# EXTRACTION 2018

**August 26–29, 2018 | Westin Ottawa | Ottawa, Canada**

# PRELIMINARY PROGRAM

**www.ExtractionMeeting.org**

MetSoc CIM ICM

SME Society for Mining, Metallurgy & Exploration

TMS The Minerals, Metals & Materials Society

Organized by the Metallurgy and Materials Society (MetSoc) of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM); the Society for Mining, Metallurgy & Exploration (SME); and The Minerals, Metals & Materials Society (TMS).

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## Part A: Extractive Metallurgy Markets and Economics

*Program Organizers:* Luisa Moreno, Tahuti Global; Boyd Davis, Kingston Process Metallurgy Inc

Sunday PM
August 26, 2018

Room: Confederation I
Location: Westin Ottawa

*Session Chair:* To Be Announced

**1:00 PM Invited**
**TBA: Mark Selby**: *Mark Selby*[1]; [1]RNC Minerals
TBA: Mark Selby

**1:30 PM Invited**
**Project Financing – A Capital Markets Perspective**: *Luisa Moreno*[1]; [1]Tahuti Global
There are numerous mining companies listed in stock exchanges around the world, and most are looking for capital to advance their projects. Investors and investment banks review hundreds of projects every year but only a few are regularly covered by analysts. What are the key investment criteria of money managers and their mining analysts? How investment banks determine the mining companies to raise money for? and how mining analyst select the companies stocks to buy or sell? We will offer an insight on the decision-making process of money managers, buy and sell side analysts, and investment bankers that are in the business of researching and help finance mining companies.

**2:00 PM Invited**
**TBA: Michael Samis**: *Michael Samis*[1]; [1]Ernst & Young, LLP
TBA: Michael Samis

**2:30 PM Invited**
**The Impact Factors on Chinese Copper Smelter Profitability**: Chuanyu JIANG[1]; *Yao Suping*[1]; [1]China NERIN
China has been the biggest copper producer and consumer in the world for many years, with the annual production of cathode copper over 7 million tons and annual consumption over 10 million tons in 2017. The copper industry is playing a significant role in the economic development in China. Currently there are around 30 copper smelters with production over 100kt/a, which are distributed in many provinces over China. As you know, Chinese copper smelters outsource significant amount of concentrates from oversea market, however, many of them are not located along the coast, but far away inland with long road / or rail transportation. There is a question on how these copper smelters to make money? and what are the impact factors to a copper smelter profitability? This speech will indicate certain considerations on the smelter profitability while a project is planned with couple of real cases.

**3:00 PM Invited**
**A Extractive Metallurgist in the World of Concentrate and By-Product Sales**: *Jay Hemenway*[1]; [1]Ocean Partners
Have you ever wondered how the value associated with a metal bearing concentrate is calculated? In this session the speaker will explain the how and why concentrate contracts are structured the way they are and what the various terms and acronyms mean. Specific topics will include how to calculate payable metals, treatment and refining charges, penalties and what 'Quotational Period' means and its impact on the final value a Miner will receive. Real life examples and sample calculations will be an integral part of the presentation. In addition to calculating value, the speaker will take a brief look into the actual sales process from the time the concentrate is produced until the final payment is made.

**3:30 PM Panel Discussion**

## Plenary Session – Plenary Session

Sunday PM
August 26, 2018

Room: Confederation I
Location: Westin Ottawa

*Session Chair:* To Be Announced

**4:00 PM Introductory Comments**

**4:10 PM Plenary**
**Notes from the Century Before (When Mining Went Global)**: *Jeremy Mouat*[1]; [1]University of Alberta
This talk will describe metallurgical practise in 1918. Metallurgy was then at an interesting juncture. This was due in part to the impact of the First World War, which in August 1918 was entering its fifth year. That conflict had taught the combatants something of the insatiable appetite of industrialized warfare. This underscored the importance of logistics generally and the heavy demand for munitions in particular. In addition, the latter emphasised the need for considerable stockpiles of base metals, notably zinc, nickel, lead and copper. The post-1918 world would include much discussion of a new phrase, "strategic minerals." In the minds of many, metallurgy had become key to a country's ability to wage war. Metallurgy in 1918 was also gaining a new maturity. By this point, most mine mills had begun to incorporate two new key innovations, the cyanide and flotation processes. As a consequence, ore could be treated far more efficiently than in the past. This development came at a critical time, since mines were increasingly relying on what were then considered low-grade ore. To do so effectively, mining had to develop economies of scale, a shift that was only possible by the adoption of the new and relatively sophisticated metallurgical processes. Once this shift was made, the mining industry could treat complex ores not only in North America, South Africa and Australia but also in what were then distant and little-known places, as the emergence of such enterprises at Chuquicamata in Chile or the Burma Mines in Myanmar suggests. The history of mining in the mid to late twentieth century was in many ways a product of the industry's further extension around the globe as well as refinements in metallurgical practice, ones whose genesis dates back to the period around 1918.

**4:40 PM Plenary**
**Mining 4.0, Metallurgy and the Future of the Industrial Economy**: *Peter Warrian*[1]; [1]University of Toronto
The past decade experienced an unprecedented metals price super cycle and at the same time a 28% decline in mining productivity. It also witnessed the marginalization and elimination of the classic centres of Canadian metallurgy. Do we think these things are connected? The mental model for mining executives for turning back the productivity paradox is to use the new digital infrastructures to lift the roof off the mine and run operations like an Industry 4.0 automotive factory. There are serious problems with this model. First, atleast in Canada, it is led principally by precious metals producers which are connected to the financial economy and not to the industrial economy. Second, there is very little metallurgy in precious metals mining. Third, there are good reasons to think that the application of Industry 4.0 to mine production will be very different than that which is currently being discussed. The digital economy absolutely requires mining. It also requires mining to be positively regarded as making a critical contribution to an environmentally, socially and economically sustainable future economy. To successfully revive metallurgy and gain public support for its long term viability, the connection will have to be made between digitalization of ore bodies, metallurgy, materials science and digital manufacturing.

**5:10 PM Concluding Comments**

## Pyrometallurgy Keynote – Monday AM

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| Monday AM | Room: Governor General III |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Dean Gregurek, RHI Magnesita

**8:00 AM Introductory Comments**

**8:10 AM Keynote**
**Role of Research in Non-ferrous Metallurgy Development - Peter Hayes Contributions to Modern Pyrometallurgy**: *Phillip Mackey*[1]; Evgueni Jak[2]; [1]P.J. Mackey Technology; [2]PYROSEARCH, Pyrometallurgy Innovation Centre

A whole new group of non-ferrous pyrometallurgical processes with the ability to utilize tonnage oxygen and capture sulphur dioxide were developed and commercialized over the period 1940s-1980s. Many of these earlier process developments were undertaken with limited knowledge of the process chemistry and influence of key process variables; in many cases, piloting helped provide much new physico-chemical data, but gaps remained. The second generation versions of these technologies of today provide all the primary copper, nickel and lead produced worldwide by pyro-metallurgical smelting. Further, process development has continued and a new generation of copper and lead smelting technologies have also been developed in China since the 1990s. The older reverberatory and blast furnaces have been progressively replaced by the newer technologies - a good example being the introduction in 1992 of the copper IsaSmelt technology at the Mt. Isa smelter in Australia where the former fluid bed roaster and reverberatory furnaces were replaced by a single new smelting unit, together with an acid plant for sulphur dioxide collection. The development of these new technologies was made possible by investment in fundamental and applied research. The lesson for the future is, in order to sustain these improvements, continued investment in research and development capability is required - to do otherwise is to risk obsolescence and lack of competiveness in the world market. Dr. Peter Hayes at The University of Queensland is one of the many researchers and process engineers who have contributed to the fundamental understanding of metallurgical processes over this period of rapid change in technologies. The present paper briefly outlines some of the many contributions Peter Hayes has made to the understanding of kinetics, mechanisms and phase equilibria in metallurgical systems, and metallurgical process development.

**8:25 AM Keynote**
**The Role of Research in Pyrometallurgy Technology Development - From Fundamentals to Process Improvements - Future Opportunities**: *Evgueni Jak*[1]; [1]PYROSEARCH, Pyrometallurgy Innovation Centre

Pyrometallurgy is an important sector of modern industrial society actively participating in solving current environmental, economic, materials scarcity and other challenges. Recent advances in analytical methods, experimental techniques, thermodynamic, phase equilibria and process modelling tools provide new opportunities to increase the productivity of pyrometallurgical reactors, the treatment of complex feeds and metal recoveries. Fundamental theoretical models can now be used to make a significant next step towards the development and implementation of computerised models describing real industrial processes – Virtual Reactors, and computer-aided smart-decision-making systems that may be called Pyro-GPS by analogy to GPS; these developments can facilitate knowledge-based improvement and optimisation strategies. The implementation of these improvements require ongoing collaboration between researchers, industry and government.

**8:45 AM Keynote**
**Sulfide Smelting: Thirty-Five Years of Continuous Efforts to Find New Value Adding Solutions**: *Gerardo Alvear Flores*[1]; Mario Loebbus[1]; Bianca Springub[1]; A. Fallah[1]; A. Tappe[1]; [1]Aurubis AG

It is now 35 years since the organization of the first sulfide smelting conference in 1983. Since then, the smelting base metals industry has experienced several changes driven by the necessity to improve economic, operational and environmental performances and meet the increasing market demand for metals. In this challenging environment, it is relevant to recognize which are the main challenges that the industry will face in the coming years.This paper discusses some relevant aspects required to continue developing the base metal industry. Aspects such as the need to supporting the generation of fundamental metallurgical knowledge, acquisition and proper use of data with advanced analytics methods, technological innovation to develop sustainable process flowsheet are discussed with emphasis on efforts conducted by Aurubis.

**9:20 AM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 1 Sulfide Smelting Operations Flash

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Monday AM | Room: Governor General II<br>Sponsored by Hatch |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Ilkka Kojo, Outokumpu Technology Oyj

**9:50 AM Invited**
**Sulfide Smelting Development in Japan during the Past Half Century**: *Takahiko Okura*[1]; [1]Ehime University

Japanese non-ferrous industry introduced large-scale smelting plants along seashores for overseas concentrates with increasing demand of metals around 70's. Although serious environmental pollution became obvious, with economic growth, the industry got rid of pollution by installing new processes and improving operation technologies. At present, over 99.8 % of sulfur input to smelters is fixed as stable compounds. Through those decades Japan had steep rises of oil prices, sudden change of exchange rate, and inadequate treating charges, we were faced to consider the closure of smelters. The industry has survived by increasing productivity, saving energy and reducing manpower. Furthermore the industry made great effort to recycle valued metals from scraps and wastes for the resources-recycling society. Academic research also contributes to support these individual technologies. Thus the industry has fostered world-acclaimed technologies in terms of efficiency and energy conservation. This paper presents technology development and environmentally-benign sulfide smelting processes.

**10:15 AM**
**Review of Boliden Harjavalta Nickel Smelter**: Hannu Johto[1]; *Petri Latostenmaa*[2]; Esa Peuraniemi[2]; Karri Osara[2]; [1]Outotec (Finland) Oy; [2]Boliden Harjavalta Oy

Boliden Harjavalta have been operating nickel flash smelter to nickel sulphide concentrate melting since the year 1959 in Finland. The process were modified in the year 1995 to novel converter-less semi-low iron nickel matte smelting (DON) and since that, the process have been applied to multiple chemically variable nickel sulphide concentrate melting with high environmental performance. In this paper, the status of the current smelter operations is described together with recent modernizations of the nickel flash smelting and slag cleaning furnaces.

**10:40 AM Invited**

**20 Years of KIVCET\8482 Furnace Operation at Teck's Trail Operations**: *Robert Snodgrass*[1]; P. Barrick[1]; R. Moore[1]; [1]Teck Metals Ltd.

Teck Metals Ltd. has been operating an integrated zinc-lead smelter since the early 1900s at Trail, British Columbia, Canada. The application of KIVCET\8482 flash smelting technology in 1997 for treatment of zinc plant residues and lead concentrates has allowed Trail Operations to make significant improvements in environmental and process performance. Considerable development has taken place over the past 20 years of operation to improve furnace integrity, operational stability and metallurgical control. These ongoing improvements have resulted in driven rates well beyond the design capacity and combined with improved online time, the KIVCET\8482 furnace has achieved consistently increasing throughput. This paper presents a review of the key learnings and developments in the operation of the KIVCET\8482 furnace at Trail Operations.

**11:05 AM**

**Redesign and Rebuild of the Pan Pacific Copper Flash Smelting Furnace**: *Glenn Stevens*[1]; Tatsuya Motomura[2]; Tomoya Kawasaki[2]; Misha Mazhar[1]; Gary Walters[1]; [1]Hatch; [2]Pan Pacific Copper

After 40 years of operation with the original steel frame and hearth, Pan Pacific Copper determined it was necessary to rebuild the Saganoseki Flash Smelting Furnace to continue safe operation. The original design employed a rigid steel frame, which, through hearth growth, led to severe distortion of the frame. Contributing to the continued growth of the hearth were thermal cycles that occurred during the government mandated annual shutdowns. Hatch designed a unique sprung bound, pivoting binding frame to maximize crucible size within the existing furnace footprint, while integrating the PPC designed cooling jackets. The bound system maintains tight brick joints, while the new conductive hearth design with integrated bottom cooling freezes a protected layer of matte to accommodate higher furnace throughput. Minimization of furnace downtime for the rebuild was achieved through effective construction planning, highly trained contractors, and through an efficient start-up and ramp-up to full production.

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## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 1 Novel Processes/Integrated Plant Designs/Recycling/ Environmental Impact

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Monday AM | Room: Governor General III |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Greg Richards, Teck Metals Ltd.

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**9:50 AM Invited**

**Flexibility and Innovation in Materials Processing**: *Maurits Van Camp*[1]; Christina Meskers[1]; Tom Hennebel; Isabel Vermeulen; [1]Umicore Group R&D

Everyone talks about "flexibility". Flexible processes, agile organisations, open innovation, and entrepreneurial people… all necessary to address the societal challenges ahead. It sounds so easy, The transition to "flexibility" is hard work. The economy as a whole, and thus all actors in it, was an industrial economy. Today it is changing into a knowledge and innovation economy. In the innovation economy the actors – industry, academia, government – work together in a highly complex, continuously changing system. Each actor has its role to play and the interplay between the actors drives the transition. Each actor, which consists of numerous individual organisations and people, goes through this transition at its own speed. Understanding how people and organisations learn and innovate together is the key enabler for "flexibility" and innovation. Real-life experiences from learning in R&D and operational environments, and multi-stakeholder cooperation for open innovation illustrate these concepts.

**10:15 AM Invited**

**Integrated Pyrorefining of Lead at Teck's Trail Operations**: *Gregory Richards*[1]; C. Curtis; [1]Teck Metals Ltd

The Trail smelter of Teck Metals Ltd. produces about 90,000 tonnes of lead through two stages of refining following KIVCETTM smelting. Bullion from the KIVCET furnace is first treated in a pyrorefining plant in preparation for Betts electrorefining which makes 99.99% pure lead. Pyrorefining consists of number of integrated unit operations to remove primarily copper, arsenic, antimony and tin. The operation of this plant to meet the specifications for electrorefining requires attention to bullion management and selective use of reagents. The processes used for pyrorefining are reviewed in terms of chemistry and control.

**10:40 AM Invited**

**Plasma Fuming for Clean Slags: Rationale, Challenges and Solutions**: *Bart Blanpain*[1]; Yiannis Pontikes[1]; Muxing Guo[1]; Annelies Malfliet[1]; [1]KU Leuven

Resource efficiency has become one of the key global societal and technical challenges. Metallurgical slags present a valuable opportunity to decrease our dependency on natural resources. As regulatory requirements are pushing the limits ever further, metallurgical plant operators are continuously developing process modifications and new processes to meet these requirements. Plasma fuming has been identified as one of the processing options with a high potentiality to deliver clean slags. In this presentation we will show some of the experimental and modelling results that were obtained at KU Leuven for the development and the application of this new technology.

**11:05 AM Invited**

**Relating Reported Carbon Dioxide Emissions to Iron and Steelmaking Process Details**: *P.Chris Pistorius*[1]; [1]Carnegie Mellon University

Over the past few decades, the carbon intensity of ironmaking and steelmaking has been reduced considerably through improved efficiency in blast furnace ironmaking, partial replacement of coke with less carbon-intensive fuels, and increased use of scrap and direct-reduced iron in steelmaking. To evaluate possible further reductions in carbon intensity, accurate process information is needed. A preliminary test of the fidelity of publicly reported data as a source of process information is reported here. The data sources are industry round-ups for electric furnace steelmaking and blast furnace ironmaking (published by the Association for Iron and Steelmaking Technology), and data recorded by the Environmental Protection Agency under the US Greenhouse Gas Reporting Program. From a comparison for an integrated steelmaking plant and an electric furnace plant, it appears that the values from the two data sources are consistent. The comparison does rely on process details, such as the quantitative relationship between injected oxygen and carbon emissions in electric furnace steelmaking.

**11:30 AM Invited**

**Development and Improvements of Novel Pyrometallurgical DC-arc and High-intensity Furnaces Equipped with Water-cooled Copper Coolers**: *Lloyd Nelson*[1]; [1]Anglo American Platinum Ltd

Experiences and challenges will be outlined: i) in development of novel DC plasma-arc furnace smelting processes, spanning piloting originally on chromite smelting, to recycling of zinc-bearing slags and steel and stainless steel plant dusts; to issues of scale up in industrial DC-arc furnace applications including treatment of cobalt-copper slags. ii) in applying copper cooler technology to high-intensity smelters including: electric furnaces ranging from circular DC single-electrode, to AC circular 3-electrode and rectangular 6-electrode configurations to variously produce PGM base metals, ferronickel and ferrocobalt; to ACP TSL PGM base metal matte converter furnaces.iii) in further progressing the novel ACP TSL PGM matte converter implemented primarily to effect environmental compliance, including: process configuration and integration related to enforced change from piloted batch to industrial "continuous" processing; role of risk mitigation in the novel process integration; consequent pay metals recovery and energy recovery impacts imposed also by solid furnace matte feed and granulated solid converter slag treatment; and cogeneration of electricity from the ACP waste heat water cooling system.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 2 Refractories

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Monday AM | Room: Ontario |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Taufiq Hidayat, PYROSEARCH

**9:50 AM**

**Process Zones Observed in a 48 MVA Submerged Arc Furnace Producing Silicomanganese According to the Ore-based Process**: *Joalet Steenkamp*[1]; Johan Gous[2]; Wiebke Grote[3]; Robert Cromarty[3]; Helgard Johan Gous[3]; [1]MINTEK; [2]Transalloys; [3]University of Pretoria

Excavation of industrial-scale furnaces allows for the systematic study of reaction sequences by identifying the different reaction zones within the furnace. In 2013, Transalloys excavated a 48 MVA submerged arc furnace that was used for silicomanganese production using the ore-based route. The excavation method was reported elsewhere as was observations made in terms of refractory wear and modes of electrical energy dissipation prior to excavation. The paper presented here, reports on the process reaction zones observed during the excavation and subsequent phase chemical analyses of a number of process samples obtained during the excavation. The zones identified were a loose burden zone, a dry coke-bed zone, a wet coke-bed zone, a hard build-up zone, and an alloy zone. The presence of the hard build-up zone below one of the electrodes and absence of a slag zone below all three electrodes are unique features of the SAF excavated at Transalloys.

**10:15 AM**

**Heat Transfer to Copper Coolers in Freeze Lined Furnaces: The Role of Radiation and the Influence of Slag Liquidus**: *Mark Kennedy*[1]; Allan MacRae[2]; Michael Shapiro[1]; [1]Proval Partners SA; [2]MacRae Technologies Inc.

Prediction of the thermal duties of copper coolers in freeze lined furnaces is challenging. Where copper coolers are immersed in liquid slag the heat transfer is often defined by a natural convection cell immediately adjacent to the wall, in the absence of other factors producing forced convection. Slag coolers are typically not fully immersed, slag temperature, liquidus and superheat can vary, and bath levels may change significantly with batch tapping, leading to substantial variations in radiation heat fluxes. Radiation heat transfer is discussed with reference to the non-obvious impact of slag liquidus on radiation losses in the exposed cooler sections. Reference is made to literature and the results of analytical and FEM models.

**10:40 AM**

**Effect of Clays Minerals Contained into Copper Sulphide Concentrates on Refractory Brick Wear during the Smelting Stage**: *Julio Ossandón*[1]; Leandro Voisin[1]; Camila Pizarro[1]; [1]Universidad de Chile

Clay minerals such as kaolinite and montmorillonite are hydrous aluminum/magnesium phyllosilicates that are usually present in the gangue associated with sulphide copper ores, follows the froth flotation concentrate, and during smelting stage generate oxides which move to the equilibrated slag, changing their transport phenomena properties. Then, impurity elements from clay minerals strongly affect the slag and may change the refractory consumption, either directly or through an unexpected change in operation conditions. In this study, the relation between refractory brick wear and slag composition was investigated by experimental laboratory tests. Synthetic fayalite based slags, doped with different amounts of clay minerals were melted into magnesia-chrome refractory crucible at 1250°C under controlled partial pressure of oxygen. Samples were analyzed by using XRD, SEM and ICP technics. The results were used to elaborate mass balances and corrosion models as a function of kaolinite and montmorillonite contents into the feed to the smelting stage.

**11:05 AM**

**Interfacial Reaction between Magnesia Refractory and EAF Slag**: *Jin Sung Han*[1]; Jung Ho Heo[1]; Il Sohn[2]; Joo Hyun Park[1]; [1]Hanyang University; [2]Yonsei University

Magnesia-based refractory is generally used in electric arc furnace (EAF) due to its relatively high corrosion resistance and high temperature strength. However, the magnesia refractory is attacked by EAF slag and thus the lining life decreased. Thus, it is significant to identify the interfacial reaction between magnesia refractory and EAF slags. Even though previous researchers reported the degradation of magnesia refractory in various slag compositions, there are still insufficient studies on the interfacial reaction mechanism between magnesia refractory and high-FeO EAF slag. Therefore, in the present study, the influence of high-FeO slag on the corrosion behavior of MgO refractory was evaluated. As a consequence, (Fe,Mg)Oss layer was observed at the slag-refractory interface and its thickness increased with increasing content of FeO in the slag. The specific reaction phenomena and formation behavior of (Fe,Mg)Oss layer were evaluated by thermochemical computing program, FactSageTM7.0.

**11:30 AM**

**The In Situ Micro Raman Study of the NO3- Electrochemical Behavior in Molten NaNO3-KNO3 Mixtures**: *Sheng Zhuo*[1]; Li Liang[2]; [1]Other; [2]Pangang Group Research Institute Co., Ltd.

We have designed the high temperature Raman micro-furnace and cell which suit for study the electrochemical process of the NO3- in molten NaNO3-KNO3 salt. During the cycle voltammetry and constant potential electrolysis process, the Raman laser beam was focused near the electrode, then the Raman spectra is obtained and the reduction process of NO3- is analyzed. In the CV cathodic scan process, the new peak attribute to v_1mode of NO2- emerge, and the peaks assign to superoxide ions (O2-) and peroxide ions (O22-) are not found. In the constant electrolysis process the peaks at 1130 cm-1 and 800 cm-1appear when the potentials between -2.0V and -3.2V(vs. Pt). The results show that when the NO3- be reduced in molten NaNO3-KNO3 mixtures, the reduction product O2- cannot stability existence, the O2- will react with NO3- and then existence in the form of superoxide ions (O2-) and peroxide ions (O22-).

## Part C-1: Hydrometallurgy 2018 – Environmental 1

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Monday AM | Room: Les Saisons |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM Invited**

**Hydrometallurgical Extraction of Lead in Brine Solution from a TSL Processed Zinc Plant Residue**: *Rajiv R. Srivastava*; Jae-chun Lee[1]; Tam Thi Nguyen; Min-seuk Kim[1]; Jingu Kang[2]; [1]Korea Institute of Geoscience and Mineral Resources (KIGAM); [2]Young Poong Sukpo Zinc Refinery

Brine leaching of a TSL processed zinc-plant residue (ZPR) containing 83.3% anglesite mineral has been investigated for lead recovery. A prior treatment of ZPR in acid solution did not show any significant effect of acid concentration in zinc dissolution. The study reveals the solubility limits of $PbCl_2$ as an important factor with respect to the brine concentration and pulp density in lixiviant. The dissociated sulfate ions hinder the formation of $PbCl_2$ on prolong leaching (above 60 min), while exhibiting the reverse solubility for lead present as anglesite ($PbSO_4$). A 3-step leaching process could yield > 92% leaching efficiency while maintaining the parameters as: 10% pulp density in a 250 g/L NaCl solution, 80 °C temperatures, and 60 min time. This leaves the insoluble ferrite, sulfides and oxy-sulfates of zinc and lead in the final residue as revealed by the XRD characterization.

**8:30 AM Invited**

**Hydrometallurgical Recovery of Lead from Zinc Calcine Neutral Leach Residue**: *Andrzej Chmielarz*[1]; Ryszard Kurowski[1]; Agnieszka Fijalkowska[1]; [1]Instytut Metali Niezelaznych

Neutral leaching of zinc calcine generates sludge containing lead (10-15%)as sulphate, and zinc (15–20%), bound into sulphides and ferrites. The material is usually subjected to HAL, or to Waelz process. The product of the last is crude ZnO of significant lead content (15–20%), thus limiting its further treatment for IS Process. Selective lead recovery from the sludge can be reached thanks to solvation properties of triethylenetetramine (TETA). That compound extracts a whole molecule of $PbSO_4$ into aqueous phase. After phase separation lead recovery as carbonate is carried out through $CO_2$ action. TETA based technology was verified in the process of lead recovery from neutral leach residue. The results show potential for recovery of over 80% of lead in a form of $PbCO_3$ (˜70% Pb), with about 30% reduction of sulphates and 20% loss of mass of the leached material. The leaching residue contains 2% of lead only.

**8:55 AM**

**Alkaline Metals Removal from Radioactive Wastewater by Combined CO2 Capture and Adsorption into Bone Char**: Elbert Nigri[1]; André Santos[1]; Leonardo Santos[1]; *Sonia Rocha*[1]; [1]UFMG

Radioactive wastewater from nuclear source of electrical energy production needs to be treated and disposed. Sr, Ca, Mg and Ba are common elements in this effluent which can cause incrustation and also be dangerous to human health (90Sr). Fixation of $CO_2$ can be applied to brines to remove the ions mentioned and provide a solution where $CO_2$ is sequestered and the deleterious elements precipitated, becoming one of the possible steps to get the water reused back into the process. Moreover, removal of several metals from distinct wastewater have been evaluated using bone char through adsorption. The chemical similarity of calcium and strontium makes the substitution of these metals into hydroxyapatite structure of bone char. This paper evaluated the combined action of precipitation and adsorption process with injection of $CO_2$ and bone char adsorbent in simulated nuclear wastewater. Removal of 89.0% (Sr) and 83.3% (Ca) was obtained in combined process. The presence of bone char as seed increased the precipitation kinetics, allowing a Sr removal of 85.2 % in five minutes, higher than 75.3 % obtained in absence of seeds. However, at longer times (25h) removal of 91.6% (Sr) and 89.8% (Ca) were obtained in absence of seeds. Analysis of solids have evidenced that $CO_2$ was consumed to precipitate the metals in carbonate form.

