A Definitive Feasibility Study (DFS) was completed in July 2018. The DFS incorporated findings from 1 tpd pilot plant trials. As part of these trials, rheological testwork was conducted to determine the flow characteristics of the slurry path from PAL feed to neutralised tailings thickener discharge.

The fully-sheared yield stress at a nominal operating solids concentration of 48wt% PAL feed and resultant process streams ranged from 3 to 53 Pa across the process. The yield stress was dependent on pH. The yield stress of flocculated and thickened streams was a strong function of shear history, ranging from several hundred Pascals at the thickener underflow to tens of Pascals once sheared. These findings validated the process design operating a much higher solids density than typical PAL operations. This led to a much lower volumetric flowrate and reduced capital requirements.

For all streams except the thickener underflows, viscous behaviour followed a Herschel Bulkley, yield-shear thinning flow model. Thickener underflows however showed anomalous viscosity results which confounded traditional viscosity testing. Pipe loop tests are planned to provide further flow data for these materials.

Keywords: Clean TeQ Sunrise, Nickel Laterite, Rheology, Pressure Acid Leach, Yield Stress, Continuous Resin-in-Pulp

THE ROLE OF DYNAMIC FACTORS IN AUTOCLAVE SCALING

By

Mike Miller

Mike Miller Consulting Services, Australia

Presenter and Corresponding Author

Mike Miller

ABSTRACT

Precipitation reactions play an important role in the operation of both Pressure Acid Leach (PAL) and Pressure Oxidation (POx) autoclaves. In commercial autoclaves, conditions are consciously chosen to promote the selective precipitation of unwanted elements, typically iron and aluminium. To the extent that residue precipitation is uncontrolled, scale deposition becomes an unwelcome fact of life for autoclave operators, and a significant source of downtime and expense. Although there have been significant studies into the equilibrium chemistry and kinetics of the process, much of this has focussed on metal recoveries. So far, very little has been written on the role of reaction dynamics in determining the extent of scaling within the autoclave.

This paper includes a summary of the major scaling mineralogies and the available data relating to their equilibrium chemistry and reaction kinetics. After this, the reaction dynamics within a typical PAL-style autoclave are considered, and the variables that are available for controlling scale deposition are discussed. This is illustrated by examples where process dynamics have impacted on the extent and nature of scale precipitation in the autoclave. Finally, practical guidelines for scale control are suggested.

Keywords: PAL, PoX, Autoclave, Pressure Leaching, Shrinking Core, Kinetics, Scale, Scaling, Alunite, Jarosite, Kieserite, Process Design, Process Operations.

THE CLEAN TEQ SUNRISE PROJECT – PILOT DEMONSTRATED UPGRADE OF PRESSURE ACID LEACH DISCHARGE THROUGH USE OF CONTINUOUS RESIN IN PULP TECHNOLOGY

By

Tim Harrison, Jim Wall, Stephen Grocott

Clean TeQ Limited, Australia

Presenter and Corresponding Author

Tim Harrison

ABSTRACT

With the objective of further validating design data for the Clean TeQ Sunrise Project, during 2018 Clean TeQ Limited conducted an integrated pilot plant operation of the ore leach and continuous Resin in Pulp circuits. These pilot activities were conducted with ALS Metallurgy in their Balcatta facility, Western Australia. Pilot plant feed ore was prepared and composited from 60-tonnes of sample collected from the Clean TeQ Sunrise deposit in central New South Wales.

Pilot plant activities were split into two major programs;

1) ore preparation pilot including low charge attrition ball milling, fine screening for upgrade via quartz rejection, chromite rejection and feed thickening, and
2) integrated feed preparation pre-heating, pressure acid leach (PAL), pre-reduction (PR), partial neutralisation (PN), continuous resin in pulp (cRIP), tailings neutralisation and thickening.

Clean TeQ's cRIP pilot plant incorporated a 10-stage adsorption circuit in which the counter current contact of ion exchange resin with partially neutralised PAL discharge slurry achieved selective extraction of nickel, cobalt and scandium. The loaded resin, collected from adsorption Stage 1, was washed to remove entrained pulp by using a trommel screen coupled with an elutriation wash column. Loaded resin was desorbed using sulfuric acid. After desorption, the barren resin was washed for acid recovery, prior to conversion to a neutralised form to limit proton return to the cRIP adsorption circuit.