**9:20 AM Invited**

**Assessing Alternative Pre-treatment Methods to Promote Metal Recovery in the Leaching of Printed Circuit Boards (PCBs)**: *Thandazile Moyo*[1]; Blessing Chirume[1]; Jochen Petersen[1]; Dee Bradshaw[1]; [1]University of Cape Town

PCBs are a metal rich fraction of e-waste streams. Reported successful cases of PCB recycling for metal recovery are carried out in large volumes in high technology and high capital investment smelter house operations. Hydrometallurgical processes can possibly provide an option for the scalable processing of smaller volumes of PCBs and can be set up at lower capital costs. However, to date, the hydrometallurgical treatment options available rely on precursor comminution processes that also have high capital and energy costs. This study evaluates the options of using chemical pre-treatment and other alternative pre-treatment methods to promote the leaching of metals which are otherwise inaccessible. Custom made PCBs of known metal content have been used to evaluate the effectiveness of each pre-treatment method. This has been assessed using a diagnostic base metal leach. Surface analysis tools have been used to assess where residual metal sits on the PCB post leaching.

**9:45 AM Break**

**10:15 AM**

**Kinetics Study and Application of Box-Behnken Design to Investigate Leaching of Copper from Waste Printed Circuit Boards Using Alkaline Glycine-Peroxide Solution**: *Rohn Kenneth Serapio*[1]; Terence Lucero Menor[1]; [1]University of the Philippines-Diliman

Recycling of waste printed circuit boards (WPCBs) becomes progressively appealing due to its recoverable valuable metals. However, most of the process applied today are economically and environmentally unsatisfactory. Thus, the purpose of this research is to attest the potential of glycine, an inexpensive and eco-friendly amino acid, as an alternative lixiviant of copper from WPCBs. Leaching experiments with 16% pulp density at 400rpm were conducted. Box-Behken design was employed as experimental design. From the results, it was found out that glycine can effectively leach Cu from WPCBs. Maximum extraction of 32% Cu was achieved at 3.7:1 Cu-to-glycine molar ratio, pH 10.26, 0.6%(v/v) $H_2O_2$ and ambient temperature. At 45°C, dissolution further reached 46% using the same combination of parameter settings. Cu extraction was also observed to increase exponentially with time. The rate-determining step was found to be product layer diffusion and the activation energy of the process was estimated at 3041.36cal/mol.

**10:40 AM**

**Synthesis and Properties Characterization of Crystalline Polyferric Sulfate Adsorbent Used for Treating High As(III)-content Contaminated Water**: *Pingchao Ke*[1]; Zhihong Liu[1]; [1]Central South University

A crystalline polyferric sulfate (PFS) adsorbent was synthesized by oxidizing and precipitating ferrous ions under atmosphere. The morphology, structure, composition and specific surface area (SSA) and adsorptive efficacy to As(III) of the adsorbent were characterized by SEM/EDS and TEM images, XRD patterns, FT-IR spectra, BET SSA analyses and adsorption experiments. The adsorbent presents as morphology of near-spherical aggregate and good crystallinity. A small amount of goethite co-precipitated with PFS in the case of the initial ferrous concentration of 1 mol/L and increased the SSA of the aggregates. The absorbent with the largest SSA showed good adsorption to As(III) and good filtering performance in the high As(III)-content solution of 10-100 mg/L under acidic, neutral and alkaline conditions (pH 2.09-9.01), and its maximal adsorption capacity and adsorption efficiency were 7911 µg/g and 96% separately.

**11:05 AM**

**Recovery and Separation of Valuable Metals from Electronic Waste**: *Hyunju Lee*[1]; Emily Molstad[1]; Brajendra Mishra[1]; [1]Worcester Polytechnic Institute

The advance of the electronic technologies reduced the life of electronic equipment, as a result, it increased the generation of waste from electrical and electronic equipment. Various methods such as physical and chemical process have been attempted to recover metals from electronic wastes (e-waste). In this study, the e-waste sample was investigated to obtain valuable metals including Au, Ag, Cu, and Fe using physical and chemical methods. In the physical process, size and magnetic separation were performed and then each particle fraction weight and composition were measured. In the chemical process, a two-step process was performed for selective metal recovery. The acid solutions (HNO3, HCl, H2SO4) were used for recovery of base metal as a first leaching process and second leaching (thiourea) process was performed for selective precious metals (Au, Ag) recovery. All experiment was conducted with a variation of time and temperature.

**11:30 AM**

**Custom Fiberglass Reinforced Plastic Piping (FRP) Applications in Mineral Processing**: *Dave Chapman*[1]; Tony Zacharewych[1]; [1]RPS COMPOSITES

There are a variety of choices of materials for mineral extraction processing. Traditionally, end users have used metallic piping for fluid handling and little is known about the advantages (or limitations) of non-metallic piping systems. This presentation will review custom FRP pipe systems and their use in severe corrosive and erosive process streams. These systems can be designed to various pressure and temperature ratings and different components (such as resin and glass type) can be varied to suit the process conditions.

## Part C-1: Hydrometallurgy 2018 – Extraction/Processing 1

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Monday AM | Room: Confederation I |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**

**Electrochemical Behavior of Chalcopyrite in Presence of Sodium Peroxodisulfate**: *Hojat Naderi*[1]; Jochen Petersen[1]; [1]Yazd University

In this research assisted leaching of chalcopyrite using sodium peroxodisulfate was studied using solid paraffin-based carbon paste (CPE) and chalcopyrite mineral electrodes, and the behavior of these two was compared. Electrochemical techniques such as Tafel analysis and electrochemical impedance spectroscopy (EIS) were used to investigate the surface reactions. Various parameters, such as pH, Na2S2O8 concentration and simultaneous presence of ferric and peroxodisulfate ions, were studied and the results were compared. The results suggest that decreasing the pH results in trans-passive dissolution of chalcopyrite. Addition of sodium peroxodisulfate increases the exchange current density of the corrosion process and prevents formation of a passive layer on the surface of the electrode. Lower charge transfer resistance was obtained at higher concentrations of Na2S2O8 for both the CPE and solid mineral electrode. Equivalent electrochemical circuits were modeled and the model parameters were compared.

**8:30 AM Invited**

**Activation of Chalcopyrite Particles for Improved Copper Recovery in the FLSmidth® ROL Process**: *Adam Karcz*[1]; Anne Juul Damø[1]; Jytte Boll Illerup[1]; Kim Dam-Johansen[1]; David Chaiko[2]; [1]Technical University of Denmark; [2]FLSmidth USA, Inc.

As a means of efficiently extracting copper from chalcopyrite, FLSmidth® has developed a patented Rapid Oxidative Leaching (ROL) process, which is capable of recovering > 98% of copper in less than 6 hours. This two-step process combines a chemical pretreatment step followed by mechanically-assisted, oxidative leaching with acidic ferric sulfate lixiviants in atmospheric conditions. The pretreatment step, which uses 0.1 to 5.0 wt.% copper(II) to activate chalcopyrite, has a significant impact on the improvement of leaching kinetics. The subject of this presentation will be the investigations into the effects of copper "doping" on the mineral phase through characterization of the changes in the crystal lattice (e.g. TEM diffraction) and electronic structure (e.g. XPS binding energies). The conclusions ascertained in those studies will be supported with theoretical understanding through computational modeling using DFT code (FHI-aims), which will construct a complete story on the role of chemical activation.

**8:55 AM**

**Alternative Lixiviant for Copper Leaching from Chalcopyrite Concentrate**: *Junmo Ahn*[1]; Jiajia Wu[1]; Jaeheon Lee[1]; [1]University of Arizona

Chalcopyrite leaching by conventional sulfuric acid with ferric as an oxidant is well known to be hindered by surface passivation. In this study, different chemical lixiviants were used to investigate the effects on overall copper extraction. Baseline sulfuric acid leaching with ferric ion as an oxidant was carried out and sulfurous acid with ferric ion was also performed. MSA (Methanesulfonic Acid) with ferric ion or hydrogen peroxide as an oxidant was also studied for copper leaching from chalcopyrite. Copper extraction by 30 g/l MSA was higher at 0.6% H2O2 (94%) compared to 0.3% (67%) and 1.5% (75%). Maximum copper extraction of 23% was observed at 21oC using MSA and almost 100% copper extraction was achieved at 75oC by MSA. The activation energy of the chalcopyrite leaching by MSA was calculated to be 39.9 kJ/mol and the kinetic is chemical reaction controlled.

**9:20 AM Invited**

**Hydrometallurgical Processing of Copper-Arsenic Concentrates**: *Jan Smit*[1]; Kelvin Buban[1]; Mike Collins[1]; Preston Holloway[1]; [1]Sherritt

Sulphidic copper concentrates are generally processed by pyrometallurgical means; while oxidative pressure leach processing of such materials has been shown to be technically feasible, there has traditionally been little incentive to choose this route in favour of a smelting option. However, for concentrates with elevated arsenic levels, oxidative pressure leaching offers distinct advantages, as smelter air emission standards and restrictions on concentrate importation have tightened. The current state of pressure leach technology allows for high copper extractions from arseniferous copper concentrates, while producing an environmentally stable process residue, without atmospheric emissions of sulphur dioxide or arsenic. In its studies on pressure leaching of copper concentrates, Sherritt has shown that arseniferous feed materials can be converted into environmentally stable residues, with excellent copper extractions. The results of recent batch and pilot plant test work are discussed, including the deportments of copper, arsenic and precious metals.

**9:45 AM Break**

**10:15 AM Invited**

**Sustainable Development Considerations in Copper Hydrometallurgy**: *Krishna Parameswaran*[1]; [1]tfgMM Strategic Consulting

This paper illustrates sustainability considerations in copper hydrometallurgy using examples of practices at ASARCO LLC, an integrated U.S. primary copper producer as well as others in the industry. Using the classic Brundtland Commission development of sustainable development, i.e., “development that meets the needs of the present without compromising the ability of future generations to meet their own needs,” the paper discusses how copper mineral processing, electrowinning and electrorefining practices can be sustainable. These examples include: water and energy conservation, resource conservation, implementation of green chemistry and promoting product stewardship.

**10:40 AM**

**Improved Process for Leaching Refractory Copper Sulfides with Hydrogen Peroxide in Aqueous Ethylene Glycol Solutions**: *Angel Ruiz-Sánchez*[1]; Gretchen Lapidus[1]; [1]Universidad Autónoma Metropolitana

Ethylene glycol additions to aqueous acid solutions for leaching copper sulfides increase both copper and iron extractions compared to a conventional sulfuric acid leach with hydrogen peroxide (H2O2). The role of ethylene glycol is to prevent peroxide destruction, which normally occurs in solutions that contain both cupric and ferric ions. However, despite this improvement, ethylene glycol and sulfuric acid concentrations must be high (3.5 M and 0.7 M, respectively) to obtain satisfactory conversion levels at room temperature. In the present investigation, EDTA was used as an additive to complex the cupric and ferrous ions, lowering the requirements of ethylene glycol and H2SO4 to 0.11 M and 0.007 M, respectively, while minimizing oxidant decomposition. The experimental results for a mainly chalcopyrite, copper concentrate showed complete copper extraction in 24 hours at room temperature, with the stoichiometric quantity of EDTA for the copper and iron dissolved. Tests using seawater were equally as successful.

**11:05 AM**

**Copper Recovery from the Mine Tailings by Combination of Flotation with High-pressure Oxidative Leaching and Solvent Extraction**: *Atsushi Shibayama*[1]; Baisui HAN[1]; Kazutoshi HAGA[1]; Zoran STEVANOVIC[2]; Radojka JONOVIC[2]; Ljiljana AVRAMOVIC[2]; Daniela UROSEVIC[2]; Yasushi TAKASAKI[1]; Nobuyuki MASUDA[1]; Daizo ISHIYAMA[1]; [1]Akita University; [2]Mining and Metallurgy Institute Bor

The aim of this research was to develop a copper recovery process from mine tailings (0.38%Cu) using flotation followed by high-pressure oxidative leaching (HPOL) and solvent extraction. The results of HPOL using the concentrate of mine tailings obtained by flotation under the optimal conditions of the previous study shown that an efficient copper dissolution of 94.4 % was achieved in an H2O media, while the copper concentration of PLS reached to be 2.9 g/L. The solvent extraction of PLS obtained from the optimal HPOL showed that 91.3 % copper was recovered in stripped solution under the determined optimum conditions, in which the copper concentration achieved to be 44.8 g/L. Finally, a proposed copper recovery process from the mine tailings was developed by combination of flotation, HPOL, and solvent extraction, while a total copper recovery about 70 % was achieved.

**11:30 AM Invited**

**Dezincing of Galvanized Steel by Sulfuric Acid Leaching**: *Joseph Grogan*[1]; Gerard Martins[2]; Corby Anderson[2]; [1]Gopher Resource; [2]Colorado School of Mines

Leaching of galvanized steel coatings allows the steel substrate to be used as a zinc-free scrap source to steel and iron furnaces. In this study the behaviors of sulfuric acid leaching solutions are investigated. The ranked significance of the variables are shown to be acid concentration > temperature > zinc concentration. Examination of the leaching mechanism finds the rate-limiting step to be the cathodic hydrogen reduction reaction. This rate is not only influenced by acid concentration, but also by the hydrogen reduction exchange current density. Dezincing leaching rates are improved by taking advantage of the higher exchange current density of the iron substrate versus the zinc coating. This is accomplished in practice by increasing the exposed interfacial zinc:iron surface area through shredding. Also, a leach control mechanism is proposed through online monitoring of the zinc-iron couple mixed potential.

## Part C-1: Hydrometallurgy 2018 – Extraction/Processing 2

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Monday AM | Room: Provinces II |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM Invited**
***Douglas Centenary Commemoration - 1918-2018***
**Engineering the Science: James Douglas, Early Hydrometallurgy and Chile**: *William Culver*[1]; [1]State University of New York
A series of institutions in Canada and the United States are planning events of one or another nature to commemorate the centenary of James Douglas' death. The motivations vary, but all believe he deserves to be remembered for his contributions to Canadian culture, Arizona's economic development, to mining and metallurgy, and to letters. The intention of the 2018 commemoration is to further honor Douglas' contributions to the several mineral industry engineering professions, in addition to recognizing his writing about the industry and the world in general. Perhaps Douglas' greatest legacy is the least known – his words. Douglas left thousands of words that remain of interest and value today. He considered his writing a hobby and a relaxation, but he wrote constantly and left behind hundreds of articles, letters to the editor, book reviews and reflections. Douglas is known in the 21st century as one of those great individuals whose name is on buildings, endowments, and awards. The most prestigious award for a North American metallurgist (non-ferrous) is TMS/SME's James Douglas Gold Medal, established in 1922 by the AIME.

**8:30 AM**
**Making the Right Selection: A Comparative Analysis for the Treatment of Refractory Gold Concentrates**: *Rod Clary*[1]; Paul DiNuzzo[1]; Thomas Hunter[1]; Saleem Varghese[1]; [1]Jacobs
Building on work completed in earlier papers, the current paper presents a techno-economic evaluation of two recently demonstrated technologies for treatment of arsenic containing refractory gold concentrates. Using defined project parameters and inputs, the authors compare capital and operating cost estimates for pressure oxidation (POx), and the Albion Process™. The paper incorporates data now publicly available from the Albion Process™ plant, at the GeoProMining Gold (GPM Gold) project in Armenia since 2014 as well as recent POx circuits.

**8:55 AM**
**Evolution of Metallurgical Parameters at Mantoverde Heap Leaching Operation**: *Gabriel Zarate*[1]; [1]GZ Consultores
Mantoverde is a heap leach-SX-EW plant that was commissioned in December 1995 at a production rate of 42,130 ton of copper per year and 5.4 million ton of ore per year. Since then, copper production has steadily been increased to a maximum of 61,000 ton in 2010. In order to get these copper production and throughput rates, a number of changes have been introduced in the metallurgical parameters of the plant operation since the start up, among them particle size, heap height, acid addition distribution in curing and leaching solution and leach cycles. Most of the modifications have been implemented after carrying out extensive column test work programs.The modifications implemented and the results obtained, as well as the test work programs carried out, are discussed in this paper.

**9:20 AM**
**The Effect of Aeration on Chalococite Heap Leaching**: *Wenying Liu*[1]; Giuseppe Granata[2]; [1]University of British Columbia; [2]Waseda University
Aeration provides oxygen and carbon dioxide for microbial activities to occur, a fundamental process occurring in chalcocite heap bioleaching. The aeration rate and aeration system design are critical for achieving optimum copper extraction. Mathematical modelling is an effective tool for assessing the effect of aeration on copper leaching behavior. In this study, the HeapSim-2D model was applied to simulate the effect of aeration on copper extraction from chalcocite using heap bioleaching. The model was calibrated using the historical data from two chalcocite heap bioleach pads located in Chile, one with aeration and the other without aeration. The model could satisfactorily simulate the copper leaching behavior in both cases. The modelling results showed that aeration greatly enhanced copper extraction, which was in agreement with site monitoring data; aeration rate and the design of aeration system played a key role in optimizing the process performance.

**9:45 AM Break**

**10:15 AM**
**Study of the Diffusion of Cu(II) as an Oxidant Through Simulated Particle Pores in a Novel Model Apparatus**: Buhle Manana[1]; *Jochen Petersen*[1]; Rahul Ram[2]; [1]University of Cape Town; [2]Monash University
In heap leaching, the oxidative dissolution of minerals embedded deep within large particles cannot be understood on the basis of the solution conditions on the particle surface. In the present study the diffusion of the oxidising species through inner particle pores is simulated in a model apparatus that separates a platinum electrode under controlled reduction potential from the bulk solution through narrow pores of varying length. The Cu-NH3 system was chosen as a model system, and Cu2+/Cu+ as the redox couple of interest. Platinum wires inserted in the pores allowed the measurement of varying redox potentials along the pore length. Results showed that there exists a narrow (0.5mm) zone near the reduction surface that is depleted of the oxidant, and in which its supply to the surface is strongly diffusion limited, even if it is in abundance in the bulk solution and most of the length of the pore.

**10:40 AM**
**Filtration Properties of Ferric Hydroxide Precipitate in Nickel Production**: *Ina Beate Jenssen*[1]; Mona Aufles Hines[1]; Ole Morten Dotterud[2]; Oluf Bøckman[2]; Jens-Petter Andreassen[1]; [1]Norwegian University of Science and Technology; [2]Glencore Nikkelverk AS
Ferric iron removal from the nickel electrolyte at Glencore Nikkelverk in Kristiansand is achieved by precipitation followed by filtration. It is desirable to improve filtration properties of the precipitated iron hydroxide in order to decrease the filtration time. Precipitation of iron hydroxide was studied onsite in a continuous reactor with ferrous-containing process solution as the feed material. The system was controlled with feedback regulation for pH, simulating the precipitation occurring in the plant at different temperatures and residence times. pH and redox potential was controlled by addition of $NiCO_3$ and chlorine gas, respectively. After three residence times the slurry was filtered in order to determine the filter cake resistance. XRD analyses showed that the final product was akaganéite. It was possible to decrease the filter cake resistance by either increasing residence time or temperature, although enhanced temperature levels reduced the filter cake resistance by one order of magnitude.

**11:05 AM**

**The Effects of Experimental Variables on Iron removal from Nitrided Malaysian Ilmenite by Becher Process**: Eltefat Ahmadi[1]; Noor Izah Shoparwe[1]; Najwa Ibrahim[1]; *Sheikh Rezan*[1]; Norlia Baharun[1]; Kamar Shah Ariffin[1]; Hashim Hussin[1]; M.N. Ahmad Fauzi[1]; [1]Universiti Sains Malaysia

Iron-free titanium oxycarbonitride (TiOxCyNz) is a promising feedstock for production of titanium tetrachloride ($TiCl_4$) at low temperatures. In this study, the effects of leaching variables such as temperature, time and concentration of the leaching solutions were evaluated on iron removal from the nitrided Malaysian ilmenite by Becher process. The nitrided ilmenite was prepared by isothermal reduction with graphite at 1200\176C for 3 hours in $H_2$-$N_2$ atmosphere. The aerated leaching experiments were conducted at 50-90 \176C with addition of 0.3-2 wt. % of $NH_4Cl$ solution. The highest extent of iron removal ($X_{Fe}$) was obtained at about 96.2% for the sample leached at 90 \176C for 7 hours with 2.0 wt. % $NH_4Cl$. The iron concentrate and titanium oxycarbonitride product were characterized by ICP-OES , XRD, XRF and SEM-EDX analyses. The results indicated that the aeration leaching process was a successful route to prepare low-iron titanium oxycarbonitride.

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## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Monday AM

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

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| Monday AM | Room: Provinces I, sponsored by Purolite |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**8:00 AM Introductory Comments**

**8:05 AM Invited**

**The Feasibility of Separation of Rare Earth Elements by Use of Electrodialysis**: *Sanaz Mosadeghsedghi*[1]; Maziar Sauber[1]; Saviz Mortazavi[1]; [1]NRCan

In this study, the feasibility of the application of ED/EDR in separation of light and heavy REEs in synthetic solutions and leachate samples was investigated. The experiments were performed using a bench scale ED/EDR system to determine the technical feasibility and barriers and propose solutions for efficient application of ED/EDR for REE separation.

**8:30 AM Invited**

**Separation of Cobalt and Metals in Acidic Chloride Solutions Using Diffusion Dialysis**: *Zizheng Zhou*[1]; David Dreisinger[1]; [1]UBC

The separation of cobalt from other base metals can be achieved using diffusion dialysis in a two-compartment reactor separated by an anion exchange membrane. In this work, a Neosepta AFX membrane was used to study the separation of various metals in an acid-chloride solution. The separation of one metal from another was investigated on the basis of the various chloro-complex stabilities. The metals investigated included cobalt, nickel, copper(II), iron(III), aluminum, zinc and cadmium. The impact of several critical experimental conditions, including the initial metal and chloride concentration in the feed solution and their initial concentration in the receiving solution, on the separation factor and the metal transfer rate is reported in this work.

**8:55 AM**

**Application of Donnan Dialysis to the Separation and Recovery of Cations During Hydrometallurgical Recycling of Lithium Ion Batteries**: *Alexandru Sonoc*[1]; Jack Jeswiet[1]; [1]Queen's University

Donnan Dialysis uses ion exchange membranes to extract and separate cations. The driving force is provided by differences in chemical potential, rather than by electric fields or pressure. A Donnan Dialysis based process to recover lithium, nickel, cobalt, manganese, and organic acid lixiviant from recycled lithium ion battery cathodes is under development. In this paper we present a model of Donnan Dialysis and results of simulations of the aforementioned process. The simulations show that 170 m$^2$ of membranes can process 1000 L of leachate ($[Li+] = 0.285$ M, $[Co^{2+}] = [Ni^{2+}] = [Mn^{2+}] = 0.095$ M, pH 2) in two days and recover 94.1% of the lithium (as lithium carbonate), 99.4% of the transition metals (as mixed sulphates ready for solvent extraction), and all of the organic acid using 423 moles of $H_2SO_4$ and 268 moles of $KHCO_3$.

**9:20 AM**

**Electrolytic Salt Splitting for Sulfuric Acid and Caustic Recovery: Can it be Cost-effective?**: *Alexander Burns*[1]; Clive Brereton[1]; [1]NORAM Engineering

Electrolytic salt splitting is a technology where acid and/or base is regenerated from a neutral salt using membrane electrolysis. The mining industry has been slow to adopt this technology due to challenges associated with impurities, as well as economic factors such as the relatively low cost of disposal and reagent repurchase. However, recent advances in brine treatment, membranes, and cell design have made electrolytic salt splitting feasible for a wider range of feeds, while stricter environmental regulations have made the bulk disposal of salt solutions more difficult.In this paper, a typical salt splitting flow sheet is presented, based on recent NORAM projects. The flow sheet is compared to other technologies, taking into account factors such as electricity cost, reagent cost, maintenance, and scalability. The results can be used to help evaluate the feasibility of electrolytic salt splitting under local economic conditions at a proposed installation site.

**9:45 AM Break**

**10:15 AM**

**The Industrial Application of Ulltrafiltation and Reverse Osmosis for the Recovery of Copper, Silver and Cyanide from Gold Leach Liquors**: Farhang Hedjazi[1]; *A. John Monhemius*[1]; [1]Anglo Asian Mining plc

Anglo Asian Mining have recently installed an industrial-scale UF/RO plant to treat barren leach liquors from the integrated heap leach/agitation leach/resin-in-pulp gold ore treatment facilities at their Gedabek gold-copper mine in Azerbaijan. The UF/RO plant is designed to treat 60 cu.m/hr of leach solution to produce discharge quality water. The RO concentrate, which contains elevated concentrations of copper, silver and cyanide, is sent to the company's SART plant for the recovery of the metal values as a precipitated sulphide concentrate and the cyanide, which is recycled to leaching. The new water treatment plant improves the sustainabilty of the operations at Gedabek by enabling replacement of fresh water input with RO permeate and safe discharge of permeate to the environment, during periods of excess water balance. The paper will include pilot plant data and early results from the full-scale plant, together with a preliminary assessment of the economics of the process.

**10:40 AM**

**Extraction of Clean Water from Contaminated Effluents by Forward Osmosis**: *Georgios Kolliopoulos*[1]; Vladimiros Papangelakis[1]; [1]University of Toronto

Water is a critical commodity of our generation and a key compound for the chemical and mining industry. Sustainable industrial development is directly associated with the ability to recover clean water from contaminated sources. Forward Osmosis (FO) is a low-energy footprint membrane process allowing the recovery of clean water from high salinity effluent streams. In FO, water is recovered spontaneously into a concentrated draw solution (CDS). Energy is required to separate the recovered water from the resulting dilute draw solution (DDS). In the current work, the fundamentals of the FO process and the various aspects affecting its performance are discussed. An in-depth energy and cost analysis of FO is presented and the outcome is compared to conventional water recovery processes.

**11:05 AM**

**Preliminary High Rate Compressible Media Filtration Provide Promising Benefits For Leach Liquor Clarification**: *Anthony Galvan*[1]; [1]Schreiber LLC

High rate compressible media filter (CMF) tests produced exceptional total suspended solids (TSS) removal at hydraulic loading rates of 97.8 to 122.2 m/h. The compressible media is manufactured from a robust resin fiber that can withstand low pH and high temperature up to 149 oC. The media porosity can be varied by applying compression on the media. At 40% compression, the CMF can remove particles greater than 4 microns. Three synesthetic samples were generated by Hazen Research (Golden, Colorado) to represent the copper Pregnant Leach Solution (PLS), Raffinate and Electrolyte solution. The preliminary results showed the CMF was very effective in removing TSS (without the use of chemical conditioning) from the PLS, Raffinate and Electrolyte solution with TSS removals of 98%, 97%, and 96%, respectively. At these high hydraulic loading rates, the resultant equipment footprint will be minimized appreciably over conventional clarification and alternative filtration equipment.

**11:30 AM Invited**

**Membrane Technologies for Improving Mining and Refining Processes**: *Larry Lien*[1]; [1]MDS

Membrane technology has been available for over 50 years, but has been used sparingly in the general mining industry. However, recent developments in polymer chemistry, spiral wound element construction, pretreatment equipment and techniques and an expanded understanding of membrane fouling and cleaning techniques have dramatically improved the reliability and robustness of membrane based systems in the mining industry. These improvements have expanded the use of "new" technology to enhance the use of membrane technologies to separate metals from large volume heap leach mining solutions containing copper, zinc, iron, gold or silver. Moreover, membrane technologies are ideally suited to fractionations that add value to processing fluids from refineries like separating metals from acids or concentrating acids and producing high quality process fluids. Finally, waste waters from Acid Mine Drainage (AMD) can be cost effectively processed to meet surface discharge standards.

## Part C-3: Processing of Critical Metals – Critical Materials / Lithium

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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| Monday AM | Room: Governor General I |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM Invited**

**Material Criticality: Comparing China, the EU, Japan and the USA**: *Roderick Eggert*[1]; [1]Colorado School of Mines

A critical material provides essential functionality to an engineered material, component or system, has few if any easy substitutes, and is subject to supply-chain risk. This paper compares the manufacturing sectors of China, the European Union, Japan and the United States in terms of what materials are 'critical' to their manufacturing sectors.

**8:30 AM**

**Lithium Extraction and Utilization: A Historical Perspective**: *Ice Peerawattuk*[1]; Erin Bobicki[1]; [1]University of Toronto

Growing demand for batteries is leading to an unprecedented growth in the lithium industry. Although innovation in battery technologies has pushed lithium into the spotlight, lithium was not always known for its application in batteries. The primary use of lithium — prior to the introduction of commercial lithium-ion batteries in the early 2000s — was in the ceramics, glass, grease and medical industry. Before turning into its usable form, lithium products must be upgraded from its raw material. Processes for recovering lithium include: thermal treatment, water leaching, solar evaporation, ion exchange, carbonation, and electrodialysis. Presented is a historical review of lithium applications and the different techniques of converting lithium-rich minerals and brines into usable products with additional discussion on future lithium extraction processes.

**8:55 AM**

**Extraction of Lithium from Brine - Old and New Chemistry**: *Michael Dry*[1]; [1]Arithmetek Inc.

Conventionally, lithium-bearing brines are processed via solar evaporation, chemical purification and either electrolysis to lithium hydroxide, or the precipitation of lithium carbonate. Current interest in the lithium-ion battery is forecast to greatly increase the demand for lithium, but many lithium-bearing brines are not easily amenable to the conventional extraction process and new approaches are being developed. This paper will review the chemistry of selected brines currently being processed and some brines targeted for processing that are not amenable to the conventional route. The process chemistry associated with the conventional lithium extraction route and a number of the new approaches will be outlined and explored. The focus will be on what makes some brines bad candidates for conventional processing and how the new approaches are attempting to overcome that which makes conventional processing unsuitable.

**9:20 AM**

**Development of Sileach\174 Technology for the Extraction of Lithium from Silicate Minerals**: *Chris Griffith*[1]; Adam Roper[1]; Adrian Griffin[2]; Andrew Skalski[2]; [1]ANSTO Minerals; [2]Lithium Australia NL

Lithium Australia NL (ASX:LIT) and ANSTO Minerals (AM) have been working together since 2015 on the development of halide accelerated leaching for the extraction of lithium from Li-bearing micas, spodumene and hectorite clays. This technology has been termed SiLeach\174. The driving force behind development of SiLeach\174, initially, was to develop a hydrometallurgical process to extract lithium from micas and spodumene without the need for energy intensive, high temperature processing. This driving force remains today and continues to hold promise in realising the value of previously under-utilised lithium resources. A comprehensive understanding of the technology and its applicability to the processing of micas and spodumene currently exists, and the flowsheet has been rigorously piloted. Production of battery grade lithium carbonate has been demonstrated.This publication will provide an overview of the development of the Sileach\174 technology and associated downstream purification steps.

**9:45 AM Break**

**10:15 AM Invited**

**Lithium and Boron Extraction from the Rhyolite Ridge Ore, Nevada USA**: *Peter Ehren*[1]; Bernard Rowe[1]; [1]Global Geoscience Limited

A shallow Boron-Lithium resource deposit with the boron and lithium minerals Searleslite (40%wt) and Sepolite (2% wt) are found among principally calcite, feldspar, dolomite and quartz. The equivalent commercial value is about 7-9 %wt Boric acid and 0.8-1.0 %wt Li2CO3 equivalents. Selectively agitated leach at SGS Lakefield laboratory showed that Searleslite can be acid leach between 20-80 oC and at a pH lower than 4, on the other hand, lithium can be can leached between 20-80 oC and at a pH of 1. So, in other words lithium can be recovered at low temperatures if sufficient free acid available. This opened the way to investigate heap leaching of the mineral and how the composition of pregnant liquor solution (PLS) is evaluating during direct and counter current leaching with sulfuric acid. The key results of these tests will be described in this paper.

**10:40 AM**

**Assessment of Some Lithium Pegmatite Ore Bodies to Determine their Amenability to Processing for the Extraction of Lithium**: *Mark Aylmore*[1]; [1]Curtin University

Various processes have been developed using a combination of elevated temperature and chemical treatment processing to recover Li from silicate minerals. To facilitate further process development, a comprehensive understanding of the deportment of Li and associated minerals in ore bodies is essential to allow the industry to predict the response of ore reserves to metallurgical treatment options. This paper describes results from the integrated use of the John de Laeter Centre's state of the art analytical and mass spectrometry techniques to characterise a selection of Li bearing ore bodies and determine their amenability to potential processing options for the extraction of Li. The mineralogy, mineral associations and liberation characteristics of ore-bearing and gangue minerals where characterised using by a combination of the TIMA and XRPD studies. The Li content and distribution within minerals were defined using LAM-ICPMS and field emission scanning electron microscopy techniques (ESBD, ToF-SIMS) and atomic probe microscopy.

**11:05 AM**

**Revisiting the Traditional Process of Spodumene Conversion and Impact on Lithium Extraction**: Colin Dessemond[1]; Francis Lajoie-Leroux[1]; *Gervais Soucy*[1]; Nicolas Laroche[2]; Jean-François Magnan[2]; [1]Université de Sherbrooke; [2]Nemaska Lithium inc.

Since the middle of the twentieth century, the traditional process has been dominating the production of lithium compounds from spodumene ores to sustain the ever-growing lithium market, both due to an economic viability and the need for technical grade (99.5 % purity) product. This process includes thermal conversion of spodumene, acid roasting of converted spodumene and lithium leaching. However, this process has not been challenged since and very few studies tried to explain the limitation of 90 % to 95 % lithium yield extraction or optimize the thermal treatment of spodumene ores. Here, spodumene conversion and lithium extraction were carried out into a rotary kiln using a 2 mm to 2 cm spodumene concentrate instead of a micrometric one using traditional conditions such as 1050°C, 30 min conversion treatment or 250°C, 30 min, 30 % sulphuric acid excess lithium extraction treatment. X-Ray Diffraction analyses were performed on the converted material to determine the rate of conversion of the concentrate by Rietveld analysis. It was observed that the a-spodumene particles fractured and divided during the thermal treatment while the impurity particles were not affected. A sifting was performed on the converted concentrate and it was determined that 65 % of the initial mass became finer than 180 µm. the sifting size was fixed at 180 µm because it is the average size of a flotation spodumene concentrate. X-Ray diffraction analyses and lithium content measurement were performed on both fractions and it was determined that the coarser fraction contained most of the impurities and that the finer fraction had a very high lithium content of 3.24 wt%. Lithium extractions were performed on both fractions separately and it was determined that while the coarser fraction's lithium yield was only of 61 % the finer fraction's lithium yield went up to 99 % without any additional treatment. These observations may open more economical ways for the traditional process by potentially bypassing two third of costly and energy demanding steps such as grinding or flotation.

**11:30 AM**

**Flowsheet Development for Benefication of Lithium Minerals from Hard Rock Deposits**: *Mano Oliazadeh*[1]; Massoud Aghamirian[2]; Syed Saad Ali[2]; Erin Legault[2]; Charlotte Gibson[3]; [1]Lycopodium Minerals Canada; [2]SGS Canada Inc.; [3]Queen's University

Spodumene [$LiAl(Si_2O_6)$] is the most common and desirable economic lithium-bearing mineral due to its high lithium content. In Canada, there are several spodumene deposits at the development stage that have the potential to help narrow the forecast lithium supply gap stemming from the widespread acceptance and increasing use of electric vehicles. Spodumene processing can be conducted using Dense Media Separation (DMS), flotation or combination of both. If spodumene liberation is sufficient at coarse particle sizes, DMS can be used for primary lithium concentrate production and silicate gangue minerals rejection. If liberation is not sufficient, flotation is then the main processing route for spodumene concentration. Even in cases where DMS is a viable beneficiation option, flotation may still be required to process the DMS middlings and/or the undersize fraction which is outside the particle size range for DMS. Considering flotation as a technique for spodumene beneficiation, there are several alternatives including the use of mechanical flotation cells, column flotation cells, coarse particle flotation cells, and/or Staged Flotation Reactor (SFR), either alone or in combination. Ore sorting can be incorporated at the start of the spodumene flowsheet to remove gangue minerals, particularly amphibole and pyroxene in the early stages. The main objective of flowsheet development for hard rock lithium deposits is to evaluate the ability of these options to produce a spodumene concentrate with a concentrate grade above 6% $Li_2O$, lithium recovery of above 80%, and with the minimum operating and capital cost. This paper aims to describe the various processing options available for the beneficiation of spodumene from hard rock deposits and compare the associated operating and capital costs for each.

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## Part D: Sulfide Flotation – Flotation Plant Design and Operational Challenges

*Program Organizers:* Ronel Kappes, Newmont Mining Corporation; Tarun Bhambhani, Solvay

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| Monday AM | Room: Quebec |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Ronel Kappes, Newmont USA Ltd.

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**8:00 AM Introductory Comments**

**8:10 AM Keynote**

**Recent Advances, Key Challenges in Flotation Circuit Design and Optimization**: *Peter Amelunxen*[1]; [1]Aminpro

The limitations of the flotation process are perhaps the most important constraints that must be evaluated when selecting and sizing a sulfide minerals concentration plant. Flotation requires that minerals be liberated sufficiently, not just for separation of the valuable minerals, but also to allow for hydraulic conveyance of the concentrated minerals in the froth phase, in the launders, and in the pipelines. These liberation requirements drive the selection of the comminution equipment, because, for a given ore, the grind size defines the comminution circuit energy requirements. They also drive the selection of the tailings dewatering and impoundment facilities, because particle size distribution plays a key role in dewatering unit capacities, in the volume of sands available for dam construction, and in the slope profile of the tailings. For these reasons, together with the increasingly capital-intensive nature of modern mass mining projects, industry is focusing more and more on the precision, limitations, and applicability of modern flotation circuit design and optimization methods. This presentation reviews the significant recent advances in flotation simulation approaches, and the key challenges that must still be overcome. The review is focused on both technical aspects, such as testing methods and modeling approaches, as well as non-technical aspects, such as the impacts of the mining cycle, the plant capital intensity, and risk tolerance.

**8:55 AM**
**The Value of Incremental Performance Improvement in Concentrators – How to Secure and Quantify Small Gains**: *Norman Lotter*[1]; Tim Napier-Munn[2]; [1]Flowsheets Inc.; [2]JKMRC, SMI, U of Queensland
Incremental performance gains in an operating concentrator offer low-risk, low-cost financial gains with high returns, provided that the right metallurgical skills are available to the project. Seeking continuous improvement is also essential to ensure sustainability of the gain. However this strategy is often regarded as fruitless because of the large variance in plant data, exacerbated by the difficulty of 'proving' that a benefit has been achieved. Successful incremental improvement requires plant trials that use appropriate experimental design and statistics to test the observed differences arising from the old and new process treatments, e.g. reagent suite change, etc. We advocate a policy of continuing improvement driven by rigorous performance testing protocols and a formal 'risk analysis' approach to judging the observed changes in the plant. A key aspect is the choice of hurdle rate for decision-making which best balances risk and reward. Case studies using industrial data are discussed.

**9:20 AM**
**A Study on Reagent Optimization in Primary Molybdenum Flotation to Decrease Variability of Iron and Lead in Final Concentrate and Reduce Costs**: *Denita Kippers*[1]; [1]Climax Molybdenum
Primary Molybdenum operations have unique process configurations and reagent selection than Mo byproduct operations in order to produce concentrate that meets the high quality grades required for industry. The Climax Henderson Primary Molybdenum mill was experiencing seasonal fluctuations in meeting iron and lead levels in the final concentrate. The mill operations underwent an extensive project to identify processing conditions, decrease reagent usage, dosage points, and seasonal timing to increase concentrate grade and reduce variability. This discussion will provide process data that demonstrates; 1) relationship between lab testing and plant data, 2) decrease in Orfom® D8 and NOKES depressant usage by modifying ratios and dosage points, and 3) identifying seasonal conditions to decrease the buildup of summer iron levels.

**9:45 AM Break**

**10:15 AM**
**The Evolution of the Newmont Phoenix Process Flowsheet**: John Cole[1]; James Orlich[1]; [1]Newmont USA Ltd.
The Phoenix Mill flowsheet was originally designed with the intention of providing flexibility to manage the complex ore feed mineralogy and varying gold associations, using a combination of gravity, flotation, and cyanidation processes. Since start-up in 2006, the mill has achieved varying degrees of success depending on the ore types processed, but in general has struggled to adequately handle ore variability. Recently, a series of plant modifications have been conceived which are expected to significantly improve overall recoveries and improve plant operability. This paper discusses the original circuit design and operational issues, and describes the plant modifications completed to date, as well as the potential for future improvements.

**10:40 AM**
**Optimization of Hudbay's Constancia Concentrator**: *Marcial Medina*[1]; Hugo Granados; Peter Amelunxen; [1]Hudbay Minerals Constancia
The Hudbay copper/molybdenum concentrator in southern Peru was commissioned in 2014 and reached design production in April 2015. The concentrator was originally designed for 68K TPD but since commissioning has been able to achieve significantly higher throughputs and overall productivity than originally considered. This paper describes how geometallurgical profiling, in combination with a rigorous program of plant sampling and model validation, can be used to create predictive models of future plant performance. These models are then used to guide the optimization efforts of the operating team. The paper is divided in three parts. The first describes the primary milling and flotation equipment and arrangements (as-designed, and as currently operated). The second describes the grinding circuit model calibration and process optimization work, and the third describes the flotation modeling and optimization. Observations and key learnings are also presented.

**11:05 AM**
**Concentrator Operational Modes in Response to Geological Variation**: *Alessandro Navarra*[1]; Minerva Álvarez[1]; Karla Rojas[1]; Andrew Menzies[1]; Randolph Pax[2]; Kristian Waters[3]; [1]Universidad Católica del Norte; [2]RAP Innovation & Development; [3]McGill University
Geological variation may be managed by alternating between modes of operation. These modes provide an integrated response to changes in feed mineralogy, and other operational conditions within the mineral value chain. The decision to alternate between modes depends on current and forecasted stockpile levels. Moreover, the optimization of stockpile thresholds that would trigger a mode change is related to the classical RQ problem from inventory theory. Especially for concentrators that are designed for blended feeds, there may be production intervals in which a particular ore class is at risk of stockout. Indeed, geological uncertainty causes stockout risk, which should be balanced with other key performance indicators, including throughput and recovery. Computations are presented, in which a concentrator had originally been designed for a certain ore blend and, after years of successful operation, requires alternate modes to realign its operations with geological forecasts.

**11:30 AM**
**Carbon Dioxide Use for Flotation pH Control**: *Dave Tahija*[1]; [1]Hecla Greens Creek Mining
Carbon dioxide is widely used as an alternative to sulphuric acid in the water treatment and other industries. It has recently been brought into use as a pH control reagent in flotation circuits. Besides being safer to use and more environmentally friendly than conventional acids, carbon dioxide provides much faster pH control and less interference with flotation selectivity and froth stability. The general chemistry of carbon dioxide dissolution and carbonate chemistry will be discussed and the usage history of carbon dioxide at operating facilities described.

## Hydrometallurgy Keynote – Monday

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| Monday PM | Room: Confederation I |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:00 PM Introductory Comments**

**2:05 PM Keynote**
**Critical Metals, The Foundation of Our Society's Essential Technologies**: *Larry Seeley*[1]; [1]Seeley Group Ltd
Rhenium supply is critical to the Aerospace Industry of Commercial Airliners and Airforce. This industry, related Industry and air travel needs Rhenium to exist for the production of jet engines. Gallium is important in the high capability of power amplifiers and switches in cell phones with the Telecommunication Business and all Users of this industry dependent on Gallium availability. Neodymium and Samarium are crucial to the production of small and large high-power magnets in electric motors used in computers, cars, airplanes, robots, and almost all electrical power-driven systems. Our Society, Our Businesses, Our Security, and Our New Way of Life depend on the Supply of these and other Critical Metals. Governments, Public, and Industries must become more aware of the fragile nature of primary production and recycle of these metals that form a basis of many of our industries. Dependant only on present commercial practices is high risk for Industries, Countries and Governments. Enlightenment Supply Insurance System needs to be put in place.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 2 Process Fundamentals - Slags

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Monday PM | Room: Governor General II<br>Sponsored by Hatch |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Maurits Van Camp, Umicore Group R&D

**2:00 PM Invited**
**Effect of Slag Composition on Carbothermal Reduction of Lead-rich Slag**: *Baojun Zhao*[1]; [1]The University of Queensland
In recent years sinter – blast furnace production of lead metal has been replaced by carbothermal reduction of lead-rich slag in a bath smelting furnace. The new operation results in a greatly simplified operation with more efficient capture of SO2 and lead fugitive emissions. In addition, the lead slag is lower in sulfur (<0.5%) compared to sinter and reducing the environmental problems in the reduction process. In the present study, experiments have been carried out on the reduction of lead-rich slag in graphite crucible to understand the reduction kinetics of the carbothermal reduction of lead-rich slag. The extent of reduction was measured by the volume of CO-CO2 gas produced at a given temperature and time. The effects of PbO concentration, Al2O3 and MgO additions and CaO/SiO2 ratio on the reduction rate have been determined. The microstructures and phase compositions of the slag have been determined before and after the reduction.

**2:25 PM Invited**
**Modelling Metallurgical Furnaces - Making the Most of Modern Research and Development Techniques**: *Evgueni Jak*[1]; [1]PYROSEARCH, Pyrometallurgy Innovation Centre
Recent advances in analytical, experimental techniques, and computer-based theoretical modelling of fundamental properties and elemental processes, provide new opportunities to develop the next level of whole-of-reactor pyrometallurgical furnace models. These models have the potential to significantly improve the prediction of, and adding value to, industrial operations. In non-ferrous smelting, the starting point of these models is the development of multicomponent thermodynamic databases for gas-slag-matte-speiss-metal-solids phases supported by systematic experimental research. The whole-of-reactor-models additionally should take into account kinetic processes taking place at micro- and macro- scales, and other key factors. Examples of applications of the latest research tools and modelling approaches to analysis of industrial flash and top submerged lance (TSL) sulphide smelting processes are presented. Different levels of industrial modelling are discussed from elemental local reactions, through general and more detailed whole-of-reactor-models, to plant sections and further to whole plant operation models. Some principles for development of pyrometallurgical reactor models are discussed.

**2:45 PM Invited**
**Pyrometallurgical Processing of Desulphurization Slags**: *Christoph Pichler*[1]; Jürgen Antrekowitsch[1]; Karl Pilz[2]; [1]Montanuniversität Leoben; [2]voestalpine Stahl GmbH
A special desulphurization slag accrues during the processing of iron ore to steel, which is needed to generate high quality steel. Sulphur removing is done by different technologies, but the most common one is the generation of a high sulphur containing slag by sulphur affine elements. Currently, this desulphurization slag is partly recycled, however, huge amounts are still dumped. To utilize this desulphurization slag for future purposes, a recycling process must be established. Therefore, first characterization of this material started some years ago at the Chair of Nonferrous Metallurgy, Montanuniversität Leoben. Subsequent trials in lab scale size were performed, also some investigations for different treatment steps were evaluated, starting with a parameter study in a hot stage microscope at various gas-atmospheres. Finally, the developed recycling process concept was verified in pilot scale trials to confirm the new recycling technology. Due to the successful treatment process, also a patent was applied.

**3:10 PM Invited**
**High Temperature Phase Formation at the Slag/Refractory Interphase at Ferronickel Production**: *Christoph Sagadin*[1]; Stefan Luidold[1]; Christoph Wagner[2]; Alfred Spanring[2]; [1]Montanuniversitaet Leoben; [2]RHI Magnesita
Corrosion mechanisms between high melting synthetic ferronickel slags and refractory were investigated. The used slags were prepared by mixing and melting of specific oxides. Substrates of the applied refractory material and specimens of FeNi slags were heated in a hot stage microscope up to 1650 °C. The experiments were carried out under a defined gas atmosphere of 60 % CO and 40 % CO2. A further examination of the formed phases between slag and the refractories by scanning electron microscope. The investigation indicates that the slag penetrates between magnesia grains and partly dissolves magnesia. Spot analyses show that iron diffuses into the grains, which transform to magnesiowustite, meanwhile SiO2 forms different types of olivine like forsterite and monticellite. Thermodynamic calculation corroborate the formation of these detected minerals. The combination of practical lab scale experiments and the thermodynamic calculations should finally contribute to an improvement of the refractory lifetime and performance.

**3:35 PM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 3 Furnace Developments

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Monday PM | Room: Les Saisons<br>Sponsored by Hatch |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Rodney Jones, Mintek

**2:00 PM**
**ISASMELT™ Technology for Sulfide Smelting**: *Ben Hogg*[1]; Stanko Nikolic[1]; Paul Telford[1]; Paul Voigt[1]; [1]Glencore Technology
Since the development of the top-submerged lance (TSL) technology for copper and lead smelting by the cooperation of Mount Isa Mines (MIM), now Glencore, and the Commonwealth Scientific Industrial Research Organisation (CSIRO) the core of the ISASMELT™ technology has always resided in the lance systems. Through continuous innovation and operation of our own smelters, first at MIM and subsequently at Mopani and the Kazzinc Copper and Lead smelters, Glencore Technology have expanded the core equipment supply to enhance the plant operability. The success of Glencore Technology's expertise can be directly measured by the success of the Kansanshi Copper Smelter plant, which achieved 100% nameplate capacity within three months of start-up. This paper describes the ISASMELT™ core equipment and how it is applied to smelt sulfide materials. It highlights the strength of the ISASMELT™: continuous innovation to facilitate the versatility and continued increased capacity with every plant implementation.

**2:25 PM**

**Refractory Design and the Role of Numerical Simulations**: *Daniel Kreuzer*[1]; Christoph Wagner[1]; Günter Unterreiter[1]; Jürgen Schmidl[1]; [1]RHI MAGNESITA

The sulfide smelting industry is striving for up-scaling their operations by increasing the throughput and efficiencies of the furnaces. The physical phenomena related to refractory materials prevailing in smelters and furnaces are highly complex. The refractory materials are exposed to fairly high temperatures, thermo-mechanical stresses, penetration of pores, erosion and chemical corrosion. The application of numerical simulation tools is needed for the refractory engineering task to consider those phenomena and to evaluate the impact of operational regimes on the refractory design and finally on the integrity of the furnaces. The work discusses case studies of simulations addressing problems and questions related to the refractory design process. Practical simulation approaches which employ simplified models are introduced as the engineering process demands results in a reasonable time.

**2:50 PM**

**Online Temperature Control of Metallurgical Processes through a Pyrometer Tuyere**: *Klaus Gamweger*[1]; Goran Vukovic[1]; [1]RHI Magnesita

An efficient process control is essential for a high quality and cost effective metallurgical production. One of the main process parameters is the temperature of liquid metal and slag. The standard procedure with hand-held pyrometers or thermocouples only provides intermittent data with variable accuracy due to emissivity variations and dust accumulation on the optics and high operational costs of consumable thermocouples respectively. The integrated, infrared, digital, fiber optic pyrometer located at the rear side of the pyrometer tuyere, allows continuous non-contact temperature measurements of the melt in submerged position. Depending on the installation position in the furnace temperatures of metal and / or slag can be monitored and connected to the burner control system. An additional benefit is the safety aspect since it is no longer necessary to expose operators to a hazardous environment to measure process temperatures.

**3:15 PM**

**Hatch's Flash Furnace Burner Technologies: Recent Results**: *Matthew White*[1]; Wesley Taylor[1]; Ross Haywood[1]; Tom Gonzales[1]; Bijan Shahriari[1]; [1]Hatch

In flash smelting and flash converting of copper, burner performance depends on achieving a uniform spatial distribution of feed, and the correct distribution of particles of different size fractions in the plume. Hatch has developed a variety of technologies aimed at optimizing feed and gas distribution, as well for tackling other burner related problems. This paper outlines the technology, and results from recent smelter trials. Note- final submission is pending: 1. Client approval from one smelter (results ready, official approval being sought) 2. Completion of trial results at another smelter (estimated results to be ready by Spring 2018).Slight chance of abstract withdrawal if both of these conditions are not met. Co-authors will be added once approvals are gained, and the abstract will be updated accordingly.

**3:40 PM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 4 Process Fundamentals - Refractories

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Monday PM | Room: Governor General II<br>Sponsored by Hatch |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Dean Gregurek, RHI Magnesita

**4:10 PM**

**Wear Phenomena in Non-ferrous Metal Furnaces**: *Dean Gregurek*[1]; Christian Majcenovic[1]; Karl Budna[1]; Jürgen Schmidl[1]; Alfred Spanring[1]; [1]RHI Magnesita

In non-ferrous metal furnaces the installed magnesia-chromite refractory lining is exposed to several stresses, rather complex in their interaction. Therefore, a detailed investigation and understanding of wear mechanisms through "post mortem studies" is an important prerequisite for refractory producer. Additionally, in order to determine the most suitable refractory products and to improve the lining life of refractories, practical corrosion testing with processing slags is performed. For this purpose the test-facilities, such as induction furnace, rotary kiln but also cup test and drip slag test, allow the best possible understanding of chemothermal brick wear on pilot scale. Prior to testing a complete mineralogical investigation and thermo-chemical calculation via FactSageTM of the slag is carried out. Based on such research results, combined with specific process knowledge RHI Magnesita can recommend appropriate brick lining solutions for non-ferrous metal furnaces.

**4:35 PM Invited**

**A Scientific Roadmap for Refractory Corrosion Testwork**: *Juergen Schmidl*[1]; Alfred Spanring[1]; Dean Gregurek[1]; Karl Budna[1]; [1]RHI Magnesita

In non-ferrous metallurgy the service life of refractory materials typically ranges from several weeks up to three years or more and is strongly dependent on operating conditions. To support customers with the most viable refractory solution for their needs RHI Magnesita follows a structured approach of thermo-chemical calculations, experimental evaluation from lab scale up to industrial field tests and post-mortem analysis of used materials.This paper will give an overview of the most recent developments of the experimental setup for the so called HF-IF test which is a dynamic corrosion test with the customers process slag to determine fundamental properties of different refractory material types under process conditions. It is shown that the present experimental procedure is an excellent tool to simulate refractory wear in industrial processes, diminishing risks associated with plant trials and support decision making to choose the optimal refractory solution for the customer.