The integrated pilot activities were successful in demonstrating the ability of cRIP to achieve near-complete extraction of soluble nickel, cobalt and scandium from the slurry. Residual nickel and cobalt concentrations of less than 10 and 5 mg/L respectively were achieved, reflecting > 99.5% metal extraction in cRIP. The pilot campaign also demonstrated the selectivity of the ion exchange resin in recovering nickel, cobalt and scandium directly from the neutralised PAL discharge slurry, in preference to lower-affinity cations and impurity species including calcium, magnesium and manganese. The desorption process configuration proved particularly effective at scrubbing co-extracted magnesium and manganese from the loaded resin, resulting in a partially purified and enriched nickel, cobalt, and scandium liquor for downstream refining.

This paper outlines the successful integration of cRIP in the overall process for nickel, cobalt and scandium extraction and upgrading directly from acidic PAL leach slurry, along with the main operating parameters and resulting plant performance.

Keywords: Nickel, Cobalt, Scandium, Continuous Resin in Pulp, Ion Exchange, Pressure Acid Leach, Impurity Rejection, Pilot Plant, Sunrise.

SYNERGISTIC COPROCESSING OF NICKEL LATERITE ORES AND SULPHIDE CONCENTRATES USING THE ROASTPAL PROCESS

By

Hermann Scriba

LiNiCo Pty Ltd, Australia
Battery Metal Synnovation

Presenter and Corresponding Author

Hermann Scriba

ABSTRACT

Over the past two decades a number of new HPAL processing plants have been established in Australia and surrounds. There are significant differences in the detail of each HPAL application, however, common features are the requirement for addition of large quantities of sulphuric acid and leaching of nickel and cobalt from the laterite ore in autoclaves at temperatures between 250 and 270°C. While some operations have used imported acid, the majority of HPAL plants have employed sulphur-burning acid plants on site to generate sulphuric acid and steam for heating and power generation.

The recent surge in Electric Vehicle (EV) battery production has triggered increased demand for cobalt and nickel, with demand and price expected to increase in tandem with growth in EV production. This has resulted in a flurry of interest in previously sub-economic laterite and sulphide projects and deposits.

A new proprietary process concept, dubbed the RoastPAL Process, is presented whereby sulphide ores or concentrates, ideally containing cobalt and/or nickel, can be roasted to produce sulphuric acid, steam and power. The calcine is then processed through the HPAL plant together with the laterite ore to co-recover the contained metal values. By way of an example it is demonstrated how this combined processing can result in improvements in project economics, including lower unit capital and operating costs and increased productivity and revenue from the co-recovered pay metals. The paper reflects on likely mineral deposits and scenarios that could be considered for such synergistic processing.

The RoastPAL Process potentially represents enabling technology for some sulphide and laterite deposits. It can also be considered for integration into existing HPAL operations, to utilise available processing and refining capacity, extend project life and increase operational profitability.

Keywords: Nickel, Cobalt, Laterite, Sulphide, HPAL, PAL, Pressure Leach, Synergy, Pentlandite, Pyrite, Pyrrhotite, Roasting, Roast

ARE WE HEADING INTO THE 4TH GENERATION OF PAL PLANTS FOR LATERITES?

By

Alan Taylor

ALTA Metallurgical Services, Australia

Presenter and Corresponding Author

Alan Taylor

ABSTRACT

Starting with Moa Bay, Cuba, in 1959, we have seen three generations of PAL plants for treating nickel-cobalt laterites. Are we now seeing the beginning of a 4th generation?

Current driving forces include the projected increase in demand for nickel and cobalt for the battery industry, potential growth in demand for scandium, limited future availability of new copper-nickel-cobalt sulphide orebodies, and the desirability of developing alternative sources of cobalt. PAL Project categories under consideration are the expansion of existing PAL operations, new major projects, and new smaller scale projects with scandium as a major product.

Expansion of existing PAL Operations reported to be under consideration include the quadrupling of Gordes in Turkey, and a US$1.5 billion major expansion of Ramu in PNG.

New major PAL projects at various stages of development include the Sunrise Project, Australia, by Clean TeQ, the Morowali Project, Indonesia, by a consortium led by GEM, China, the Pomalaa Project, Indonesia, by Sumitomo and PT Vale Indonesia, and the North Konawe Project, Indonesia, by PT Antam.

New smaller scale PAL projects with scandium as a major product include the Nyngan Project, by Scandium International Mining, the Platina (formerly Owendale) Project, by Platina Resources, the Sconi Project, by Australian Mines/Metallica Minerals, and the Flemington Project, by Australia Mines/Jervois all located Australia.

The main differences from the 3rd phase PAL plants lie in downstream processing due to the emphasis on products for the battery industry or scandium market, or both in some cases.

Keywords: Laterites, PAL, Nickel, Cobalt, Scandium, Battery Industry Projects, Downstream Processing