**5:00 PM**

**Investigation of Refractory Failure in a Nickel Smelting Furnace**: *Wilson Pascheto*[1]; Roy Berryman[2]; Robert Beaulieu[2]; Maysam Moham[1]; [1]XPS Consulting & Testwork Services; [2]Koniambo Nickel SAS

This paper present Root-Cause-Failure-Analysis (RCFA) of MgO-based refractories used in a DC smelting furnace. The failure was initially identified by an unusual expansion/contraction of the furnace heart during operation. Cracks on the refractories were envisaged after a major shutdown of the furnace. To determine the mechanism and causes of the refractory failure, refractory samples were taken from the furnace and subjected to different analysis including Scanning Electron Microscopy (SEM), Energy-dispersive X-ray spectroscopy (EDX), Qemscan and Electron Probe Micro Analysis (EPMA) as well as creep testing at different conditions (ASTM C832). The various characterisation tests revealed that there was an interaction between refractory bricks and molten material during furnace operation, which resulted in lower creep resistance of the MgO-based refractories. This was verified by comparing creep performance of the infiltrated brick samples and new brick samples at different temperatures and applied stresses.

**5:25 PM**

**Mechanism Study of Si3N4 and SiC Reacting with the Melts in Copper Production**: Yang Jiang[1]; Mao Chen[1]; Lijie Feng[2]; Junhong Chen[3]; *Baojun Zhao*[1]; [1]University of Queensland; [2]LuZhong Refractory Pty. Ltd.; [3]University of Science and Technology Beijing

Si3N4 bonded SiC (Si3N4-SiC) has been widely used as an important refractory material in iron and steel industry. Previous studies showed that Si3N4-SiC reacts significantly with Cu2O, industrial matte and FeS which limits its application in copper industry. It was not clear the reaction mechanisms between Si3N4-SiC and the melts. In the present study, Si3N4 and SiC were reacted with FeS, Cu2S, matte, Cu2O and FeO separately to understand the mechanisms. The reacted samples were quenched, mounted and analysed using Electron Probe Micro-Analysis (EPMA). The phases present and their compositions have been identified and measured. The systematic study will provide useful information for improving the SiC-based refractory materials.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 5 Cont: Anciliary Operations

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

Monday PM
August 27, 2018

Room: Les Saisons
Sponsored by Hatch
Location: Westin Ottawa

*Session Chair:* Thomas Battle, Extractive Metallurgy Consultant

**4:10 PM**

**Mathematical Modeling of Waterless Matte Granulator for Debottlenecking of Conventional Sulfide Smelters**: *Alessandro Navarra*[1]; Frank Mucciardi[2]; [1]Universidad Católica del Norte; [2]McGill University

Within conventional copper and nickel-copper sulfide smelters, ladles of molten matte are fed into converters. These converters blast oxygen-enriched air into the matte, thereby eliminating iron and sulfur. The converting reactions are exothermic and, indeed, the converter heat balance is often a limiting consideration on the smelter throughput. If a portion of the matte were fed in solidified (granulated) form, this would support higher oxygen enrichment, and lower volumes of converter offgas, allowing higher throughput. This approach is not applied in conventional smelters, partly because of the copious amounts of water that must be evaporated in typical granulators, as in the Kennecott-Outotec process. The current paper recalls a waterless matte granulator that had been pioneered in the 1990's, and is applicable to conventional smelters. A mathematical formulation is presented that can be used in the context of simulation-based optimization, to estimate the size and impact of waterless matte granulation.

**4:35 PM**

**Desulfurization of the Non-Ferrous Smelter Flue Gases Based on Scrubbing with a Carbonate Eutectic Melt and Natural Gas Regeneration**: *Valery Kaplan*[1]; Nurlan Dosmukhamedov[1]; Igor Lubomirsky[1]; [1]Weizmann Institute of Science

We propose a method for removing SO2 from poor flue gases by carbonate eutectic melt with regenerating the post-scrubbing melt by purging it with natural gas, which is available in the vast majority of metallurgical plants. The test showed that the concentration SO2 of flue gas after scrubbing did not exceed 1.5 ppm (less than the natural level in atmosphere) and sulfur extraction yield in the scrubbing stage from flue gas to the carbonate melt was 95.0%. Thereafter all sulfur (99.5%) was successfully regenerated from carbonate-sulfate melt by a close to stoichiometric amount of the natural gas. We presented that nearly complete sulfur removal from the melt is possible at 550 C and that the reaction rate is sufficiently high.One can foresee that this carbonate melt-based SO2 removal technique may become a practical and economically attractive method for limiting sulfur emission to the atmosphere from non-ferrous metallurgical processing plants.

**5:00 PM**

**Advanced Thermochemical Fundamental and Applied Research to Improve Integrity of the Steel Water Jacketed Furnace at Port Pirie**: *William Watt*[1]; Taufiq Hidayat[2]; Denis Shishin[2]; Evgueni Jak[2]; [1]Nyrstar, Port Pirie Operation, Australia; [2]PYROSEARCH, Pyrometallurgy Innovation Centre, School of Chemical Engineering, The University of Queensland, Australia

Lead blast furnace water-jacket stability was investigated using analysis of the phase chemistry in the industrial samples exposed to the aggressive high temperature environment using SEM and EPMA, phase equilibria analysis and thermodynamic modelling using FactSage with the thermodynamic database for the slag / matte / metal / speiss / solids multi-component Cu2O-PbO-ZnO-Al2O3-CaO-MgO-FeO-Fe2O3-SiO2-S major and As-Bi-Sb-Sn-Ag-Au minor elements system. Results showed that the integrity of the furnace walls is critically dependent of the stability of the oxide-based freeze-lining dependent on various factors including most critical one – the proportion of solids determined by the slag chemistry and fluxing. The stability of the water-jacket steel wall without freeze-lining is determined by formation of the complex Fe-rich speiss phase at critical As concentrations. Lead blast furnace modelling using FactSage indicated limiting thermochemical conditions for the water-jacket stability. Factors and controls critical to the water-jacket integrity are discussed.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 3 Process Fundamentals and Reaction Kinetics

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

Monday PM
August 27, 2018

Room: Governor General III
Location: Westin Ottawa

*Session Chair:* Ken Coley, McMaster University

**2:00 PM Invited**
**Kinetics of Dephosphorisation of Iron Carbon Alloys; the Importance of Competing Reactions, Slag Properties and CO Bubbles**: *Kenneth Coley*[1]; Kezhuan Gu[1]; Brian Monaghan[2]; Philip Drain[2]; [1]McMaster University; [2]University of Wollongong
Data on the kinetics and thermodynamics of dephosphorisation is analyzed in terms of the dynamic partition ratio, determined by a combination of slag thermodynamic properties and the balance of oxygen supply and consumption. A recently developed phosphate capacity correlation is combined with data on kinetics to quantify the most significant parameters in controlling the interfacial oxygen potential. The role of slag composition, entrained gas fraction and temperature are discussed in addition to metal carbon and sulphur content. It is demonstrated that the mass transport of oxygen in the slag is enhanced by factors increasing conductivity and inhibited by entrained gas. The mass transfer of phosphorus in the metal is described considering surface renewal induced by CO bubbles.

**2:25 PM Invited**
**Prediction of Critical Cooling Rate for Metallurgical Slags**: *Mansoor Barati*[1]; [1]University of Toronto
Critical cooling rate (CCR) is the rate of temperature drop in slag above which it solidifies into an amorphous product. This is of interest from both fundamental and practical points of view as slag structure, in part, determines its subsequent use. In this investigation, experiments were carried out to quantify the rate of slag crystallization as function of its composition. The CCR was then quantified and related to the slag basicity. A detailed analysis of the data showed that using a fundamental model of crystallization, it is possible to develop a correlation for predicting the CCR of slags. The correlation was successfully employed to reproduce the measured CCRs.

**2:50 PM Invited**
**A Study of Cementite Formation in the Reduction of Hematite by CO-CO2 Gas Mixture Using High Temperature XRD**: *Oleg Ostrovski*[1]; Yury Kapelyushin[1]; Yasushi Sasaki[1]; Jianqiang Zhang[1]; [1]University of New South Wales
Formation of cementite in the reduction of hematite by CO-CO2 gas was studied in situ using high temperature XRD (HT XRD) analysis. Reduction of hematite was examined in the temperature range 873-1173 K by CO-CO2 gas mixture with high carbon activity. When carbon activity in the system was 1.5, cementite was formed only at 1023 K; it was not observed in experiments at 973, 1073 and 1123 K. Formation of cementite was observed at 923-1073 K when carbon activity increased to 3-5; and at 873 K when carbon activity was 10. Formation of cementite at 973-1073 K proceeded through metallic iron; however, in the reduction of hematite at 873 and 923 K, it was formed directly from wüstite. XRD spectra were used to estimate concentration of carbon in austenite and iron to oxygen ratio in wustite.

**3:15 PM**
**Pretreatment of Manganese Ores with Methane**: *Eli Ringdalen*[1]; Leiv Kolbeinsen[2]; [1]Sintef Materials and Chemistry; [2]NTNU
The effect of methane on conversion of manganese ore to MnO was investigated experimentally. Samples of 500 to 1000 grams were heated to different temp¬era¬tures up to 1100°C in Ar or CH4 atmospheres. Weight changes, carbon deposition and morpho¬logy of the particles were examined. Experiments in Ar gave knowledge about how heating alone affected reduction of manganese oxides. Weight loss during heating with Ar increased linearly with increasing temperature. The main objective was to investigate deposition of carbon on the ore particles for use as reductant during subsequent high temperature processing. The amount of deposited carbon from methane was less than expected. During heating of high oxidic manganese ores, oxygen is released at relatively low temperatures. This will participate in the occurring reactions and the extent of the water gas shift reaction (WGSR) is believed to be of importance for carbon deposition from methane on this type of ore.

**3:40 PM Break**

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 4 Silicon

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

Monday PM
August 27, 2018

Room: Ontario
Location: Westin Ottawa

*Session Chairs:* Muhammad Akbar Rhamdhani, Swinburne University; Merete Tangstad, Norwegian University of Science and Technology

**2:00 PM**
**Condensation of SiO and CO in Silicon Production – A Literature Review**: *Andrea Broggi*[1]; Merete Tangstad[1]; [1]NTNU
Condensates produced by SiO(g) and CO(g) have a crucial importance in silicon production. Condensation will follow the reactions 3 SiO(g) + CO(g) →2 SiO2 + SiC and 2 SiO (g) →Si + SiO2. Solid compounds generated during silicon production contain Si, SiO2 and SiC in different microstructures and amounts. In industrial systems, condensates limit the SiO(g) escape to the off-gas system. On the other hand, they can block the charge flowing towards the high temperature zone, hence the necessity of studying an optimized condensation process. The review concerns SiO(g) condensation and its interaction with CO(g). The report gives an overview of the condensates found both at laboratory and at industrial scale. The two main compounds are the Si-SiO2 and the SiOx-SiC mixtures. The hypothesis on the mechanism of formation of SiC-SiOx condensates is presented through a wide selection of performed works. The advantages and disadvantages of the former experimental procedures are discussed.

**2:25 PM**
**Phase Transformations from Quartz to Cristobalite**: *Karin Jusnes*[1]; Merete Tangstad[1]; Eli Ringdalen[2]; [1]NTNU; [2]Sintef Materials and Chemistry
The aim of this work was to investigate phase transformations from quartz to cristobalite, through an amorphous intermediate state. Quartz is used as a raw material in silicon and ferrosilicon production, and the phase transformation could affect the furnace operations. During the transformations, properties like density, surface area, and mechanical strength could change. By knowing how fast a quartz sample will transform, it could help anticipating how the furnace will react. This information could help the industry when selecting the most suitable quartz for their operation. The study investigate thoroughly how the phase transformations in three different quartz types are behaving at temperatures around 1600 and 1700 °C, and how they are differing from each other. The results shows that the amount of quartz are varying from 100 % to about 5 % at 1600 °C from one type to another. Large variations are also seen at 1700 °C.

**2:50 PM**
**Parameters Affecting the Oxidation of Liquid FeSi Alloy**: *Yan Ma*[1]; Ingeborg Solheim[2]; Ida Kero[2]; Gabriella Tranell[1]; [1]Norwegian University of Science and Technology (NTNU); [2]SINTEF Materials and Chemistry
Active oxidation of liquid Silicon and Ferrosilicon in the tapping, refining and casting steps of alloy production processes lead to the formation of amorphous silica-based particulate matter in the plant environment. This fugitive emission of silica is an undesired outcome from an OHS perspective for workers in the industry. The extent and properties (particle size distribution (PSD), flux, composition) of these fumes will depend on factors such as surrounding gas flow velocities, melt temperature, gas humidity, alloy composition etc. In the current study, large laboratory scale experiments were carried out in which an impinging air jet blown onto the surface of different FeSi alloy melts at different temperatures and gas compositions. The fuming rate and fume characteristics (composition, morphology, PSD) were investigated and the results compared with thermodynamic/kinetic models of the system.

**3:15 PM Break**

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 5 Process/Flow Modelling I

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

Monday PM
August 27, 2018

Room: Governor General III
Location: Westin Ottawa

*Session Chair:* Tanai Marin-Alvarado, M4 Dynamics Inc.

**4:10 PM Invited**
**Forming Micro-bubbles in Liquid Steel**: *Roderick Guthrie*[1]; Mihaiela Isac; [1]McGill University
Gas injection into liquid steel baths is widely practiced since the early days of Bessemer's pneumatic steelmaking process. What has not been fully appreciated is the critical role of bubble sizes for delivering higher quality commercial steels than is presently possible, as first proposed by Prof P. Hayes. Using a full-scale-water-model of a typical 4-strand Ladle-Tundish-Mold system, we demonstrate the potential advantages of modifying a typical ladle shroud to generate microbubbles within the water flowing into the tundish. This is possible by taking advantage of high shear rates and turbulence kinetic energy available in that region. These microbubbles enhanced the removal of "micro-inclusions" (hollow glass microspheres) in the 5-50 micron size range, to the upper surface of the tundish. There, they were absorbed into an overlaying "slag" phase. Accompanying CFD studies confirmed that no microbubbles in the size range generated (500-900µm), pass through the submerged entry nozzles into the moulds.

**4:35 PM Invited**
**Innovative Applications of Bubbles and Drops to Ferrous Process Technology**: Youn-Bae Kang[1]; Jungwook Cho[1]; Sangjun Kim[1]; *Hae-geon Lee*[1]; [1]POSTECH
In order to overcome weak points of steel for its engineering applications, in particular, for environmentally benign, energy-efficient, lightweight engineering systems. a number of new steels have been proposed, especially to improve strength-to-weight ratio (specific strength). Mass production of these steels, however, has encountered a serious roadblock particularly in the steel refining and casting processes. This is because their chemistries and cleanliness requirements are vastly different from those of the conventional steels, and thus an incremental improvement of the prevailing process technologies is found hard to meet the requirements. In this study, a new process is proposed, which employs inert gas bubbles in the shroud nozzle, liquid steel drops in the degassing chamber, and the siphon transport for continuous casting. The effectiveness of the individual steps is discussed with experimental results.

**5:00 PM**
**Multiphysics and Thermodynamic Modeling of Kinetically Controlled Processes using Constrained Free Energy (CFE) Method in Pyrometallurgy**: *Tanai Marin-Alvarado*[1]; Pertti Koukkari[2]; [1]M4 Dynamics Inc.; [2]VTT Chemical Technology
Detailed modelling of complex processes involving reaction kinetics, fluid flow, heat and mass transfer (multiphysics), requires defining several ODEs describing the mechanism using temperature dependent rate and equilibrium constants, like combustion (fuel or flash smelting) or reactors that are not at equilibrium, such as rotary kilns, some cases of electric furnaces, etc. The Constrained Free Energy (CEF) method is a novel approach that allows to simulate chemically limited systems using the Gibbs Free Energy minimization technique by adding immaterial constrains to the equilibrium calculations. In practice, this allows to solve a model with simplified reaction mechanism while retaining the full description of several components and phases. The CFE method has been coupled to Multiphysics modelling, to simulate the oxidation of TiCl4(g) to produce TiO2 powder. The results are compared to available detailed modeling of the complex reaction mechanism and then are extended to a transient 2D axial-symmetric tubular reactor model.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 6 Halides/Salts

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

Monday PM
August 27, 2018

Room: Ontario
Location: Westin Ottawa

*Session Chairs:* Boyd Davis, Kingston Process Metallurgy Inc; Christopher Pickles, Queen's University

**4:10 PM**
**Carbochlorination of Low-grade Titanium Slag to Titanium Tetrachloride in Molten Salt**: *Li Liang*[1]; [1]Panzhihua Iron&Steel Research Institute
Thermodynamic analysis and experiments were conducted in order to verify the feasibility of preparing crude titanium tetrachloride (TiCl4) via the carbochlorination of low-grade titanium slag in molten salt. Titanium slag, assaying 74.6 wt. % TiO2 with high calcium and magnesium oxide impurities, was treated by an optimized carbochlorination process in NaCl molten salt. These impurities in the titanium slag were chloridized simultaneously, and chlorination products FeCl2, MnCl2, MgCl2, CaCl2 and CrCl3 were collected in the furnace slag. XRD and SEM/EDS analysis of residue shown that SiO2 and Al2O3 in titanium slag were difficult to chlorinate completely. Theoretical calculations and experimental studies reveal the content of TiCl4 in the products was more than 98.8 wt. % and thus proved the feasibility of utilizing low-grade titanium slag for TiCl4 preparation by molten salt chlorination technology.

**4:35 PM**
**Chlorine Addition to Slag Fuming Processes: A Thermodynamic and Experimental Study**: *Sabrina Van Winkel*[1]; Lennart Scheunis[2]; Annelies Malfliet[1]; Frederik Verhaeghe[2]; Bart Blanpain[1]; [1]KU Leuven; [2]Umicore
Slag fuming furnaces are used to recover zinc and other volatile metals, and to produce a clean slag which can be valorised. In contrast to typical fuming processes, where metals are volatilized in their elemental state, this work investigates the possibilities to volatilize Pb and Zn as chlorides. The effect of addition of different chloride sources and amounts has been evaluated using thermodynamic calculations based on industrial data taken from three existing zinc fuming plants. Chloride additions have a more pronounced effect when the fuming process operates at less reducing conditions. Additions of $CaCl_2$ and $MgCl_2$ are the most effective in reducing the necessary fuming time. Lab scale fuming experiments were done to validate the results of the calculations.

**5:00 PM**

**Study of High-grade $TiO_2$ Production from Ilmenite via Selective Chlorination and Chlorine Recovery Processes**: *Jungshin Kang*[1]; Gyeonghye Moon[1]; Min-Seuk Kim[1]; Toru H. Okabe[2]; [1]Korea Institute of Geoscience and Mineral Resources; [2]The University of Tokyo

Study on the selective chlorination and chlorine recovery processes was conducted to directly produce high-grade $TiO_2$ from ilmenite by utilizing Ti scrap and iron chloride waste. Specifically, $FeCl_2$ and the scrap mixture and ilmenite were placed in carbon and quartz crucibles, respectively, and the crucibles were positioned in a quartz tube. The experiments were conducted at 1193 – 1248 K. In the chlorine recovery process, $TiCl_4$ and iron metal were produced via reactions between the scrap and $FeCl_2$, and the chlorination ratio of the scrap approximately corresponded to 94.6 %. Additionally, $TiO_2$ with a purity of 96.2 % was produced through the selective chlorination of iron in ilmenite by using the generated $TiCl_4$. The iron removal ratio of ilmenite approximately corresponded to 98.2 %. Thus, this study demonstrated the feasibility of establishing an effective and environmentally-friendly titanium production process using Ti scrap and iron chloride waste.

**5:25 PM**

**Calciothermic Reduction and Electrolysis of Sulfides in $CaCl_2$ Melt**: *Ryosuke Suzuki*[1]; Nobuyoshi Suzuki[1]; Shungo Natsui[1]; Tatsuya Kikuchi[1]; [1]Hokkaido University

$TiS_2$ was, as example, reduced to Ti either by calciothermic reduction or electrolysis in a $CaCl_2$ melt. Upon calcium reduction at 1133 K in $CaCl_2$ melt, the concentration of sulfur decreases to 0.03 mass% S when an amount greater than twice the stoichiometric calcium amount is added. Upon electrolysis reduction at 1173 K in $CaCl_2$-CaS melt, the concentration of sulfur decreases significantly to 0.01 mass% S when a sufficiently large amount of electric charge is supplied. Our results indicate that it is possible to achieve sulfur removal via both calciothermic reduction and electrochemical reaction from sulfide in molten chloride. Conversion from oxide to sulfide can be combined with these techniques to prepare various metal powders with low residual oxygen.

## Part C-1: Hydrometallurgy 2018 – Environmental 2

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

| | |
|---|---|
| Monday PM | Room: Provinces II |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM**

**Water: An increasingly valuable and Challenging Resource for the Mining and Metallurgical Industry to Manage Effectively**: *V. Ramachandran*[1]; [1]Ram Consultants

Preservation of water resources will be one of humanity's biggest challenges in this century.As an industry with major potential impacts on water resources and due to the rising cost of process water, the mining and metallurgical industry has a responsibility to contribute to the goal of preserving both the quantity and quality of water available within watersheds we operate in.A hierarchy of options to minimize water usage in the watershed is also critical. Technology is needed to measure parameters of interest,in real-time, as well as to treat water to improve its quality for reuse or release into the watershed. Chemistry related to removal of various constituents will be addressed. This paper will address issues associated with managing water to provide context for a discussion of potential technologies for more advanced water treatment plants and residuals management.

**3:20 PM**

**Redesigning Hydrometallurgical Processes for Better Environmental Performance: New Revenues and the Sustainability of Mining Territories**: *Virginia Ciminelli*[1]; Daniel Majuste[2]; Eder Martins[3]; Adelson de Souza[3]; [1]Universidade Federal de Minas Gerais; [2]Universidade Federal de Mins Gerais; [3]Nexa Resources

The competitiveness of the mineral industry is increasingly dependent on the more efficient use of natural resources and therefore, the extraction processes have been modified. The production of electrolytic zinc is taken as case study. The first example is a roasting-leaching-electrowinning(RLE) circuit. The introduction of a Waelz furnace in the flowsheet allows for the recovery of zinc from electric arc furnace dust produced in steelmaking and the treatment of zinc ferrites formed during roasting, thus reducing the generation of wastes in both the steel and zinc production. A second example addresses a unique flowsheet that combines the treatment of zinc sulfide and silicate ores. Improvements related to decreasing water consumption and increasing energy efficiency, turning tailings into additives for agriculture, and into new metal products will be presented. It will be shown that better environmental performance results in new revenues, increasing social approval and the sustainability of mining territories.

**3:45 PM Break**

**4:10 PM Invited**

**FRP Applications in Solvent Extraction and Electrowinning - An Update**: *Rafic Moubarac*[1]; [1]Experco Composites Inc

FRP (Fiberglass Reinforced Plastics) will first be introduced as a well proven corrosion resistant material of construction which is used in hydrometallurgy for solvent extraction of metals and electrowinning. FRP equipment applications and case histories will be reviewed, updated and shown, for global projects where that equipment has been successfully used since the sixties. Recent applications for lithium and rare earth metals extraction and refining will also be reviewed.

**4:35 PM**

**Development of an Encapsulation Process to Extend the Stability of Scorodite under Wider pH and Redox Potential Range Conditions**: *Fuqiang Guo*[1]; George Demopoulos[1]; [1]McGill University

Scorodite ($FeAsO_4 \cdot 2H_2O$) is suitable mineral carrier for immobilization of arsenic-rich wastes. Its stability is, however, highly pH dependent (typically at $4 \le pH \le 7$) and satisfactory only under oxic disposal conditions. In this work an encapsulation process using mineralized aluminum hydroxy-oxides is developed to enhance the stability of scorodite under wider pH and redox potential range conditions. The encapsulation involves blending and ageing of synthetic scorodite produced by McGill's atmospheric scorodite precipitation concept with aluminum hydroxyl gels derived from controlled hydrolysis of aluminum salts. The amorphous hydrolyzed Al-gel encapsulates the scorodite particles, which upon short-term aging transforms into crystalline $Al(OH)_3$/AlOOH mineral phases providing a robust protection microscopic barrier. Long-term stability testing demonstrates the encapsulation system to be highly effective in suppressing arsenic release under either oxic or anoxic ($100mV < E_h < 600mV$) potential and alkaline pH ($7 \le pH \le 9$).

**5:00 PM**
**Arsenic Immobilization in Nanostructured (Al) Fe-(hydr)oxides**: *Virginia Ciminelli*[1]; Erico Freitas[1]; Delbem[1]; Massimo Gasparon[2]; [1]Universidade Federal de Minas Gerais; [2]University of Queensland

A mechanism responsible for long-term arsenic immobilization in nanostructured Fe-(hydr)oxides, and based on a non-classical aggregation crystal growth is discussed. Experimental evidence is provided by the analyses of tailings from pressure oxidation-gold cyanidation, soil samples from a gold mining region, and synthesized samples aged for up 120 days at ambient temperature. The common pattern is the predominance of oriented aggregates of nanostructured (Al)Fe-(hydr)oxides where arsenic is mainly found in the interstices of nanoparticles-building-units. Arsenic concentrations as high as 6.9±0.3 wt% As and 1.6±0.5 wt% As were determined in grains of ferrihydrite and hematite, respectively. The role of aluminum is discussed. The combination of statistically sound scanning electron microscopy with automated image analysis and high-resolution transmission electron microscopy is shown to bring a new understanding of the association of arsenic with iron (hydr)oxides, and proved effective to substantiate data on tailings stability and potential risks to human health.

**5:25 PM Invited**
**Arsenic Removal from Arsenic Bearing Materials Produced from Metallurgical Processes of Copper, Lead and Zinc**: *Zhihong Liu*[1]; Zhiyong Liu[1]; Jianxin Zhang[1]; Siwei Li[1]; Yuhu Li[1]; [1]Central South University

In recent years, the removal of arsenic from different types of high arsenic containing materials produced in nonferrous metallurgical processes have been experimentally studied in the complex materials processing research group from Central South University. These materials include secondary zinc oxide, antimony and arsenic bearing flue dust, arsenic sulfide residue and arsenate bearing flue dust. The separation of arsenic from other valuble metals was carried out hydrometallurgically; and for each type of arsenic bearing material, different process has been employed individually to remove the arsenic effectively. In this paper, the flowsheets and experimental results have been summarized.

## Part C-1: Hydrometallurgy 2018 – Extraction/ Processing 3

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

Monday PM
August 27, 2018

Room: Confederation I
Location: Westin Ottawa

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM**
**Modular Reactors and Utilization in Small Scale Direct Leaching Zinc Plant Expansions**: *Tuomas Hirsi*[1]; Björn Saxen[1]; Teemu Ritasalo[1]; Marko Lahtinen[1]; [1]Outotec

Outotec atmospheric direct leaching has so far been implemented for zinc production capacities of around 100 000 t/a. Lately, there has been growing interest in small scale direct leaching plants, producing circa 30 000 t/a of Zn. Such small leaching plants can provide extra front end capacity in existing roaster-based plants and also enable feed materials not suitable for roasting.In small scale plants the proven OKTOP 9000 direct leaching reactors are not readily applicable, due the large size. For smaller installations a modular approach is proposed providing multiple advantages, such as reducing the construction time and amount of site work required causing less disturbance to regular plant operation with reduced cost. In this paper, we present advantages that can be achieved by using modular OKTOP-C reactors and also discuss process design when joining small scale direct leaching to existing Zinc plant. Also benefits of direct leaching expansion are presented.

**3:20 PM**
**Developements in Modelling of Zinc Hydrometallurgy**: *Tuomas Vielma*[1]; Justin Salminen[2]; Ulla Lassi[1]; [1]University of Oulu; [2]Boliden Kokkola Oy

An internally consistent thermodynamic model was derived for the system ZnSO4-H2SO4-H2O. Temperature dependent Pitzer parameters and thermodynamic properties of the solid phases were optimized based on various types of experimental data. The model reproduces experimental data with good accuracy, especially near compositions and conditions typical for hydrometallurgy of zinc. The model extrapolates well even up to 15 m H2SO4 solutions, however. With addition of new minor components such as SiO2 or CaSO4, different steps of the hydrometallurgical process can modelled. Application of this kind of modelling can add valuable insight to solution purification and cumulation of impurities. This can achieved in practice by applying thermochemical software such as FactSage or ChemSheet.

**3:45 PM Break**

**4:10 PM**
**Jarogain Process - A Hydrometallurgical Option to Recover Metal Values from RLE Zinc Residue and Steel Dust**: *Pertti Koukkari*[1]; Petteri Kangas[1]; Mari Lundström[2]; Sami KInnunen[2]; Jussi Rastas[3]; Pekka Saikkonen[3]; [1]VTT; [2]Aalto University; [3]Promeca Oy

The novel Jarogain process combines treatment of the jarosite residue of zinc manufacturing and processing of arc furnace dust from steelmaking to a holistic recovery technology. The new hydrometallurgical approach is targeted to recover the major constituents (Fe, Zn, Pb) as well as valuable components such as Ag, Au, In and Ga from the jarosite-dust mixture as reusable concentrates. The fractionation process proposed by VTT and Aalto University takes advantage of jarosite being readily fine powder and directly available for wet chemical processing. Jarogain process provides a low cost and energy efficient opportunity for jarosite utilization as value added products. The experimental proof-of-concept of key stages of the process will be outlined with a comparison of available pyrometallurgical treatments of jarosite waste. The techno-economical assessment is based on estimated investment and variable production cost using the discounted cash flow (DCF) analysis.

**4:35 PM Invited**
**The Betts Process at Trail Operation – Experiences from Over a Century of Operation**: *Sara Fitzel*[1]; J. A. Gonzalez; [1]Teck Metals Ltd.

The Betts process for electrorefining of lead has been in operation since 1902 in the Trail Operations Metallurgical complex. The Betts process allows production of high purity lead in a single electrochemical step. Process improvements and plant expansions have taken place over the many decades of operation of this process which has proven to be robust, flexible, and capable of successfully treating a large range of anode bullion compositions. This paper reviews the history of the Betts lead electrorefining process, the innovations and quick industrial adoption of new discoveries that took place at the turn of the nineteen century and resulted in the implementation of a process that integrated very well with Trail Operations metallurgical needs then and now.

**5:00 PM**
**Building A Cloud-based Operator Training Simulation Software for Pressure Oxidation Process**: *Mikko Loponen*[1]; Kristian Lillkung[1]; [1]Outotec
Outotec has developed an operator training simulator (OTS) platform suitable for various hydrometallurgical processes. The complete solution is run in the cloud, where virtual client instances can be managed on-demand. The aim is to build a generalizable model that produces coherent results even when operating outside of ideal parameters, allowing the operator to train in unsteady state conditions such as start-up and shutdown. Complex software products are commonly associated with significant development time and cost. Utilizing modular software architecture, only the control system and process model are tailored for the OTS, whereas modules such as user administration and cloud-based client machine spawning can be imported, shortening development time. A generic pressure acidic oxidation process (POX) operator training simulation consisting of feed preparation, autoclave, dual-stage flash evaporation and off-gas scrubbing is described. Process is simulated using Outotec HSC Sim 9 process simulator and controlled by Siemens Simatic PCS7 control system.

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## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Monday PM

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

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| Monday PM | Room: Provinces I, sponsored by Purolite |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**2:50 PM Introductory Comments**

**2:55 PM**
**A Review on Application of Crown Ethers in Separation of Rare Earths and Precious Metals**: V. I. Lakshmanan[1]; Jonathan Chen[1]; *S. Vijayan*[1]; [1]Process Research Ortech Inc.
Crown ethers are gaining importance in separation technology specifically for rare earth elements (REEs, La to Lu plus Y) and precious metals (Au, Ag, Pt, Pd, Rh and Ir) due to their specific binding ability, metal complex stability and high extraction efficiency. The selectivity of crown ethers in extraction of these metals depends on different factors, including the cavity diameter and nature of a donor atom of the crown ether, size and charge of the metal ion, diluents and counter ion. Demand for strategic REEs and precious metals are consistently increasing in the world while the separation of these metals is most challenging tasks. In this paper, the use of crown ethers in separation of REEs and precious metals, reaction mechanisms and simplified process flowsheets will be elucidated. New reagents with high selectivity for the separation of these metals are further expected to produce high purity metals.

**3:20 PM**
**Cadmium and Nickel Adsorption Study using Biosorbent**: *Peijia Lin*[1]; Jaeheon Lee[1]; [1]University of Arizona
Wheat straw was chemically modified by alkaline treatment followed by succinylation and sodium carbonate treatment for the use of cadmium and nickel adsorbent. The adsorption efficiency was calculated in different conditions. The experimental parameters were adsorbent dosage, degree of succinylation, initial metal concentrations, and solution pH. The biosorbent was analyzed by FTIR (Fourier-Transform Infrared Spectroscopy) to investigate the changes of surface functional group. The maximum adsorption percentage of cadmium (>99%) was achieved using 5 g/l adsorbent with 50 mg/l initial cadmium concentration. The competition between the cadmium and nickel adsorption was investigated showing 97.8% cadmium recovery and 88.9% nickel recovery from binary solution containing both nickel and cadmium. Cadmium affected nickel adsorption more than nickel did on cadmium. The adsorption kinetic study showed that the reaction was pseudo-second order kinetics and the adsorption isotherm was well fit by Langmuir adsorption model.

**3:45 PM Break**

**4:10 PM Invited**
**Imprinted Resin - The 21st Century Adsorbent**: *Sue Ritz*[1]; Jon Gluckman[2]; Brandi Maull[2]; Dae Jung Kim[2]; [1]Jack Rabbit Consulting; [2]6th Wave Innovations
Gold extraction has relied on coconut carbon in adsorption circuits for several decades. This paper describes a new type of adsorbent that exceeds the selectivity of carbon and improves on the mechanical properties of other available resins. IXOS® resin has been proven in on-site trials in increase adsorption of precious metals in a head-to head comparison with carbon. Additionally, IXOS® selectivity against copper cyanide complexes allows it to be used in circuits that currently struggle with copper contamination. IXOS® potential to eliminate or reduce the application of SART technology will expand the opportunities to exploit more complex precious metal deposits. This paper will describe the technology behind IXOS molecular imprint, it's comparison to carbon adsorption in the field, and the effect of efficiency on long-term recovery from heap leach METSIM simulation software

**4:35 PM Invited**
**Nickel Recovery from Hyperaccumulator Plants Using a Chelating Resin**: *Marie-Odile Simonnot*[1]; Baptiste Laubie[1]; Mathilde Guilpain[1]; Claire Hazotte[1]; Vivian Houzelot[1]; Guillaume Echevarria[1]; Jean Louis Morel[1]; [1]University of Lorraine
A wide variety of plants are able to extract nickel (Ni) from soils and accumulate this metal in their aerial parts. Some plants, e.g. Alyssum murale, growing in the Balkans, contain 1% of Ni, while tropical trees, e.g. Rinorea bengalensis accumulate 3% Ni in their leaves. Hydrometallurgical processes have been developed to recover Ni in the form of metal or salts, starting from A. murale. They include 1) a combustion step, to obtain ashes, containing 15 to 20% Ni, 2) a leaching step and 3) purification. The whole chain has been thoroughly investigated, and the processes up-scaled to the pilot scale. This presentation shows how the process has been extended to tropical plants and gives highlights for the further development of agromining.

**5:00 PM Invited**
**New Highly Selective Ligands for the Purification of the Lanthanides, Actinides, and Medical Isotopes**: *Gauthier Deblonde*[1]; Abel Ricano[1]; Rebecca J. Abergel; [1]Lawrence Berkeley National Lab
Highly selective and efficient processes are deeply needed for producing high-purity isotopes for research or medical applications and for treating the radioactive waste. Herein, we describe a new approach for separating metal ions based-on bio-inspired synthetic chelators. Versatile liquid-liquid extraction processes were developed for the separation of a variety of strategic elements. These new chelators exhibit a much higher selectivity than other ligands used for extraction such as the carboxylic acids. Separation factors (SF's) of about 100 were obtained for americium(III) and gadolinium(III). SF's of 1,000 to 10,000 were obtained for berkelium and adjacent actinides (Am, Cm, Cf, Es). In a single step, SF's of 30,000 to 300,000 for plutonium and lanthanide(III) ions can be obtained. Separation factors as high as 1,000,000 can also be reached for actinium against other f-elements. The results support the development of practical, versatile, and highly selective systems based on these bio-inspired chelators.

## Part C-3: Processing of Critical Metals – Rare Earth Elements

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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|---|---|
| Monday PM | Room: Governor General I |
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**2:50 PM Introductory Comments**

**2:55 PM**
**Hydrometallurgical Extraction of Rare Earth Elements from Coal Sources**: *Rick Honaker*[1]; Xinbo Yang[1]; Alind Chandra[1]; Wencai Zhang[1]; [1]University of Kentucky

Rare earth elements (REEs) contained in coal and associated mineral matter exist in several forms including micro-dispersed minerals, ion adsorption onto clay surfaces, and chemically bound. Tests found that REEs can be effectively recovered from certain components of three coal sources by leaching under mild conditions followed by solvent extraction. A range of pH values were evaluated at solution temperatures of 25 degrees C and 75 degrees C. When using 1 mol/L of sulfuric acid, nearly 85% recovery of the REEs was extracted from the middlings material collected from an operating plant. Acid leaching of a second middling source from another plant resulted in 60% of the total REEs being recovered under the same leaching conditions. Solvent extraction treatment of the leachate produced from six different coal sources resulted in products containing up to 50% total REEs from feedstocks starting with around 300 ppm.

**3:20 PM**
**Rapid and Selective Leaching of Actinides and Rare Earth Elements from Rare Earth-Bearing Minerals and Ores**: *Laurence Whitty-Léveillé*[1]; Nicolas Reynier[2]; Dominic Larivière[1]; [1]Université Laval; [2]Natural Resources Canada

Often unnoticed, radioactivity handling in the rare earth elements (REE) mining industry is an environmental and economic concern that needs to be properly addressed. Actinides, such as uranium and thorium, are frequently co-dissolved with REEs in currently used hydrometallurgical processes, which results in radioactive contamination of the infrastructure across the extraction cycle. The present study investigates, through an optimization approach based on experimental design, a sequential leaching procedure with Na2CO3/NaHCO3 and HCl for the rapid and selective dissolution of REE and actinides. The experimental design investigated takes into consideration the main operating parameters (i.e. time, temperature and concentration) and the different types of minerals, REE composite and ores. The final sequential procedure was rapid (1 h), effective and led to segregation between Th, U and REE with limited dissolution of the gangue constituents, notably Fe, Si and Ca.

**3:45 PM Break**

**4:10 PM Invited**
**Supercritical Fluid Extraction of Rare Earth Elements from NiMH Battery**: *Gisele Azimi*[1]; Y. Yao[1]; J. Zhang[1]; J. Anawati[1]; [1]University of Toronto

Today's world relies upon advanced green technologies that are made of critical elements with unique properties. Examples include rare earth elements (REES) that are critical in the manufacturing of wind turbine and electric/hybrid vehicle batteries, key components of a greener future, but facing supply uncertainty and near zero recycling. To tackle their supply changes, activities have begun for their urban mining from waste electrical and electronic equipment (WEEE) that contain considerable amount of REEs, but their current level of recycling is less than 1%. Current recycling practices use either pyrometallurgy, which is energy intensive, or hydrometallurgy that utilizes large volumes of acids and solvents and generate large volumes of hazardous waste. In this study, we developed a novel and sustainable process to recycle REEs from WEEE, in particular NiMH battery. The developed process relies on supercritical fluid extraction (SCFE) utilizing CO2 as the solvent, which is abundant, safe, cost effective, and inert. The effect of seven operating parameters, namely temperature, pressure, residence time, sample to chelating agent ratio, agitation rate, complex formulation, and methanol addition, on the REE extraction efficiency was investigated, and optimum operating conditions were determined. This work is the first to utilize a very efficient and safe process that runs at low temperature to extract metals from postconsumer products with minimum hazardous waste generation, while offering about 90% leaching efficiency for REEs. We expect our process find widespread applicability in urban miming of REEs using a green chemistry.

**4:35 PM**
**Extraction and Purification of Rare Earth Elements and Cobalt from NdFeB Magnet Wastes**: *Hoda Emami*[1]; Pouya Hajiani[1]; [1]INNORD/Geomega

In this study, a combined pyrometallurgical and hydrometallurgical technique has been used to recover mixed rare earth elements (REE) and cobalt from a NdFeB magnet waste, while addressing the cost of reagents. This process is considered adjustable to various NdFeB magnet wastes, regardless of their composition. Prior to the leaching, the magnet scrap was pretreated by two rounds of roasting (750 C in air) and a mechanical grinding in between, to convert iron metal to ferric oxide.Subsequent leaching was performed in an optimized condition (pH, temperature and retention time) where the extraction ratio of REE to Fe III is the most. After removing iron content from leachate (pH˜3), REE was precipitated selectively and purified further. The produced REE concentrate reaches 99% purity with 85% recovery in a single run. The Cobalt oxide was isolated from PLS as a by-product of 99.8% purity.

**5:00 PM**
**Sulfuric Acid Baking and Leaching of Rare Earth Elements, Thorium and Phosphate from a Monazite Concentrate**: *John Demol*[1]; Elizabeth Ho[2]; Gamini Senanayake[3]; [1]ANSTO Minerals/Murdoch University; [2]ANSTO Minerals; [3]Murdoch University

Monazite, a rare earth and thorium phosphate mineral, is one of the major minerals processed for extraction of rare earths. Industry practice for treating monazite concentrates is to use either a sulfuric acid bake or caustic conversion route. In the sulfuric acid bake, monazite concentrate is mixed with concentrated sulfuric acid and roasted. The rare earth phosphate mineral is converted to rare earth sulfate which dissolves in a subsequent water leach. As the bake temperature increases above 300°C, thorium becomes less soluble. Although acid baking is practised in industry, the bake reactions are not well understood. In this paper, a combination of chemical analysis, XRD, SEM-EDS, IR and thermal analysis was used to identify reaction processes occurring during sulfuric acid baking of a 93 wt% monazite concentrate between 200 and 800°C. The effects of these reactions on the leachability of the rare earths, thorium and phosphate were also examined.

**5:25 PM Invited**
**Development of a Metallurgical Process for Eramet's Mabounié Nb-REE Project**: *Ghazaleh Nazari*[1]; Josselin Lamotte[2]; Michel Ries[2]; Jerome Agin[2]; Eric Tizon[2]; Sina Kashani-Nejad[1]; Mark Bellino[1]; Brian Krysa[1]; [1]Hatch; [2]Eramet
ERAMET, through its subsidiary COMILOG, have rights to a rich niobium and rare earth deposit in Gabon. The Mabounié deposit, is located 50 kilometers from the town of Lambaréné, in a fairly remote location. ERAMET has been developing a process to recover value metals for several years, and approached Hatch Ltd to design a sizeable Demonstration Plant to help them further optimize the process, and prove the flowsheet is technically viable. The process employs concentration techniques to recover an upgraded Nb/REE feed material for processing in the subsequent leach step. Rare earths and niobium are selectively leached, and subsequently precipitated. Following precipitation, rare earths undergo bulk separation and are purified to produce LRE and mixed MRE/HRE products, which will be further processed by Third Parties. This paper provides a high-level overview of the process, summarizes the motivation for a Demonstration Plant in the vicinity of the deposit, and discusses technical challenges faced during the flowsheet definition and design phase. Key challenges are focused on, and summaries of the methodologies used to address each challenge, as well as the solutions to overcome the challenges are discussed. The paper provides motivation for further process simplification and concludes with a project update.

## Part D: Sulfide Flotation – Flotation Process Mineralogy and Geometallurgy

*Program Organizers:* Ronel Kappes, Newmont Mining Corporation; Tarun Bhambhani, Solvay

| Monday PM | Room: Quebec |
|---|---|
| August 27, 2018 | Location: Westin Ottawa |

*Session Chair:* Tarun Bhambhani, Solvay

**2:00 PM Introductory Comments**

**2:10 PM Keynote**
**Optimizing Cu/Mo Float Circuits with Process Mineralogy Tools**: *Wolfgang Baum*[1]; [1]Ore & Plant Mineralogy LLC
This keynote address will provide an assessment of critical process mineralogy parameters and the use of modern mineralogy tools in Cu/Mo flotation. It will be shown that challenges with under-performing flow sheets, incorrect mill sizing, poor design of re-grinding, overreagentized circuits and/or run-away float conditions, can be minimized or avoided by using robust ore characterization programs and, subsequently, daily process mineralogy. Mixing slow and fast floating ores can be prevented or minimized by routine mineralogy. Continuous clay mineralogy has emerged as a significant improvement tool for flotation. Early detection and tracking of Mineralogical "Red Flags" via surveys of process streams continues to be an underutilized tool. Automated Laboratories are as important as other autonomous technology efforts. Operating without a best-equipped mineralogy lab is basically lacking a fire department and an emergency room.

**2:55 PM**
**Steady State Flotation Circuit Modelling**: *David Hatton*[1]; [1]SGS
A steady state flotation simulator has been developed. It is derived from fundamental flotation principles, incorporates the mechanisms of recovery by attachment and entrainment, and includes a predictive water recovery model. The simulator has been designed for Geometallurgical application and is able to simulate thousands of samples or blocks within fractions of seconds. Harnessing the simulation speed has allowed for extensive further development. This includes: automated plant survey result model fitting, lab test result fitting for ore characterisation, circuit economic optimisation from a calibrated model, production forecasting, and sensitivity analysis through Monte Carlo simulation.A brief overview of the simulation methodology and the fundamental principles used has been summarised. Case studies are presented to demonstrate the application of the simulator for circuit operation optimisation from an economic perspective, production forecasting, cell sizing, Geometallurgical flowsheet selection and plant sensitivity analysis.

**3:20 PM**
**The Use of Diagnostic Leaching for Flotation Insight**: *Kymberley Worrell*[1]; [1]Newmont
The Cripple Creek and Victor Gold Mine was acquired by Newmont in August 2015, the project was commissioned in February 2014. The high grade mill to date has been throughput limited due to mechanical and design issues. In order to create the most value from a throughput limited plant a campaign to characterize the feed ores was undertaken. A diagnostic leach methodology was developed to determine gold associations to ore type. The resultant associations are then used to characterize feed blend; gold losses and optimize gold production. The diagnostic methodology is presented along with discussion on flotation implications.

**3:45 PM Break**

**4:10 PM**
**Molybdenite Polytypism and its Implications for Processing and Recovery: A Geometallurgical-based Case Study from the Bingham Canyon Mine, Utah**: *Craig McClung*[1]; [1]Rio Tinto Kennecott
The concentration of molybdenite, a common byproduct of many copper concentrators, is more complex than other sulfides. It is this complexity that facilitated the necessity for a geometallurgical investigation of molybdenite from Bingham Canyon. The aim of this investigation was to determine the effect polytypism has on the recovery of molybdenite. The results of this investigation identified the two polytypes of molybdenite, i.e. hexagonal (2H) and rhombohedral (3R). The 2H-polytype is easily ground and faster-floating with surface attributes that are amenable to higher rates of recovery. These characteristics results in the production of a high quality molybdenum concentrate under normal operating conditions. In contrast, the 3R-polytype is difficult to grind and slower-floating with surface attributes that are less amenable to recovery under normal operating conditions. Therefore, in deposits with higher concentrations of the 3R-polytype, modifications to the normal operating parameters may be necessary to improve recovery.

**4:35 PM**
**The Importance of Understanding Mineralogy Drivers for Flotation Performance**: *Zachery Zanetell*[1]; Jennifer Thogerson[1]; [1]Newmont Mining
Flotation operations performance has become increasingly more challenging based on the complexity of available ore sources around the world. To optimize value mineral recovery, the mineralogical composition of the ore should be evaluated and understood. Utilizing a variety of mineralogical and analytical tools, flotation processing challenges can be overcome and potential limitations can be understood. Several case studies will be discussed in terms of the value that has been provided by mineralogical analysis in order to optimize flotation performance and value.

**5:00 PM**

**Application of 'Process Mineralogy' in Assessing the Process Performance of a Polymetallic Sulfide Ore Flotation Circuit**: *Edson Charikinya*[1]; Megan Becker[1]; Dee Bradshaw[1]; [1]University of Cape Town

A base-case analysis of an operational polymetallic sulphide ore flotation circuit was carried out by sampling key process streams of the circuit. The sampled streams were sized and chemically analysed using a combination of inductively coupled plasma optical emission spectrometry (ICP-OES), X-ray fluorescence spectrometry (XRF) and atomic absorption spectroscopy (AA). Liberation analysis of the sampled streams was carried out using Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) analysis. A sized mineral and liberation balance across the circuit was carried out allowing for the production of theoretical grade recovery curves which were used to determine the overall circuit performance. The base case model was further used to investigate the effects of changing mineral recovery, grade and feed ore variability on circuit performance. Results of this study demonstrate how liberation data could be successfully used in modelling and simulating a flotation circuit and in developing measures of circuit performances.

**5:25 PM**

**On-line Mineral Phase Analysis in Copper Flotation by Magnetic Resonance**: *Tom Strombotne*[1]; [1]Thermo Fisher Scientific

The need for on-line real-time determination of mineral phase in mineral beneficiation plants has been a long sought goal of mineral processors. While several methods exist for measuring mineral phase directly they do not all lend themselves to being applied on-line to moving slurry samples in an industrial plant setting. Nuclear Magnetic Resonance (MR) has been used to investigate a variety of materials with some success including a range of mineral phases in dry mineral samples with good sensitivity and rapid response times. With an interest in taking this method into mineral concentrators where there is a need to measure mineral phase on-line in slurry for flotation plant control Thermo Fisher has collaborated with the CSIRO Sensing and Sorting Program Minerals Magnetics Resonance Team to develop a prototype on-line real-time mineral phase slurry analyzer. Results from a field trial on a Copper concentrator Rougher Feed will be presented.

## Pyrometallurgy Keynote – Tuesday AM

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| Tuesday AM | Room: Governor General III |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM Keynote**
**The Changing World of Metallurgy Education**: *Peter Hayes*[1]; [1]University of Queensland
The world continues to change and with it the supply of minerals and metals, the location of centres of production of primary metal and the increasing levels of metals and materials recycling. New technologies are being developed to meet the ongoing search by industry for lower costs, cleaner production and new markets.To keep abreast with, and to utilise fully, the potential benefits of these technical advances the industry will need a professional workforce having different knowledge, skills and professional attributes than in the previous millennium. What are these skills and attributes? How to best attract and develop the metallurgists of the future, and provide for the ongoing educational and research needs of the industry?

**8:20 AM Panel Discussion**

**8:40 AM Question and Answer Period**

**9:10 AM Concluding Comments**

**9:20 AM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 6 Sustainability Towards Metallurgical Processing?

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Tuesday AM | Room: Governor General II<br>Sponsored by Hatch |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Phillip Mackey, P.J. Mackey Technology

**9:50 AM Invited**
**Circular Cities and Materials – Mobility as a Case Study**: *Maurits Van Camp*[1]; Christina Meskers[1]; Isabel Vermeulen[1]; [1]Umicore Group R&D
The transition to a circular, sustainable society is well on its way. Cities and regions are the place where this is happening bottom-up, supported top-down by the UN global goals for sustainable development by 2030. Circular cities integrate all aspects of life: housing, mobility, food, education, …. It connects across people, economic actors, institutions, and geographies for example. Circular cities are powered by renewable energy and responsible / sustainable materials; have closed water and material cycles, and are smart. The technical, industrial, economic, cultural and social systems meet and interact. The raw materials industry is a key player as it provides the materials and technologies needed for the transition. At the same time the raw materials industry itself needs to adapt. What needs to be done by the raw materials industry to be ready and contribute? Using the e-mobility value chain as vehicle this will be made tangible.

**10:40 AM**
**Energetic Impact of Smelting Primary and Secondary Materials**: *Sander Arnout*[1]; Els Nagels[1]; [1]InsPyro
Sulfide smelting takes advantage of the energy contained in the sulfide materials. The direct smelting of lead or copper ores, and the roasting of zinc ores, are exothermic processes. This enables the treatment of secondary materials such as sulfates (e.g. battery paste) and oxides (e.g. CZO from EAF dust) without additional heat need. Thermodynamics are a suitable tool to understand the thermal balance, as well as to provide practical parameters for daily use in operations. Appropriate input and output states are crucial, and need to be defined based on characterization work and process flow analysis. In this paper, the theoretical maximum replacement rate of primary concentrates by secondary streams is discussed. Next, some examples of practical possibilities are shown. A methodology is proposed to predict heat effects, including the impact on fluxing, which can be integrated in the mix design decision process.

**11:05 AM Invited**
**Sustainable Development Considerations in Primary Copper Smelting**: *Krishna Parameswaran*[1]; Joe Wilhelm[2]; Roberto Carmolinga[2]; [1]tfgMM Strategic Consulting; [2]ASARCO LLC Hayden Operations
This paper discusses energy use, opportunities for energy and resource conservation and illustrates sustainability considerations in primary copper smelting using select examples of practices at ASARCO LLC, an integrated U.S. primary copper producer as well as others in the industry. Using the classic Brundtland Commission definition of sustainable development, i.e., "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," the paper discusses how copper smelting practices can be sustainable. The examples used to illustrate sustainability considerations include: adoption of flash and bath smelting processes, emission reduction and process improvement associated with fire-refining and utilization of copper smelting slags.

**11:30 AM**
**Numerical Modeling of Irreversibility Generation in the Pierce-Smith Copper-Matte Converting Process**: *Paul Mather*[1]; Matthew Krane[1]; [1]Purdue University
Irreversibility generated in copper-matte converting to white metal, then blister copper was analyzed with a transient, equilibrium numerical model of a Pierce-Smith converting operation. It was found for both the slag and copper-blows that increases in oxygen grade of the air-blow decreased process irreversibility by up to 10% from a standard baseline-case for the slag-blow and up to 73% for the copper-blow, with corresponding increases in exergetic efficiency of 1 and 30% respectively. These effects were due to a reduction in inert material to heat.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 7 Experimental Fundamentals - Determination of Phase Equilibria, Other Physiochemical Properties

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Tuesday AM | Room: Governor General III |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Jean Lehmann, Arcelormittal Global R&D

**9:50 AM Invited**

**Reaction Behavior of Phosphorus in Multi-phase CaO-FeOX-SiO2-P2O5 Flux System**: Xiao Yang[1]; Hiroyuki Matsuura[1]; *Fumitaka Tsukihashi*[1]; [1]The University of Tokyo

Calcium oxide is one of the major fluxing agents used for steel refining. Because unreacted CaO remains in slag in most cases, discharged slag is difficult to be recycled smoothly. With the growth of environmental concerns, improving utilization efficiency of CaO is required to reduce the amount of discharged slag and energy consumption. The authors have reported a resource and energy-saving process by using multi-phase flux for dephosphorization. Reaction behavior of phosphorus in multi-phase CaO-FeOX-SiO2-P2O5 flux system was investigated. Formation mechanism of P2O5-rich phases was clarified at the interface between solid CaO or 2CaO·SiO2 and molten CaO-FeOx-SiO2-P2O5 slag. Phase relationship and thermodynamic properties of 2CaO·SiO2 -3CaO·P2O5 solid solution were observed to confirm the condensation of P2O5 in solid phase. Based on these results, reduction of CaO consumption, discharged slag curtailment, and energy-saving effects in the novel refining process by using multi-phase flux were discussed.

**10:15 AM Invited**

**Microanalysis and Experimental Techniques for the Determination of Multicomponent Phase Equilibria for Non-ferrous Smelting and Recycling Systems**: *Taufiq Hidayat*[1]; Peter Hayes[1]; Evgueni Jak[1]; [1]PYROSEARCH, Pyrometallurgy Innovation Centre, School of Chemical Engineering, The University of Queensland

Accurate description of complex phase equilibria provide foundations for the improvement of non-ferrous pyrometallurgical smelting and recycling processes. Recent advancements in microanalysis and experimental techniques enable accurate phase equilibria characterisation. Quantitative microanalytical techniques including Electron Probe X-ray Microanalysis and Laser Ablation ICP-MS enable measurements to be made of major and minor elements concentrations in different phases in samples, previously not possible when using bulk chemical analysis technique. High-temperature equilibration experiments coupled with analysis of elementary reactions at micro- and macro-scales ensure the attainment of equilibrium conditions, and therefore, ensure true phase equilibria information is obtained. Examples of application of the improved methodology on the investigation of phase equilibria of low-order to complex, multi-component gas-slag-matte-metal-speiss-solids Cu2O-PbO-ZnO-Al2O3-CaO-MgO-FeO-Fe2O3-SiO2-S system and distribution of As-Bi-Sb-Sn-Ag-Au minor elements are provided. The experimental study is closely integrated with thermodynamic database development for the above system. Examples of implementation of the research outcomes into industrial operations are demonstrated.

**10:40 AM Invited**

**Thermodynamic Study on the Equilibrium of Platinum Group Metals between Slag and Molten Metals**: *Katsunori Yamaguchi*[1]; [1]Waseda University

A fundamental study of the recycling process was carried out to recover the PGM from the three-way catalysis. Distribution ratios of platinum, palladium and rhodium between the Al2O3-CaO-SiO2 slag and molten iron or carbon saturated iron were measured at 1873 K. Distribution ratios of PGM between the slag and the liquid iron and the carbon saturated molten iron were from 4x10-6 to 5x10-4. Based on the distribution ratios, recovery of platinum, palladium and rhodium using the molten iron as metallic solvent is determined at 1873 K. We found that PGM is enriched to the molten iron or the carbon saturated iron and the slag loss of PGM is negligible small.

**11:05 AM**

**High Temperature Recovery of Rare Earth Ortho-Ferrites from Permanent Magnets**: Muhamad Firdaus[1]; *M Akbar Rhamdhani*[1]; [1]Swinburne University of Technology

There is a growing interest in magneto-electric materials in view of both fundamental understanding and their novel desirable applications. The application potential of multiferroic materials with the possibility of reversing the magnetization by applying an electric field (or vice versa) is quite promising especially in data storage application. The rare earth ortho-ferrites ($REFeO_3$) have been recently studied extensively in the context of discovery of magneto-electric/multiferroic nature materials. In this study a potential high temperature recovery of rare earth elements in the form of $REFeO_3$ from permanent magnets using direct oxidation in air was investigated. $REFeO_3$ phase can be separated from the other oxide phases ($Fe_2O_3$ and $REBO_3$) at microscopic level by thermal treatment 1100°C in air. Degree of liberation of the oxidised phase and further options for powder separation was suggested. The technique can be beneficial and favourable for alternative form of RE recycling and recovery from waste permanent magnets.

**11:30 AM**

**On the Evaporation of S from Liquid Fe-C-S Alloy**: *Youn-Bae Kang*[1]; Fahmi Tafwidli[1]; [1]Pohang University of Science and Technology

Evaporation mechanism of S from liquid Fe-C-S alloys at 1873 K was proposed by analyzing available experimental data. It has been known that increasing C content in liquid alloy increases activity coefficient of S, and it could raise driving force for the evaporation reaction S = S(g). However, experimental data of the evaporation of S in the Fe-C-S alloys could not be accounted for only by considering the increases of the activity coefficient of S. In the present study, formation of carbosulfides, CS(g) and CS2(g), was additionally taken into account in order to explain role of C for the accelerated S evaporation. Surface adsorption of S was also taken into account, which retards the evaporation rate of S. An evaporation model equation was formulated. It can be applied to calculate the evaporation rate of S over wider C content (from zero to its saturation to liquid alloy).

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 8 Waste and Recycle

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Tuesday AM | Room: Ontario |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Bart Blanpain, KU Leuven

**9:50 AM**

**Carbothermic Reduction of Red Mud with Spent Potlining as Reductant**: *Kai Erik Ekstroem*[1]; Maria Wallin[1]; Gabriella Tranell[1]; [1]Norwegian University of Science and Technology

The acceptance for landfilling of hazardous industrial by-products is diminishing, and continuously stricter regulations from lawmakers and governmental agencies call for more sustainable methods for recycling of these products. Spent potlining and red mud are two important by-products of the aluminum industry that are seeing increased resistance towards landfilling. Both have a notorious tendency to display large variations in chemical composition that can be traced back to different raw materials, processing routes and plant technologies, and has made it difficult to develop a universal method for recycling. This work explores the possibility of utilizing the carbonaceous fraction of spent potlining as a reductant for carbothermic recovery of iron from the red mud and a simultaneous inertisation of hazardous elements in a slag. The paper includes both experimental results and associated thermodynamic calculations.

**10:15 AM**

**Extraction of Pig Iron and Ferrosilicon from Low-grade Bauxite Ores**: *Jafar Safarian*[1]; [1]NTNU

Bauxite is the main raw material used for the production alumina (Al2O3) through the well-known commercial Bayer process. This process has significant challenges such as limitation in using low-grade bauxites as they contain significant amounts of impurities such as Fe, Si, Ti. The Bayer process residue, which is known as red mud, is also a global environmental challenge due to huge amount of this low value residue production. Alternative sustainable process with high potential to solve these problems and produce valuable and consumable by-products is a pyrometallurgical-hydrometallurgical process in which the low-grade bauxite ore is treated through a smelting-reduction process, yielding iron alloys and a calcium-aluminate slag. Alumina is then produced from the slag by hydrometallurgical treatment. In the present work, the reduction of pellets produced from different bauxite ores by hydrogen is studied and it is shown that complete iron oxides reduction is possible. Further smelting and smelting-aluminothermic reduction of the reduced pellets show that iron and silicon ferroalloys can be produced, in addition to a proper slag for alumina extraction.

**10:40 AM**

**Kinetics of Bauxite Residue Sintering**: *Harrison Hodge*[1]; William Hawker[1]; Peter Hayes[1]; James Vaughan[1]; [1]University of Queensland

In the Bayer process for alumina production, between 2-35% Al2O3 is lost with bauxite residue due primarily to incomplete dissolution of aluminium-bearing minerals during caustic leaching or the precipitation of sodium alumino-silicate solids. The recovery of sodium and aluminium from the residue, and particularly from the contained sodium alumino-silicates, is becoming an increasingly critical issue from both an environmental and economic standpoint. Lime-soda residue sintering followed by selective leaching has been proposed as a method to recover sodium and alumina. The factors influencing the sintering mechanisms and kinetics, and the subsequent leaching have not been well described to date. In this study, the physical and chemical changes taking place during isothermal sintering of bauxite residue in air, particularly at short reaction times are investigated using scanning electron microscope (SEM) and X-ray diffraction (XRD). The impacts of these changes on the recovery of valuable materials are reported.

**11:05 AM**

**Slag and Solvent Refining Silicon for Solar Cell Applications**: *Sridevi Thomas*[1]; [1]University of Toronto

As the world turns to green energy, the demand for photovoltaic cells continues to grow, as does the demand for raw materials; most solar cells are made from silicon of 6N purity with less than 1ppm phosphorus and boron. However, cells are currently made by blending 11N and 2-3N silicon. Making 11N silicon requires a considerable amount of time, energy and infrastructure that can contain toxic by-products. To by-pass this route, this project is looking at pyrometallurgical methods of slag and solvent refining to directly achieve 6N silicon. A calcium aluminate slag is used to refine an aluminium-silicon alloy; the effect of slag composition and additives is studied. As phosphorus and boron are the most important impurities that are also the most difficult to remove, these elements will be the focus.

## Part C-1: Hydrometallurgy 2018 – Electrolytic Processing 1

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Tuesday AM | Room: Provinces II |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**

**An Approach to Evaluate the Effect of Organic Compounds (Impurities and Additives) on Metal Electrowinning**: *Daniel Majuste*[1]; Virginia Ciminelli[1]; Paulo Cetlin[1]; Eder Martins[2]; Adelson Souza[2]; [1]UFMG; [2]Nexa Resources

This paper describes an approach to assess the effect of organic impurities or additives on metal electrowinning and product quality. In addition to electrowinning tests and electrochemical measurements, the approach includes organic analysis by Fourier Transform Infrared spectroscopy and gas chromatography; video monitoring of reaction interface; and product characterization by microscopy, crystallographic texture and bending tests. The mechanical behavior of metal cathodes was assessed with customized bending device that is able to bend the cathodes up to angles similar to that of stripping machines. The effect of potential organic impurities, as flotation collectors, flocculants, anti-foaming agents and lubricating oils, on production of electrolytic zinc is taken as a case study. The findings allowed a better understanding on the role of different organics on energy consumption and product quality and a semi-quantitative prediction for the behavior of Zn cathodes during stripping. Simple control and optimization procedures resulted in significant savings.

### 8:30 AM

**A Comprehensive Model for Metal Electrowinning Processes**: *Zongliang Zhang*[1]; Joshua Werner[2]; Michael Free[1]; [1]University of Utah; [2]University of Kentucky

Electrowinning is a significant step in metal extraction processes. Because the nature of electrowinning is to reduce metal from its oxidized state, substantial energy consumption accompanies it. Electrowinning of different metals have much in common - the deposition of the metal on the cathode and the counter reaction on the anode. An advanced model was developed that can be applied to a variety of metal electrowinning processes. A model for specific metals can be readily obtained by modifying parameters such as potential, kinetics, and side reactions in the model. The model incorporates mass transfer, gas-liquid flow, electrochemistry, and deposition, making it a comprehensive electrowinning model. The model is applied to copper, nickel, and zinc and verified with the experimental results. In addition, the parameter settings and results of different metals were compared, showing that this model has great versatility and accuracy, thereby making it an efficient and effective research tool.

### 8:55 AM

**Characterizing the Role of Polyacrylamide Additives in Copper Electrowinning**: *Christiaan Coetzee*[1]; Margreth Tadie[1]; Christie Dorfling[1]; [1]Stellenbosch University

Additives are commonly used in copper electrowinning to improve cathode morphology. Polysaccharides such as guar are generally favoured as additives due to its compatibility with solvent extraction. Polyacrylamides are, however, being considered as possible alternatives. Understanding the influence of the structural chemistry of additives on electrowinning performance is critical to utilise them efficiently. This project investigated polyacrylamides which are structurally different as electrowinning additives; their effects on copper electrodeposition were characterized and compared to that of guar. Cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) techniques were used to characterize the effects of molecular weight and ionic charge of the polyacrylamides on electrodeposition. The findings were compared against results obtained with an industrially used guar and polyacrylamide product. Equivalent circuit modelling of EIS data indicated that an increase in polyacrylamide concentration and a decrease in additive molecular weight increased the overall system resistance, supporting the findings from CV.

### 9:20 AM

**Study of Electrochemical Behaviour and Surface Morphology of Copper Electrodeposit from Electrorefining with Lignin-Based Biopolymer and Thiourea as Additives**: *Mohammad Mubarok*[1]; Rolf Lauten[2]; Ross Ellis[2]; Dani Ramdani[3]; Mohammad Syaifuddin[1]; [1]Institut Teknologi Bandung; [2]Pionera,Borregaard AS; [3]Pionera, Borregaard South East Asia

Effect of single addition of a lignin-based biopolymer additive of DP 2782 at various dosages as well as in combination with thiourea on cathode polarization during copper deposition was investigated by performing potentiodynamic and galvanostatic measurements using a potentiostat. The result of electrochemical measurements was compared with the behaviour of cathode deposition with glue and thiourea additives. Surface micro-appearance of the copper deposit after 1h galvanostatic scan under current density of 330 A/m2 and various additive type and dosage was evaluated by scanning electron microscopy (SEM) examination. It was found that the addition of biopolymer of 2.5 mg/l sufficiently gave polarizing effect of copper deposition. SEM examination of the cathode surface after galvanostatic scan revealed that the combination of the biopolymer with thiourea (2.5 mg/l and 3.5 mg/l) resulted in a compact deposit which is comparable with that resulted from the test with glue and thiourea.

### 9:45 AM Break

### 10:15 AM

**Manganese-Chloride Interactions on Pb-Ag Anode Behavior**: *Charles Abbey*[1]; Jin Wei[2]; Michael Moats[1]; [1]Missouri University of Science and Technology; [2]National Engineering Laboratory for Hydrometallurgical Cleaner Production

Manganese in electrolyte has both beneficial and detrimental effects in Zn electrowinning. Mn oxidizes to form MnO2 on Pb-Ag anodes, cell walls and pipes. MnO2 reduces anode corrosion but also leads to short circuiting and maintenance issues. Manganese ions and MnO2 interact with chloride ions and oxidized chlorine species. These interactions are not well understood. Therefore, two sets of 45+ day benchscale experiments were conducted to investigate the effects [Mn] to [Cl] ratio on anode corrosion rate and electrolyte chemistry using rolled Pb-Ag anodes. Daily Mn and Cl losses from the electrolyte appeared to be correlated. Increasing the average Mn/Cl ratio from ~7:1 to ~11:1 reduced the observed corrosion rates. Increasing the ratio above 11 did not reduce the corrosion rate further. Anodes scales characterized produced with Mn/Cl ratios at and above 11:1 contained some ⇉MnO2 while scales formed with ratios less than 11:1 did not.

### 10:40 AM

**Pb-Ca-Sn Anode Potential as a Function of Cobalt, Iron and Manganese in Synthetic Sulfuric Acid Electrolytes**: *Charles Abbey*[1]; Michael Moats[1]; [1]Missouri University of Science and Technology

Cobalt, iron and manganese play various roles in copper electrowinning using lead-calcium-tin alloyed anodes. Cobalt catalyses electrochemical water decomposition resulting in lower anode potential and reduced corrosion rates. Iron reduces cathodic current efficiency, but is required in the electrolyte to reduce higher oxidation states of manganese that oxidize organics in solvent extraction. The effect of the combined interaction of these three metal ions on the anode potential has not been quantified yet. The current work used a three factor, three level, three replicates central composite design of experiments to analyse the effects and potential interactions between cobalt, iron and manganese. The experiments consisted of chronopotentiometric analysis to assess the anode potential. High [Co], low [Mn] and either high or low [Fe] yielded lower anode potentials. Two regression models were developed to predict anode potential as a function of [Co], [Fe] and [Mn].

### 11:05 AM

**Regulatory Mechanism of Anode Slime Behavior**: *Weizhi Zeng*[1]; Michael Free; Shijie Wang; [1]University of Utah

In order to examine the effects of operating parameters on anode slime behavior and study its regulatory mechanism, a series of pilot-scale copper electrorefining tests was performed at the Rio Tinto Kennecott Copper Tankhouse. Tested anodes with known impurity compositions were observed under SEM/EDS for inclusion characterization, while the harvested copper cathodes were analyzed by DC Arc for impurity concentrations. In addition, slimes adhered to and released from the anode were weighed and analyzed by ICP for compositions respectively. It was demonstrated that Pb/As ratio in copper anode has significant effects on slime particles' sintering and coalescence; high current density tends to intensify the coalescence of slimes and dissolve part of the particles, leading to improved anode slime adhesion and cathode purity; wider cathode blank results in larger anodic current density, thus better slime particle coalescence; small flow rate was correlated with anode passivation, which increases in-situ anode temperatures and affect the coalescence of slime particles.

**11:30 AM**

**Removal of Copper from Anode Slime in Sulfuric Acid with Cupric Ion and Oxygen**: *Kyoungkeun Yoo*[1]; [1]Korea Maritime and Ocean University

Anode slime is generated during copper elecrorefining process, and copper should be removed from anode slime to concentrate precious metals. Various oxidants such as ferric ion, nitric acid, hydrogen peroxide have been investigated to oxidize copper but there are some drawbacks such as NOx gas emission and unstable or complicated process. In the present study, new Cu leaching process was developed using sulfuric acid with cupric ion and oxygen. The Cu leaching behavior was investigated using four leaching sets; without aeration and cupric ion, with aeration but no cupric ion, with cupric ion but no aeration, with cupric ion and aeration. The leaching results showed the highest leaching efficiency by adding air and cupric ion. The Cu leaching efficiency increased to 98% in the 1 M sulfuric solution at 90 °C and 400 rpm with 1 % pulp density, 10000 ppm CuSO4, 300 cc/min air for 2 hours.

## Part C-1: Hydrometallurgy 2018 – Extraction/ Processing 4

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Tuesday AM | Room: Confederation I |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**

**The Effect of Anodic Potential on Surface Layers of Chalcopyrite During Ammonia-ammonium Chloride Leaching**: *Qian Xu*[1]; [1]Shanghai University

The effect of the anodic polarization on the composition and morphology of the surface layer formed on chalcopyrite during ammonia–ammonium chloride leaching was investigated. Anodic polarization on the chalcopyrite electrode was used for oxidation and dissolution of chalcopyrite, and the resulting oxidized layers were characterized by XPS, SEM and optical microscopy. The results show the composition and morphology of the oxide layers are strongly depended on the extent of polarization. The distribution of FeOOH and Fe2O3 within the oxidized layer was inhomogeneous for the sample at anodic potentials lower than 0.3 V. At anodic potentials above 0.4 V, the oxidized layers contained many cracks, and they were fragile and easily exfoliated. The sulfide had been oxidized to sulfur species with higher oxidation states. The oxidation of the chalcopyrite seemed to undergo a cyclically oxidative process that suggested growth and spallation of oxidation layers on chalcopyrite in a layer-by-layer sequence.

**8:30 AM**

**Present and Future of Cobre Las Cruces Hydrometallurgical Plant**: *Carlos Frias Gomez*[1]; Enrique Delgado Palomo[1]; Joaquin Gotor Martinez[1]; Jorge Blanco Aviles[1]; Francisco Sanchez Ruiz[1]; [1]Cobre Las Cruces, S.A.

Las Cruces mine is one of the richest copper deposits in the world including primary volcanogenic massive sulphides and supergene cementation zone and overlying gossan. Since 2009, Cobre Las Cruces (CLC) benefits the secondary copper sulphides of supergene cementation zone, and the critical issue is that such rich-copper orebody will be exhausted in 2021. As a consequence, the future of Las Cruces mine lies on exploitation of existing primary massive sulphides (polymetallics).CLC owns a unique hydrometallurgical copper refinery producing over 73,500 tpa Grade A copper cathodes applying direct atmospheric leaching of secondary copper sulphide ores followed by copper solvent extraction and electrowinning. Main technological challenge that CLC is currently facing is to adapt and to expand existing hydrometallurgical plant to create a new “Poly-Metallurgical Refinery” able to produce in situ through hydrometallurgical way the four metals: Cu, Zn, Pb and Ag. Achievements of such ambitious project are presented here.

**8:55 AM**

**Chloride Leaching of Chalcocite Under Controlled pH and ORP**: *Mohsen Hashemzadeh*[1]; Wenying Liu[1]; [1]UBC

Chalcocite is the second most abundant copper sulfide mineral on the earth. Chloride leaching of copper sulfide minerals, specifically chalcocite, has recently attracted interest. The dissolution of a pure chalcocite mineral in the acidic ferric chloride solution has been explored in this study. The pH and ORP values were kept constant during the leaching experiments. The effect of key parameters including ferric concentration, chloride concentration, and temperature were investigated. The shrinking core models were applied on the experimental data to describe the leaching kinetics of chalcocite. Ferric concentration and chloride concentration had a considerable effect on the first stage of chalcocite leaching, while temperature was the main key parameter affecting the kinetics of the second stage.

**9:20 AM**

**Treatment of Arsenic Sulfide Sludge for Arsenic Stabilization and Copper Extraction**: *Jianxin Zhang*[1]; Zhihong Liu[1]; [1]Central South University

A process, in which arsenic in the residue is transformed directly into scorodite and copper dissolves into the solution simultaneously, was studied. The process was carried out in acidic ferrous sulfate solution under oxygen pressure. The optimum conditions of the process were determined as follows: the initial H2SO4 concentration was 10 g/L; liquid/solid ratio was 10; Fe/As molar ratio in the feedstock was 1; the addition of calcium lignosulphonate was 1% of residue; oxygen pressure, temperature and reaction time were 1.5MPa, 150 °C and 6h respectively. Under these conditions, arsenic transformed to crystalline scorodite in size of 5-10μm, and the transformation efficiency reached 97.60%; meanwhile, the copper was leached with a high efficiency of 93.34%. The stability of the leaching residue was evaluated by TCLP testing, and the results indicated the concentration of arsenic in the leaching solution was extremely low as 0.04 mg/L and met the standard of safe stockpile.

**9:45 AM Break**

**10:15 AM**

**A Novel Environmental-friendly Process to Prepare High Purity TiO2 Powder from Titania Slag**: *Ying Zhang*[1]; Xiaofang Zhu[1]; Shili Zheng[1]; Zak Fang[2]; [1]Institute of Process Engineering, Chinese Academy of Sciences; [2]University of Utah

Titanium dioxide is an important chemical which is produced by either the chloride or the sulfate processes. However, the environmental issues associated with the sulfate process are severe, since the sulfuric acid with a low centration of ~20 wt%(~4.7 mol/L H+) cannot be cost-effectively recycled to the slag digestion unit, which has to be neutralized, generating a large amount of wet and useless red gypsum (RG). In this research, the authors find that the titania slag can be effectively digested using a weaker acid solution of lower than 6 mol/L H+ when the chemically-stable slag is transformed into titanium oxide in a lower valence state via a thermochemical reduction in moderate conditions; thus the generation of the waste solid RG can be avoided. By combining the three key steps of structure rebuilding, weak acid digestion, and controlled hydrolysis, a new process is proposed for production of high-purity TiO2.

**10:40 AM**
**Study of the Rate Controlling Steps in the Removal of Magnesium Impurities in Hydrogen Assisted Magnesiothermic Reduction of TiO2 by Leaching**: *SAYAN SARKAR*[1]; Wyatt McNeill[1]; Jayson Benedict[1]; Michael Free[1]; [1]University of Utah
HAMR (Hydrogen Assisted Magnesiothermic Reduction) process is a promising alternative route of titanium production, which is convenient due to reduction at relatively lower temperatures below 750 °C and usage of cost-efficient TiO2 as the starting material. A crucial step involved in this process requires the Mg reduction of TiO2 subjected to H2 atmosphere which produces porous TiH2 along with residual magnesium impurities. Before the final heat treatment and deoxygenation steps for consolidation of the Ti powder, leaching plays a significant role in the removal of Mg impurities. In this report, we present a systematic study on the role of acid concentration (HCl), temperature, particle size and agitation on the kinetics of Mg removal in the HAMR process. This parametric study will provide a platform to ensure very low Mg content that meets with ASTM standards during production of Ti in the HAMR process.

**11:05 AM Invited**
**The Effects of Additives on the Leaching of Ilmenite Concentrate**: *Khetho Daba*[1]; Shongwe Mxolisi[1]; Ramakokovhu Mercy[1]; [1]Tswane University of Technology
Titanium dioxide extraction from Ilmenite using pyro-metallurgy method which involves melting ilmenite in the electric arc furnace for carbothermically reduced to produce cast iron and titanium slag. Titanium slag then upgrade to produce pure Titania of 98-99.5% grade by sulphate or chloride process. This method described above requires many processes which demand high capital investment and gases released are dangerous to environment. On this project hydrometallurgy of leaching is propose to be utilized for producing TiO2 of high grade (TiO2-99.978%). This study focus on the effects of additives such as Iron, phosphate, fluoride and etc. on dissolution of Iron (and other impurities) from ilmenite. In addition, the other leaching parameter which play significant role such acid concentration, temperature, solids/acid ratio, agitation and leaching residence time will be studied and optimized. This hydrometallurgy method for producing pure TiO2 from ilmenite doesn't require many processes.

## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Tuesday AM

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

Tuesday AM
August 28, 2018

Room: Provinces I, sponsored by Purolite
Location: Westin Ottawa

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM Invited**
**Advances in the Development of Electrostatic Solvent Extraction for Process Metallurgy**: *Don Ibana*[1]; Simon Assmann[1]; Marc Steffens[1]; [1]Curtin University
Electrostatic solvent extraction (ESX) is similar to conventional solvent extraction (SX) except that it uses electrostatic agitation, which promises to circumvent the inherent limitations of SX by allowing the production of very small droplets that can be made to maintain intense motion with minimal power consumption. An industrial application of the technique however is yet to be achieved.Our work to develop its application in process metallurgy has now established that electrostatic field has no effect on the stability of the reagents or the chemistry of the process. We have also established that electrostatic fields allow the production of much narrower droplet size distributions than those of mechanically agitated contactors while maintaining high droplet motions and hence, high mass transfer rates. A contactor design that allows a volumetric flowrate that is comparable to that of a conventional SX column has also been achieved. These will be discussed in this presentation.

**8:30 AM Invited**
**Experimental Study and CFD Simulation of a Pulsed Solvent Extraction Column with Novel Ceramic Internals**: Heng Yi[1]; Weiyang Fei[1]; *Geoffrey Stevens*[2]; [1]Tsinghua University; [2]University of Melbourne
Lithium extraction from salt lake brine with high Chloride levels is very corrosive and requires a large number of stages. Two types of novel anti-corrosive ceramic internals, the hybrid ceramic internal and ceramic pulsed plate internals have been tested under pilot conditions for future industrial application in this field, along with CFD models that have been developed for these two columns. Both CFD and pilot tests show that holdup of the hybrid ceramic internal is higher than that of ceramic plate by around 50%, while Sauter mean diameter of hybrid ceramic internal is smaller than that of ceramic plate by around 30%. Axial dispersion and mass transfer parameters are also presented and the results show that the hybrid ceramic internal has 50% lower axial dispersion coefficient and 50% higher mass transfer coefficient, contributing to higher mass transfer efficiency making it promising for application in the near future.

**8:55 AM Invited**
**Outotec's VSF®X Implementation to Provide Modular Solvent Extraction Technology**: *Tuomas Hirsi*[1]; Rami Saario; [1]Outotec
The world's first large scale modular solvent extraction plants have been delivered by Outotec. The first of these is now in operation and has proven that the VSF® X technology can deliver the excellent performance of the Outotec VSF® solvent extraction process. Modular delivery allows site work to be minimized and the manufacturing done in a controlled environment, allowing for serial production manufacturing benefits. Container based delivery was found to be a highly efficient way of utilizing the standardized transportation methods in global scale. Site work with modular units was found to be efficient and highly predictable. In this paper, we present the first successful Outotec VSF® X deliveries and discuss the benefits of the modular delivery and design compared to the standard solvent extraction delivery. The process performance of the VSF® X is also discussed with experiences from the first industrial reference presented.

**9:20 AM**
**Settling Behavior and CFD Simulation of a Gravity Separator**: *Jan Steinhoff*[1]; H.-J. Bart[2]; [1]Technische Universität Kaiserslautern; [2]Technische Universität Kaiserslautern
The design options of a gravity separator are still limited and rely on the study of settling behavior. A methodology will be presented were an experimentally given inlet droplet size distribution (DSD) is the basis for the calculation of the dispersion layer in a gravity separator. A pilot scale of a continuous gravity separator is presented and CFD results are validated. A transmitted light measurement technique for the determination of the DSD is presented up to a holdup of 25% dispersed phase. The resulting DSD was in the range of 20-2000 µm depending on flow rate and phase ratio. Furthermore, correlations of the real DSD with the settling behavior of the dispersion in a settling cell are discussed. The new approach to the description of gravitational separators will be presented and the applied CFD methods showed good results with the system water/paraffin.

**9:45 AM Break**

**10:15 AM**
**Equilibrium Modeling of Solvent Extraction and Stripping of Copper(II), Nickel(II), and Ammonia for Ammoniacal Process Using LIX 84-I**: Shubin Wang[1]; Jie Li[2]; Hirokazu Narita[1]; *Tanaka Mikiya*[1]; [1]National Institute of Advanced Industrial Science and Technology; [2]Central South University
Copper(II) and nickel(II) are often separated by a process via ammoniacal alkaline solutions using hydroxyoxime extractant: both of copper(II) and nickel(II) are extracted from ammoniacal alkaline solutions and, from the loaded organic phase, nickel(II) is selectively stripped with a dilute acid followed by copper(II) stripping with an acid of higher concentration. Since a small portion of ammonia is co-extracted with copper and nickel, the extracted ammonia should be scrubbed using a dilute acid before metal stripping. In the present study, a mechanistic model has been developed in order to support design and control of this process. The equilibrium distribution ratios of copper(II), nickel(II), and ammonia at 298K using LIX84-I as the extractant are successfully correlated by considering the relevant equilibria. Based on these results, quantitative prediction of equilibrium distribution ratios in the process has been made possible, and suitable conditions for the efficient separation of copper(II) and nickel(II) are discussed.

**10:40 AM**
**Modelling Solvent Extraction as a Chemical Equilibrium**: *Michael Dry*[1]; [1]Arithmetek Inc.
Solvent extraction is often modelled via loading, scrubbing and stripping isotherms. These isotherms are measured by laboratory work, each species to be extracted requiring its own isotherms. Apart from single-species McCabe-Thiel plots, translating these isotherms into process predictions entailing the extraction of any given species from a feed containing more than one species that can be extracted is not within the normal capabilities of those who must design overall circuits. This paper will present a methodology for modelling solvent extraction as chemical equilibrium reactions between the various aqueous and organic species when more than one extractable species is involved. It will cover the extraction of the relevant parameters from standard laboratory tests measuring individual isotherms and show how these parameters can then be used to model continuous solvent extraction. Examples will be presented for a single-reagent extraction and for synergistic solvent extraction.

**11:05 AM**
**Liquid-liquid Extraction of Cobalt(II), Nickel(II) and Manganese(II) from Acidic Chloride Media**: *Alexandre Chagnes*[1]; Kateryna Omelchuk[2]; [1]Georessources; [2]IRCP
Co, Ni and Mn are used in many applications including alloys manufacturing, electrode materials for lithium batteries, etc. The search of new extractants for Co-Ni-Mn separation at low pH is of great concern. In this work 6 new cationic exchangers have been synthesized. Their physicochemical properties have been investigated by determining their pKa, association constants and distribution constants between kerosene and acidic chloride solutions by potentiometry, vapour pressure osmometry and UV-Vis spectroscopy, respectively. These data have been implemented in a physicochemical model for calculating the the variation of the extraction efficiency vs. pH. Such a model is thus used to investigate the speciation in kerosene of the new extractants and the metal-extractants complexes. The ability of these extractants to selectively recover Co, Ni and Mn from acidic chloride media at low pH based on the speciation deduced from the model and the physicochemistry of extraction will be discussed.

**11:30 AM Invited**
**New Technological Advances, Challenges and Opportunities in Solvent Extraction from Energy Storage**: *Laurent Cohen*[1]; Brent Hutzler[1]; Tyler McCallum[1]; Matthew Soderstrom[1]; Owen Tinkler[1]; [1]Solvay
Since the 1970's, solvent extraction in hydrometallurgical processes has been the enabling technology in the production of high-purity metals. Examples include copper, rare earth oxides, uranium, cobalt and nickel. Notwithstanding incremental improvements in extractant formulations, few breakthroughs can be recounted in this industry outside of the initial amine-, oxime- or phosphine-based reagent chemistries. However, the advent of lithium-ion batteries and their stringent requirements for critical materials (lithium, cobalt, nickel) offer new challenges and opportunities for solvent extraction. Solvay has recently introduced three new extractants: CYANEX®572 for rare earths, CYANEX®600 for molybdenum, CYANEX®936 for lithium, all of which provide a step change in metal separation performance and selectivity. Solvay has also developed unique modeling software capabilities in cobalt/nickel separation using CYANEX®272, zinc solvent extraction using DEHPA® and rare earth separations using CYANEX®572. This paper presents these advances and summarizes the technical and economic benefits demonstrated in the laboratory and commercial applications.

## Part C-3: Processing of Critical Metals – Critical Materials / Rare Earth Elements

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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| Tuesday AM | Room: Governor General I |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**
**SCRREEN - A European Expert Network on Critical Raw Materials**: *Stéphane Bourg*[1]; [1]CEA
Coordinated by the French CEA, SCRREEN gathers more than 50 European initiatives, associations… working on Critical Raw Materials (CRM) into a long lasting network including stakeholders, public authorities and civil society representatives. SCRREEN contributes to improve the CRM strategy in Europe by (i) mapping primary and secondary resources and substitutes of CRMs, (ii) estimating the expected demand of various CRMs in the future and identifying major trends, (iii) providing policy and technology recommendations for actions improving the production and the potential substitution of CRM, (iv) addressing specifically WEEE and other EOL products issues related to their mapping and treatment standardization and (vi) identifying the knowledge gained over the last years and easing the access to these data beyond the project. This paper will present the main outputs of the project on the issues mentioned above after 18 months of existence, which can drive future R&D programs and industrial developments.

**8:30 AM**

**Leaching Kinetics of Rare-Earth Elements from Complex Ores by Acidic Solutions**: *Hüseyin Eren Obuz*[1]; Haydar Günes[1]; Dilan Ugurluer[2]; Aslihan Kara[2]; Yurdaer Babuçcuoglu[3]; Murat Alkan[2]; [1]The Graduate School of Natural and Applied Sciences; [2]Dokuz Eylül University; [3]MTA General Directorate of Mineral Research and Exploration

In this study, the leaching kinetics of rare-earth elements were investigated by using HCl and HNO 3 solutions. A standard crushed carbonatite complex ore was utilized as raw material. The complex ore contains Ce, La, Nd and Pr elements as oxide forms. The stoichiometric requirement of amount of acid was calculated due to dissolve all soluble components in the standard ore. In the leaching experiments, 100 mL acid solution with different concentration were used with 400 rpm stirring rate at room temperature. Leaching studies were realized in a glass beaker by using a magnetic mixer. Different leaching durations were selected for the kinetic studies. Solid – liquid separation was realized after leaching finishes, and products were characterized. The XRD (X-ray Diffractometer Spectrometer) and ICP - MS (Inductively Coupled Plasma – Mass Spectrometer) techniques were used for characterization. The leaching kinetics and the activation energies of reactions were calculated depending on the shrinking core model.Keywords: Rare-earth ores, leaching, kinetic studies, shrinking core model

**8:55 AM**

**Selective Extraction of Rare Earth Elements from Rich Iron Ores**: *Leandro Teixeira*[1]; Ruberlan Silva[1]; Angela Avelar[1]; Daniel Majuste[2]; Virgínia Ciminelli[2]; [1]Vale; [2]Universidade Federal de Minas Gerais

Rare Earth Elements (REE) are fundamental for modern life products and green technologies. Supply constrain and the price peak of 2011 boosted intensive research for alternatives for processing and separation. Complex monazite-type, rare earth ores usually contain high acid consumption impurities, such as iron and aluminium, and radioactive thorium in its composition. These impurities are not removed by conventional concentration processes due to fine, micro level association between the REE carrying minerals and the gangue minerals. This work presents a selective process route for REE extraction from iron rich ores. The process involves sulfation by concentrated sulfuric acid addition and pyrohydrolysis at high temperature. A thermodynamic analysis of the main reactions is presented. The experimental results show REE extraction as high as 80% with low iron and thorium extraction (below 1%), and acid consumption lower than 0.250 kg per kg of ore.

**9:20 AM**

**Selective Extraction and Recovery of Rare Earth Metals (REMs) from NdFeB Magnet Grinding Sludge**: *Waraporn Piyawit*[1]; Pisit Sawananusorn[1]; Loeslakkhana Srikhang[1]; Panya Buahombura[1]; Narong Akkarapattanagoon[1]; Tapany Patcharawit[1]; Sakhob Kumkoa[1]; [1]Suranaree University of Technology

Grinding sludge from the sintered neodymium-iron-boron (NdFeB) magnets production process were enriched with critical rare earth elements (neodymium, dysprosium and praseodymium), which can be up to 30% in the magnets. The demand of NdFeB magnets are simultaneously growing. Therefore, rare earths recovered from waste residuals would reduce a demand in primary rare earth element sources. In this study, the feasibility of recycling rare earths through a hydrometallurgical process was investigated. The selective leaching process of Nd from grinding sludge can successfully raise the rare earths concentration to 70%. The necessity of an oxidation pretreatment to improve the selectivity between Nd and Fe will be described.

**9:45 AM Break**

**10:15 AM Invited**

**Recovery of Rare Earths from Phosphoric Acid Production**: *Bruce Moyer*[1]; Derek Brigham[1]; David DePaoli[1]; Steven Sherman[1]; Patrick Zhang[2]; [1]Oak Ridge National Laboratory; [2]Florida Industrial and Phosphate Research Institute

The Critical Materials Institute (CMI), funded by the US Department of Energy, has been developing technologies toward reducing the supply risk for five rare earth elements (REEs). Producing phosphoric acid mainly for fertilizer, the phosphate industry has long been considered a potential secondary source of REEs as by-products. Although the concentration of REEs in phosphate rock is two orders of magnitude lower than that found in high-grade REE ores, the vast quantities of phosphate rock mined each year globally contain enough REEs to satisfy by many times their annual global demand. However, economic recovery of REEs from this source has been extremely challenging not only because of the low grade, but also because the REEs split into various streams during processing. This presentation will report recent results obtained by CMI on the development of methods for REE recovery from these various streams and corresponding evaluation of their feasibility.

**10:40 AM Invited**

**Recovery of Phosphorous and Rare Earth Elements from an Apatite Concentrate**: Mahmood Alemrajabi[1]; *Kerstin Forsberg*[1]; Åke Rasmuson[1]; [1]KTH Kungliga tekniska högskolan

When LKAB processes their iron ores in northern Sweden, they obtain apatite as a by-product. The apatite has been recovered by flotation and the concentrate contains about 0.4 wt% rare earth elements (REE). Both phosphate rock and REE are listed as critical raw materials for the European union. In the present project the recovery of REE within the nitrophosphate process of fertilizer production has been studied. In the first stage the REE are precipitated and separated as a phosphate concentrate. For further purification and individual separation of REE by SX, removal of phosphate to enhance the dissolution of REE in mild acidic solutions is essential. In this study, different processes such as alkaline cracking, thermal treatment, re-precipitation and selective dissolution have been applied to introduce an appropriate intermediate product for further individual REE separation.

**11:05 AM Invited**

**Hydrothermal Modification of Phosphogypsum to Improve Subsequent Recovery of Rare Earths**: *Volha Yahorava*[1]; Eugene Lakay[1]; Jakolien Strauss[1]; Wilma Clark[1]; [1]Mintek

Mintek has developed a non-destructive Resin-in-Leach method for the recovery of Rare Earth Elements (REE) from phosphogypsum (PG) waste dumps. However, PG from different sources was found to be highly variable in terms of REE recovery and physical properties. Development of a pre-treatment process was initiated to improve the robustness of the current REE recovery process in order to render it effective for any type of PG. Extensive research into the mineralogy of REE associations with PG revealed that the majority of REE are trapped inside phosphogypsum clusters which inhibits their recovery. Hydrothermal treatment of PG-containing slurry was found to result in re-crystallisation of gypsum with the release of REE phases encapsulated in it. This process was tested on various PG samples and subsequent REE recoveries improved from 5 to 80%. This approach carries a large potential for unlocking value associated with gypsum dumps worldwide.

**11:30 AM**
**Study of the Deportment of REEs in Ion Adsorption Clays towards the Development of an In-situ Leaching Strategy**: Cody Burcher-Jones[1]; Sfiso Mkhize[1]; Megan Becker[1]; Rahul Ram[2]; *Jochen Petersen*[1]; [1]University of Cape Town; [2]Monash University
The recovery of rare earth elements (REEs) through heap leach/in-situ techniques from so-called ion adsorption clays (IACs) is attractive due to their inherent simplicity. However, the underlying mechanisms of these processes are poorly understood. In this study the deportment of REEs in a typical IAC material has been instigated and was found to concentrate in the phyllo-layers of the clays, especially hallyosite. This understanding informed the testing of a variety of suitable ion-exchange reagents to liberate them. Further, the leaching of REEs from a bed of clay material was investigated over time to understand the rate of transport through the stagnant material. Results indicate that REE release is largely controlled by diffusion through the clay material, while dissolution is rapid. The successful exploitation of this type of IAC deposit would require reasonable perforation of the clay material and potentially a leaching regime of different reagents rather than just one.

## Part C-3: Processing of Critical Metals – Tungsten, Germanium, and Graphite

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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| Tuesday AM | Room: Les Saisons |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Break**

**8:25 AM Introductory Comments**

**8:30 AM**
**Thermodynamics of Tungsten Ores Decomposition Process Options**: *Leiting Shen*[1]; Xiaobin Li[2]; Pekka Taskinen[1]; [1]Aalto University; [2]Central South University
The thermodynamics of tungsten ore decomposition in mineral acid and alkaline solutions were studied. The published thermodynamic data of tungsten minerals were collected and assessed. The Gibbs energies of CaWO4 (–1538.43 kJ/mol), FeWO4 (–1053.91 kJ/mol), MnWO4 (–1206.08 kJ/mol), H2WO4 (–1003.92 kJ/mol), and Na2WO4 (–1455.58 kJ/mol, aq) at 25 °C were adopted in the calculation using HSC software. The results show that CaWO4 is decomposed more readily in Na2CO3 solution than in NaOH, while FeWO4 and MnWO4 are more reactive in NaOH solutions. From a thermodynamic point of view, tungsten ore decomposes easily in acid solutions despite most $\Delta G^{O}_{T}$ increasing slightly with temperature. Oxidizing Fe2+ to Fe3+ in acidic solutions facilitates decomposition of FeWO4, and the reaction of CaWO4 in H2SO4 solution occurs more easily than in other mineral acids, due to the formation of sparsely soluble CaSO4. The results fit well with the experimental data and industrial experience previously reported in the literature.

**8:55 AM**
**Recovery of Tungsten from Spent V2O5-WO3/TiO2 Catalyst**: *Rajesh Kumar Jyothi*[1]; In-Hyeok Choi[2]; Gyeonghye Moon[1]; Jin-Young Lee[1]; [1]Korea Institute of Geoscience and Mineral Resourses (KIGAM); [2]Korea University of Science and Technology (UST)
Currently, spent V2O5-WO3/TiO2 catalyst contributes significant amount of solid wastes following the increasing global demands. V2O5-WO3/TiO2 catalysts have usually consisted of TiO2 anatase as a supporting oxide, vanadium as a catalytic agent and other promoters such as W, Si, Ca. Although V is the main catalytic agent, relatively high content (WO3, 7 – 10 wt.%) of W is usually composed comparing to V (0.5 – 1.5 wt.%). Considering the irreplaceable properties and industrial importance of tungsten, recycling of spent SCR catalyst should be established to utilize as an another secondary source. This paper deals with the process to recover tungsten from spent V2O5-WO3/TiO2 catalyst. Proposed processes in this study are the in order of roasting, decomposition using HCl, ammonia leaching, and crystallization. According to processes in this study, ammonium paratungstate (71 wt%) was obtained as a final product. Total yield rate of W from feedstock was revealed to be 96.3%.

**9:20 AM**
**Scrap Recycling of Tungsten-Based Secondary Material for the Recovery of Tungsten Monocarbide (WC) and Other Valuable Constituents Using an Acid Leach Process: A Preliminary Study**: *Alan Shemi*[1]; Sehliselo Ndlovu[1]; Natasha Sacks[1]; [1]The University of Witwatersrand
Tungsten carbide scrap (WC-Co) is reject material from the production process and industry. Tungsten (W) ores contain about 3wt% WO3 and their W concentrates about 10-75wt% WO3. Tungsten carbide scrap typically contains 40-95wt% W. The high intrinsic value of W and the fact that the least valuable scrap contains more W than an average ore makes tungsten carbide scrap worthy material for re-use. This study investigates the selective dissolution of the cobalt (Co) binder phase, recovery of tungsten monocarbide (WC) and Co using a complexing agent-aided acid leach process. The Co component is selectively leached and dissolved chemically, leaving the WC solid particles intact. The optimal dissolution of the Co binder phase using an inorganic acid in conjunction with an organic complexing agent such as lactic, tartaric or maleic acid is a relatively novel approach with potential of reduced leaching times and possibility of regenerating the unreacted organic acid.

**9:45 AM Break**

**10:15 AM**
**A Chlorine-free Protocol for the Processing of Germanium and Tin**: *Kim Baines*[1]; Jean-Phillip Lumb[2]; Tomislav Friscic[2]; Martin Glavinovic[2]; Michael Krause[1]; [1]Western University; [2]McGill University
As a society, we are increasingly aware of the environmental impact of human activity and consequently, the dire need to develop cleaner technologies and to use our resources more efficiently. I will present our efforts towards the development of alternative methods for the processing of germanium and tin, vital technological materials, which avoid the use of highly corrosive and toxic chlorine-based reagents.

**10:40 AM**
**Solubility of Germanium Dioxide in Commonly Used Acids – Effect of Acid Strength, Temperature and Water Activity**: *Thomas Feldmann*[1]; Somayyeh Nosrati[1]; Frederic Belanger[1]; [1]5N Plus, Inc.
Despite the ubiquity of applications for germanium, there is a lack of practically useful solubility data in acidic solutions. Previous studies were done at ambient temperature and only for commonly used acids (H2SO4, HCl). Hence an investigation of the solubility of GeO2 in different acids was undertaken. Several inorganic and organic acids were studied in the concentration range of 1-11 mol/L and at 23, 40 and 60°C. In the case of H2SO4 and HCl previous data was confirmed. Lower acidity resulted in a higher solubility for Ge at all tested temperatures. Tests done at 40°C and 60°C and low to moderate acidity levels, gave slightly increased solubility values at higher temperatures compared to 23°C. This wasn't the case at higher acidity levels, i.e., the solubility curves at different temperatures converge at high acidity. Lastly, a relationship of water activity and GeO2 solubility in different acid media could be established.

**11:05 AM**
**Research on the Behavior of Germanium in the Leaching Process of Germanium-bearing Zinc Oxide by Sulfuric Acid**: *Tao Jiang*[1]; Zhihong Liu[1]; [1]Central South University
Germanium is widely used in many fields, and the extraction of germanium is very important. The effects of initial sulfuric acid concentration, liquid to solid ratio etc. on the leaching rate of germanium and zinc was investigated in this research, by using germanium bearing Zinc Oxide as raw material and sulfuric acid as leaching agent. The occurrence state of germanium and main elements in leaching residue was studied by EPMA, XRD and chemical analyses. The results illuminate that the leaching rate of germanium and zinc was 91% and 88%, respectively, under the optimal conditions. Wurtzite was the main limiting factor for the leaching rate of zinc, the leaching rate of germanium was limited by insoluble germanium. Furthermore, it is found that some germanium coexisted with Galena in the leaching residue. These results may be helpful for further improving the leaching rate of germanium in germanium bearing Zinc Oxide.

**11:30 AM**
**Natural Graphite Purification through Chlorination in Fluidized Bed Reactor**: *Kamal Adham*[1]; Gregory Bowes[2]; [1]Hatch Ltd.; [2]Northern Graphite Corporation
For use in many existing and emerging applications, the purification of natural graphite is required to achieve +99.9% carbon content with minimum metallic impurities. Currently, the hydrofluoric acid process is used, which carries certain environmental and workplace health and safety impacts. Thermal purification of graphite at temperatures over 2,500 C is a known alternative, however, such high-temperature furnaces are expensive to build and operate. Using chlorine at lower temperatures to purify graphite is also known and patented, but is currently limited to treating solid synthetic graphite shapes in small-scale batch furnaces. Chlorine treatment of natural flake graphite resources can be used commercially, if certain drawbacks are addressed through process improvements that can be helped with the use of fluidized bed reactor technology.

## Part D: Sulfide Flotation – New Developments in Flotation Chemistry

*Program Organizers:* Ronel Kappes, Newmont Mining Corporation; Tarun Bhambhani, Solvay

Tuesday AM
August 28, 2018

Room: Quebec
Location: Westin Ottawa

*Session Chair:* Ronel Kappes, Newmont USA Ltd.

**8:00 AM Introductory Comments**

**8:10 AM Keynote**
**Unlocking the True Value of Chemicals in Mineral Processing**: *D.R. Nagaraj*[1]; R.S. Farinato; Esau Arinaitwe; Tarun Bhambhani; [1]Solvay
As in many other technology areas, research and development in mineral processing chemicals have reached a plateau in contrast to mounting industry challenges related to decline in the ore grade and quality, HSE (health, safety and environmental) aspects, water and energy consumption, economic uncertainty, and rapidly eroding chemistry knowledge and expertise in the industry. This predicament can be attributed largely to a fading recognition of the critical role of chemicals in minerals extraction and their true value. While there is still additional but marginal entitlement that can be identified and achieved, without a step change in behavior, solutions to industry challenges will remain weak, incomplete and incremental, with additional entitlement being left on the table. Success in developing novel technologies and understanding the true value of chemicals will be greatly improved when we can confront the chemical complexity in mineral processing systems, in both the process and valuation sense. This in itself is one of the grand challenges facing the industry. Cooperative development is seen as necessary in order to penetrate through current performance ceilings, a situation which is increasingly important given the realities of having to produce minerals and metals economically in spite of declining ore grades and the need to fulfill HSE commitments. Unlocking the true value of mineral processing chemicals thus requires a sensible scheme for monetizing their benefits in the context of operational and HSE factors before, during and after their use. A critical overview, from an industry perspective, will be provided highlighting recent advances, current and emerging challenges, and some directions to address these challenges

**8:55 AM**
**Laboratory Study on Impact of Bubble Size Distribution and Frother Strength on Coarse and Fine Particle Flotation.**: *Frank Cappuccitti*[1]; [1]Flotec,LLC
Flotation kinetic theory which includes bubble particle collision, attachment and detachment implies that certain bubble size distributions have different effects on the flotation rates of coarse or fine particles. Stated differently, big bubbles favor coarse and small bubbles favor fine particle recovery within normal particle size ranges. Current theorizes of how frothers of different strengths function by changing the thickness of the bound water membranes around the bubbles also implies that strong frothers (thick membranes) favor coarse and weak frothers (thin membranes) favor fine particle recovery. Both lab and pilot plant tests were conducted to examine these affects and to determine if one of these mechanisms was predominant. The results contradicted the hypothesis for bubble size distribution in that that all particles sizes float best at the CCC of frothers (smallest bubble size). The results did support the idea that water member thickness does in fact impact particle size recovery.

**9:20 AM**
**Orfom® D-Series Reagents in Copper/Molybdenum Separation Operations**: *Chad Brown*[1]; Debbie Laney[1]; David Miller[1]; Benigno Ramos[1]; [1]Chevron Phillips Chemical Company LP
A majority of the worldwide copper/molybdenum separation operations utilize sodium hydrogen sulfide (NaSH) as the copper and iron sulfide depressant. While NaSH yields acceptable performance and resulting molybdenum grade, it continually provides challenges due to handling, potential exposure to hazardous gas evolution if used improperly, repulsive odor, and high consumption rates for effective copper sulfide depression. Chevron Phillips Chemical Company LP has developed and commercialized an economically viable reagent solution as a NaSH replacement in Cu/Mo separation operations. Relative to NaSH, Orfom® D-Series reagents achieve high molybdenum grade and recovery at significantly lower treatment rates, lower pH, improved handling, safety and storage profile, and do not require inert (nitrogen) gas. This paper will provide data from laboratory tests, plant scale trials, as well as commercial details. Data presented will describe process variables including dosage, conditioning time, addition points, and pH when using Orfom® D-Series reagents as a NaSH replacement.

**9:45 AM Break**

**10:15 AM**
**Mixed Collectors in Sulphide Flotation – Valuable Performance Gains**: *Norman Lotter*[1]; Dee Bradshaw[2]; [1]Flowsheets Inc.; [2]Minerals to Metals Programme
The formulation and use of mixed collectors in flotation has a published history going back to 1958. Correctly formulated for a specific application, performance gains of between 1 and 4% paymetal recovery as well as gains in concentrate grade of 10-20% relative are typical. A new theory on the mechanism of the synergy in this system was proposed in 2010. Recently, the semiconductor and electrochemical theories were added, strengthening the understanding and predictability of this system. In the case of mixtures of minerals, the mixed collector system delivers significant value by presenting a mixed set of collector radicals and dimers in a common Eh and pH domain for overall performance. Case studies are reviewed.

**10:40 AM**
**Challenges in Characterization and Selection of Flotation Frothers**: *Esau Arinaitwe*[1]; D. R. Nagaraj[1]; Tarun Bhambhani[1]; Raymond[1]; [1]Solvay
The most extensively used methods and approaches for characterizing and selecting frothers for plant application are based on measurements in clean water in the absence of solids and without consideration of physicochemical factors that are known to influence the properties and behavior of practical flotation froths. These factors include aquatic chemistry, collectors, modifiers, particle shape and size, and pH. It is thus not clear how fundamental measurements in 2-phase systems can be linked to, or can predict, plant metallurgical outcome. In this paper, a critical evaluation of the literature has been conducted in order to highlight the important role and relevance of several factors in characterizing frothers and froth zone properties. We also report preliminary results of a “systems approach” study designed to probe ways in which these factors a) influence frothing and bubble size in 2- and 3-phase systems, and b) confound correlation of fundamental measurements with flotation outcome.

**11:05 AM**
**The Role of Soluble Sodium Silicate for Enhancing Flotation Selectivity of Sulphides towards Grade and Recovery Improvements: Example from a Cu-sulphide Ore**: Liuyin Xia[1]; *Brian Hart*[1]; Vicky Sidorkiewicz[2]; [1]Western University; [2]National Silicates
Sodium silicates often known as “water glass” are one of the most widely used industrial chemicals. Silicate functions as a non-sulphide gangue mineral dispersant, depressant and modifier reagent in grinding and flotation operations. It is believed that soluble Na-silicate promotes selectivity of value added sulphides against silicates, resulting in both grade and recovery improvement. This paper seeks to link improved grade/recovery to the interaction characteristics of minerals and the sodium silicate. A systematic study was performed with individual mineral species, an artificially designed model ore and ore from a copper metallurgical operation. The function of sodium silicate was evaluated in the context of colloidal chemistry and mineral surface chemistry. Measurement of pulp rheology, settling rates and mineral zeta potential identified that silicate works as a dispersant. The dispersion is accomplished by increasing a mineral’s net surface charge, resulting in a mineral variable change in viscosity and slower particle sedimentation rates.

**11:30 AM**
**On the Unique Behaviour of Cellulose-based Frothers for the Treatment of Sulfide Tailings**: Ted Nuorivaara[1]; *Rodrigo Serna*[1]; [1]Aalto University
This study shows for the first time a systematic analysis on the use of cellulose-based surfactants for the regeneration of tailings from copper processing plants. Laboratory-scale batch flotation tests were conducted on samples obtained from a tailings pond using hydroxypropylmethyl cellulose (HPMC) as frother. The mineral flotation performance of HPMC was compared with a commercial frothing agent, namely NasFroth240 (NF240).The preliminary results show that a significant mass pull of minerals is obtained when HPMC is used, even without the addition of surface-modifying chemicals, whereas negligible amounts of mineral were reported to the concentrate when only NF240 was used. Although the enrichment of Cu from tailings was challenging, the mixture of HPMC and NF240 resulted in a comparatively higher flotation efficiency with Cu grades close to those suitable for re-processing. Finally, the use of HPMC resulted in unexpectedly higher Cu flotation kinetics than those obtained with the commercial frother.

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## Hydrometallurgy Keynote – Tuesday

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| Tuesday PM | Room: Confederation I |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**2:00 PM Introductory Comments**

**2:05 PM Keynote**
**The Evolution of Cobalt–Nickel Separation Technologies: Fifty Years of Solvent Extraction and Ion Exchange**
: *Kathryn Sole*[1]; [1]Kathryn C. Sole Consulting
The close proximity of cobalt and nickel on the Periodic Table and their frequent occurrence together in nature means that their separation in primary hydrometallurgical flowsheets is not only often necessary, but requires the use of innovative chemistry to achieve high selectivity. Today, increasingly stringent demands for the high-purity cobalt and nickel salts required for battery applications in consumer electronics, electric vehicles, and solar applications are again challenging the state of the art. The evolution of cobalt–nickel separations is traced from the basic precipitation technologies employed in 1960s, through commissioning of the first cobalt solvent-extraction plant in South Africa in 1974, to the commercialisation of organophosphinic-acid extractants (which provided a step-change improvement in selectivity) and their eventual widespread use in the 1980s and ’90s. This was followed later by their sulphur analogue, which enabled new possibilities for laterite processing in the new millennium. Separations in chloride media, which take advantage of the different speciation chemistries, and nickel extraction by oximes in ammoniacal systems are also discussed. More recently, chelating and solvent-impregnated resins have added further dimensions to the possibilities for flowsheet design and enabled higher purity products to be attained from both primary and secondary sources. Selected case studies and flowsheets are described.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 10 Process Fundamentals - Minor Elements Modelling

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

Tuesday PM
August 28, 2018

Room: Les Saisons
Sponsored by Hatch
Location: Westin Ottawa

*Session Chair:* Mark Schlesinger, Missouri University of Science and Technology

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**4:10 PM**

**Fundamental Process Equilibria of Base and Trace Elements in the DON Smelting of Various Nickel Concentrates**: *Pekka Taskinen*[1]; Katri Avarmaa[1]; Hannu Johto[2]; Petri Latostenmaa[2]; [1]Aalto University; [2]Boliden Harjavalta

The converter-less nickel matte smelting technology (DON) adopted more than 20 years ago in Harjavalta smelter has been since that applied successfully to the processing of large number of nickel sulphide concentrates of variable Ni-to-Cu ratios and MgO contents. The operational point of the technology is far from the conventional primary smelting of nickel in the smelting-converting route. Therefore, a careful scouting of the distribution equilibria of base and trace elements in the smelting conditions of DON process has been conducted, in order to obtain quantitative information about the equilibria and thermodynamic properties of the nickel mattes at low iron concentrations, less than 10 wt% [Fe] in matte. The series of investigations has included novel experimental and analytical techniques for increasing the reliability and sensitivity of the phase equilibria as well as the element distribution observations carried out in typical high-grade nickel matte smelting conditions.

**4:35 PM Invited**

**Challenges and Opportunities of a Lead Smelting Process for Complex Feed Mixture**: *Christoph Zschiesche*[1]; Mehmet Ayhan[1]; Jürgen Antrekowitsch[2]; [1]Aurubis AG; [2]Montanuniversität Leoben

Managing complex material streams within a lead smelting / reduction process has a long history at Aurubis. Since the technology changed in 1990 Aurubis operates an electric furnace at the Hamburg site. This process links the copper and the lead metallurgy and provides the requirement to process complex raw materials on the primary and a broad range of intermediates on the secondary site as well. Due to recent developments, more complexity in raw material leads to varying element deportments in intermediates which have to be managed. This requires a frequent health check of the current available capabilities and installed processes.This paper describes the outcomes of the Aurubis lead smelting health check, with special emphasis to the behavior of minor elements in the lead smelting process.

**5:00 PM**

**Application of MPE model to Nickel Smelting**: *Chunlin Chen*[1]; [1]CSIRO

Arsenic is toxic and can be found in many base metal ores, usually in combination with sulphur and metals. The smelters are required to have a better management of arsenic deportment for the control of product quality and minimize of the environment impact. The Multi-Phase Equilibrium (MPE) is a thermodynamic package developed by CSIRO, which is capable of modeling the deportment of major and minor elements including arsenic during base metal smelting. In this paper the application of the MPE model in modelling the nickel smelting process was presented. The modelling results on the majors and minors are compared with the plant data. The deportment behavior of arsenic in nickel smelting are analyzed and compared with that of copper smelting. These results should be able to assist process metallurgists in understanding the low arsenic removal during nickel smelting and exploring the potential practices for improving arsenic removal.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 7 Arsenic

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

Tuesday PM
August 28, 2018

Room: Governor General II
Sponsored by Hatch
Location: Westin Ottawa

*Session Chair:* Patrick Taylor, Colorado School of Mines

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**2:00 PM Invited**

**Arsenic Removal and Precipitation from Enargite with Sodium Carbonate Using Partial Oxidized Roasting**: *Patrick Taylor*[1]; Teuku Putra[1]; [1]Colorado School of Mines

Arsenic-bearing enargite concentrates have become more prevalent in the mining industry. Most smelters have limits on the arsenic content that they will accept. This study investigated a new method of removing arsenic from enargite containing copper concentrates through a pyrometallurgical method. The proposed method was roasting a mixture of sodium carbonate (Na2CO3) and enargite containing copper concentrates to convert the arsenic to a water soluble sodium arsenate while partially oxidizing the sulfur minerals. The roast calcine was then water leached to remove the soluble sodium arsenate (Na3AsO4) and the water leached arsenic was precipitated using ferric sulfate (Fe2(SO4)3). The results showed successful arsenic removal. The amount of sulfur retained was 50% during the partial oxidation roasting. The precipitation resulted as a stable solid ferric arsenate (FeAsO4) either scorodite or arsenic-bearing ferrihydrite compound. Methods to regenerate the sodium carbonate from the precipitation process solutions are proposed.

**2:25 PM**

**Predominance and Roaster Diagrams for the Cu-As-S-O System**: *Stanley Howard*[1]; Sadegh Safarzadeh[1]; Jan Miller[2]; [1]South Dakota School Mines and Technology; [2]University of Utah

A three-dimensional predominance volume diagram (PVD) for the Cu-As-S-O system is constructed at 673 K. Roaster diagrams that follow from the PVD, showing percent of O2, SO2, or As4O6 in the roast gas as a function of temperature, are presented as a practical tool for visualizing the phase relationships. In the Cu-As-S-O system, these relationships offer a convenient way to understand the roasting of enargite (Cu3AsS4) and tennantite (Cu12As4S13): the most important copper sulfosalts. Experimental roasting results of enargite samples are related to the theoretical diagrams.

**3:15 PM Invited**

**The Volatilization and Fixation of Arsenic**: *Corby Anderson*[1]; Larry Twidwell; [1]Colorado School of Mines

The pyrometallurgical volatilization of arsenic is an established industrial technology. This paper will survey applied techniques for this and offer the results of an optimization study. Further, once volatilized, the arsenic normally requires stabilization. A survey of these technologies will also be provided.

**2:50 PM Invited**

**Influence of Arsenic on the Chemical Wear of Magnesia-chromite Refractories in Copper Smelting Furnaces**: *Katja Reinharter*[1]; Dean Gregurek[1]; Jürgen Schmidl[1]; Alfred Spanring[1]; Christian Majcenovic[1]; [1]RHI Magnesita

Arsenic can be found in different sulfidic copper concentrates and residues, which since several years are commonly used in the copper metallurgy, as the "arsenic-free" resources are getting rare. Due to the high toxicity the removal of arsenic in the copper smelting process is a very important topic. The typical chemical slag and sulfur attack on the refractory material is getting enforced by the presence of arsenic. This work deals with post-mortem investigations of a magnesia-chromite brick and castable used in copper smelting furnaces showing an additional and increased chemical attack by arsenic. The knowledge on the wear behaviour is not only based on a detailed chemical and mineralogical characterization, but also on thermochemical FactSageTM calculations, which are carried out on provided post-mortem samples. Post-mortem investigations on used refractory materials represent an important prerequisite for the product development, as well as for special engineered lining concepts to support our customers.

**3:40 PM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 8 Process Control and Modelling I

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Tuesday PM | Room: Les Saisons<br>Sponsored by Hatch |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Takahiko Okura, Ehime University

**2:00 PM**

**Improved Copper Smelter and Converter Productivity through the Use of a Novel High-grade Feed**: *Evgueni Jak*[1]; Denis Shishin[1]; William Hawker[1]; James Vaughan[1]; Peter Hayes[1]; [1]University of Queensland

Copper sulphide processing technologies face increasing pressures associated with decreasing concentrate grade leading to increasing thermal inefficiency and lower productivity. Impurity concentrations are on average increasing, creating potential environmental risk and additional treatment costs. In copper flash smelters dust, partially oxidised materials and fume formed from the condensation of volatile impurities, is routinely recycled by combining it with the feed material. In the converting stage the heat balance is maintained by charging anode reverts and other inert materials. In both cases the thermal energy available from sulphide oxidation is not fully utilised or optimised. The productivities of both smelter and converter stages can be potentially increased through the use of a low-iron, low-impurity precipitated copper product. The calculations are carried out for fayalite and calcium ferrite converter slags using an optimised FactSage thermodynamic database. Significant increases in smelter and converter productivity are predicted for a range of technologies.

**2:25 PM**

**Study on the Temperature Distribution of Copper Oxygen Bottom Blowing Smelting Furnace**: *Shuyang Yan*[1]; Xueyi Guo[1]; [1]Central South University

The smelting temperature is an important factor in copper oxygen bottom blowing smelting process. In this work, the distribution of temperature and the calculation of heat balance in copper smelting process are studied by using Fluent software and coupling an equivalent solid heat source. The effects of gas flow rate, temperature of oxygen-enriched air and bath depth on the distribution of temperature are discussed. The results show that, there is a higher temperature zone in the action area of oxygen lance and the flue outlet. As gas flow rate increases, the smelting temperature decreases because the smelting flue gas volume increases and takes away more heat at a certain exothermic rate. The lower temperature zone of oxygen lance expands as the temperature of oxygen-enriched air decreases which is benefit for protection of oxygen lance. And the temperature decreases with the bath depth decreasing.

**2:50 PM**

**Semi-discrete Dynamics and Simulation of Peirce-Smith Converting**: *Alessandro Navarra*[1]; Gauthier Lemoine[2]; Nadim Zaroubi[2]; Tanai Marin[3]; [1]Universidad Católica del Norte; [2]McGill University; [3]M4Dynamics

Peirce-Smith converting (PSC) is applied for roughly 70% of primary copper and 50% of primary nickel production. PSC cycles produce batches of iron-free sulfide matte (or blister copper, in the case of copper smelters), that are subject to further processing. However, the number of cycles that can be performed simultaneously is limited by the offgas handling system. Moreover, PSC suffers from variation in the yield and duration of the cycles. This variation is managed by conventional smelter designs, in which the upstream smelting capacity exceeds the nominal converting capacity; PSC is thus a major bottleneck in conventional nickel and copper smelters. Stabilization and standardization of PSC operations can therefore increase smelter throughput. The current paper presents a discrete event simulation (DES) framework to assist in smelter debottlenecking. It features random number generation to represent cycle variability, and time-adaptive finite differences to represent thermochemical complexity. Sample computations are presented.

**3:15 PM Invited**

**Development of Continuous Radar Level Measurement for Improved Furnace Feed Control**: *Rodney Hundermark*[1]; Quintin van Rooyen[1]; Paul van Manen[1]; Chris Steyn[1]; Afshin Sadri[2]; David Chataway[2]; [1]Anglo American; [2]Hatch

At Anglo American Platinum's Polokwane Smelter radar instruments are being used to provide continuous level measurement in the six-in-line electric furnace used for smelting of nickel-copper concentrates containing PGMs. The radar instruments are installed directly on the furnace roof, and a mechanical system has been designed to protect them from radiation, elevated freeboard temperatures and pressures. Signal validation criteria have been implemented to ensure that proper level measurements are being used by the PLC system. The level feedback from the radars has provided for improved understanding of the furnace behaviour with respect to overall furnace level control, individual feeding events, global feed rates, feed distribution and bath disturbances. In combination with a dynamic mass balance for continuous calculation of liquid level in the furnace, the radar measurements have enabled more precise feedback control of the concentrate blacktop depth. In turn this has yielded improvements in furnace stability and efficiency.

**3:40 PM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 9 Metal Recovery

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

Tuesday PM
Room: Governor General II
Sponsored by Hatch
August 28, 2018
Location: Westin Ottawa

*Session Chair:* Taro Aichi, Dowa Metals and Mining Co., Ltd.

**4:10 PM Invited**

**Development of a Recycling Concept for Jarosite with Special Emphasis on the Behaviour of Indium and Silver**: *Stefan Steinlechner*[1]; Stefan Wegscheider[1]; Juergen Antrekowitsch[1]; [1]Montanuniversitaet Leoben

Although the industrial residue Jarosite, generated in course of the primary zinc production, contains various valuable metals, like zinc, lead, silver and indium it is dumped on open tailing dumps in most of the cases. The development of appropriate metallurgical processes for a recycling establishes on the one hand possibilities to reduce the amount of hazardous wastes dumped and on the other hand to open up new chances for a utilization as secondary resource for critical metals such as indium and zinc. In this context a pyrometallurgical process is investigated which recovers zinc, indium and silver as a dust product and the iron as an alloy. This can be realized by a combination with a second residue, the electric arc furnace dust. Therefore the paper describes the investigated process development and the achieved recovery rates for the main metals.

**4:35 PM Invited**

**Research on Recovery of Valuable Metals in Waste Acid from Copper Smelting Flue Gas Acid-making and Reduction and Harmless Treatment of Solid Wastes**: *Zhen Bao*[1]; Xinming Wu[1]; Yan Wen[1]; [1]Jinlong Copper Co., Ltd.

For the impurities in the copper smelting waste acid, SO3, Cu, As, Pb, Zn, Re and other elements enter the waste acid and generate a lot of arsenic residue, gypsum and neutralized residue, in which Cu, Zn and Re metals have not been recycled. Cu, Re and As are separated by step-wise vulcanization. The valuable metals of Cu, Zn and Re are recovered by separating zinc through pH adjustment. Calcium injection is conducted for boiler for reducing the amount of SO3. The residues generated in the form of arsenate and hydroxide will be returned together with arsenic filter cake for smelting treatment so as to achieve the purpose of valuable metal recycling and solid waste reduction and harmless treatment.

**5:00 PM Invited**

**Challenges and Possibilities of Zinc Residue Treatment**: *Justin Salminen*[1]; Minna Rämä[2]; Ari Jokilaakso[2]; Jens Nyberg[3]; Pekka Taskinen[2]; [1]Boliden Kokkola; [2]Aalto University; [3]Boliden Smelters

The majority of zinc produced in the World is by roast-leach-electrowinning route. Every ton of zinc produced results in 0.5-0.9 ton of dry residue, which is typically deposited at the site. Recently, some operators have been taken new industrial processes into use for thermally treating the iron residues. This can be expected to improve the overall recovery of the metals, and to minimize landfilled waste amounts, thus improving the resource efficiency. In this work thermal studies using have been carried out with industrial jarosite samples. In addition thermochemical simulation model has been established using MTDATA software. The model shows conditions for thermal degradation of jarosite, formation of stable slag and possibilities of fuming volatile metals. This work outlines challenges as well as the options of a thermal treatment and valorization of metals from complex iron and sulphur residue.

**5:25 PM**

**Theoretical Considerations in the Separation of Co and Ni from their Arsenic-bearing Sulfosalts: Ni-As-S-O and Co-As-S-O Systems**: *Stanley Howard*[1]; Sadegh Safarzadeh[1]; [1]South Dakota School of Mines and Technology

Three-dimensional predominance volume diagrams (PVDs) for the Ni-As-S-O and Co-As-S-O systems are constructed at selected temperatures and roaster diagrams that follow from them, showing percent of O2, SO2, or As4O6 in the roast gas as a function of temperature, are presented as a practical tool for visualizing the phase relationships. These relationships offer a convenient way visualize separation strategies through roasting. The isobaric surfaces in the PVDs are also constructed to assist in determining probable roasting paths for the arsenic-bearing sulfosalts.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 10 Flow Modelling II

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

Tuesday PM
Room: Ontario
August 28, 2018
Location: Westin Ottawa

*Session Chair:* Roderick Guthrie, McGill University

**2:00 PM**

**On the Effect of Liquid Viscosity, Density and Surface Tension on the Hydrodynamics of Top Submerged Lance Injections Systems**: *Daniele Obiso*[1]; Sebastian Kriebitzsch[1]; Michael Stelter[1]; Markus Reuter[2]; [1]VIRTUHCON, TU Bergakademie Freiberg; [2]HZDR

The present work focuses the hydrodynamic behavior of Top-Submerged-Lance gas injection in cold, non reactive liquids, using Computational Fluid Dynamics. In the last decades the injection of process gas through a TSL has imposed its role on the non-ferrous metallurgy and today dozens of furnaces are successfully operated worldwide. The aim of this investigation is to underline the effect of liquid density, viscosity and surface tension on the hydrodynamics of the system. For that, the commercial solver ANSYS Fluent\174 together with the VOF model was used to resolve the gas-liquid interface in the multiphase flow. Various aspects of the flow were studied such as the gas-liquid contact area, the mixing process inside the liquid phase, the liquid splashing and the bubble regime. The results offer a broader overview on the TSL gas injection and provide a basis for the development of a novel method for a proper scaling procedure.

**2:25 PM**

**Verification of Permeability and Forchheimer Drag Coefficients of $Al_2O_3$ Ceramic Foam Filters (CFF) at High and Low Flow Rates**: *Massoud Hassanabadi*[1]; Mark Kennedy[1]; Shahid Akhtar[2]; Ragnhild Aune[1]; [1]Norwegian University of Science and Technology (NTNU); [2]Hydro Aluminium, Karmøy Primary Production, Håvik

Filtration using Ceramic Foam Filters (CFF) is the most applied method to separate inclusions from molten aluminium. In the present work, the first and second order Forchheimer coefficients for 50 mm thick commercial $Al_2O_3$-based CFFs, of grades 30, 50, 65 and 80, have been calculated from pressure drop experiments using high (0.07-0.2 $m \cdot s^{-1}$) and low (0.001-0.01 $m \cdot s^{-1}$) flow rates of water. A 2D axial symmetric CFD model has been developed, using COMSOL® Multiphysics 5.3, to verify the experimental results. The values obtained from the model for the permeability and the Forchheimer drag coefficients proved to be in good agreement with the experimentally obtained data, i.e. <±1 pct. for the high flow rates, and <±5 pct. for the low. All calculations where based on the mass flow rate of water through the system. The point of deviation from first order to second order flow behavior is discussed.

**2:50 PM**
**Computational Modeling of a Secondary Lead Reverberatory Furnace: Effect of Burden Geometry**: *Alexandra Anderson*[1]; Joseph Grogan[1]; Greg Bogin[2]; Patrick Taylor[2]; [1]Gopher Resource; [2]Colorado School of Mines
A computational fluid dynamic (CFD) model has been developed using ANSYS Fluent 17.0 to help identify areas of high wear within the refractory lining of a secondary lead reverberatory furnace. Once a base case simulation was validated using data from an operational furnace, areas of potentially high refractory wear were determined through the calculation of the temperature and velocity distributions within the furnace and on the hot face of the refractory lining. The CFD model was used to assess whether the predicted areas of high refractory wear could be minimized through changes burden geometry. The results showed that shape of the burden geometry greatly affected the overall flow patterns and heat transfer within the furnace.

**3:15 PM**
**CFD Modelling of Sonic and Transonic Gas Injection into Liquid Metals**: *Sander Arnout*[1]; Els Nagels[1]; Vladimir Jovanovic[1]; Bart Vandensande[1]; [1]InsPyro
Many pyrometallurgical processes induce gas-liquid interactions by injection, and optimizing their layout requires a proper understanding of the flow parameters, such as gas residence time and induced mixing. Sonic and transonic injection can considerably increase the interaction, as at these high injection speeds, jet formation is expected even in the heaviest liquids. The first plant trials of sonic and transonic gas injection date back as far as the late 70s. Unfortunately, due to the high temperatures involved, experimental observations are limited. CFD (Computational Fluid dynamics) allows to study the complex reaction behavior, flow and heat transfer associated with jetting. This paper will discuss the current state-of-the-art and the importance of taking into account the entrainment of liquid into the gas stream. Next, the latest efforts of jet modelling will be discussed. This model focuses on correctly reproducing the velocity and the spreading of the plume compared to experimental observations.

**3:40 PM Break**

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 11 Process Modelling (Thermodynamics, CFD)

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Tuesday PM | Room: Governor General III |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Hae Geon Lee, POSTECH

**4:10 PM**
**Determination of Thermodynamic Activities from Experimental Data in the Liquid Region of Ternary Systems**: *Lars Klemet Jakobsson*[1]; [1]Elkem Technology
Gibbs-Duhem integration is frequently used to determine activities from experimental data. Usually, the same technique is applied both in binary and ternary systems. That is, in ternary systems, the integration is done along quasi-binary paths. Integration along quasi-binary paths require one initial point for each quasi-binary path. This does not ensure thermodynamic self-consistency across the entire liquid region of the ternary system if the initial points are uncertain. The Gibbs-Duhem equation of a ternary system together with experimental data for the entire liquid region will, given one initial point with known activity, define the activity of the entire liquid region. This work shows how to use the Gibbs-Duhem equation to obtain activities across the liquid region of a ternary system from a single known initial point. This method will also reveal if the experimental data for the liquid region and the known location of the liquidus line are not self-consistent.

**4:35 PM**
**Application of Computing Approach to Model Ferrous/Non-ferrous Extraction Processes Employing FactSage/METSIM**: *Ajay Shukla*[1]; [1]Indian Institute of Technology
The iron and steelmaking as well non-ferrous extraction processes are non-equilibrium in nature which can be represented by flow sheet with a large number of interconnected unit processes, few of them can be are in thermodynamic equilibrium and can be calculated using free energy minimization approach. The multiphase multicomponent system of slag-metal and gas in these high temperature processes can be solved by coupled reaction theory where thermodynamic equilibrium exists at the interface and controlled by mass transfer across the interface of various phases. In this presentation, case study based problems related to thermodynamic/kinetics based modeling using FactSage/MESIM have been demonstrated for BOF Steelmaking, RH degassing process, Ladle metallurgy process and couple of copper smelting process (IsaSmelt and Pierce Smith converter) and some of them are also validated using industrial data from steel plants as well as copper smelting units in India.

**5:00 PM Invited**
**Development of a Thermodynamic Database for the Multicomponent PbO-"Cu2O"-FeO-Fe2O3-ZnO-CaO-SiO2 System for Pyrometallurgical Smelting and Recycling**: *Maksym Shevchenko*[1]; Peter Hayes[1]; Evgueni Jak[1]; [1]The University of Queensland
Integrated experimental and modelling research program on the phase equilibria and development of thermodynamic databases of the lead and copper metallurgical gas / slag-matte-metal-solids systems (PbO-"Cu2O"-FeO-Fe2O3-ZnO-CaO-SiO2) is undertaken to support improvements in the pyrometallurgical smelting and recycling processes. This is the first systematic investigation of phase equilibria of slag systems in equilibrium with Pb metal, providing information for systems where copper coexists in slag with lead or zinc as major components. Experimental studies involve high-temperature equilibration of synthetic samples; rapid quenching; and measurement of the compositions of equilibrium phases using electron probe X-ray microanalysis (EPMA). FactSage-based thermodynamic modelling is integrated with experimental research. Initial thermodynamic assessments are used to identify priorities for experiments, planned to provide specific data for thermodynamic optimisation.Significant improvement in the accuracy of the phase equilibria description is achieved. Database continuous improvement and extension to include new elements are targeted. Example of industrial application is given.

**5:25 PM**
**Knowledge-based Industry 4.0 Solution for Metallurgical Operations**: *Els Nagels*[1]; Sander Arnout[1]; [1]InsPyro
The industry 4.0 evolution aims to automate virtual plant solutions to reach new levels of operational excellence. Real plant performance compared to a virtual plant performance including virtual instruments offers the possibility to capture and automate process knowledge. In this paper it is illustrated that pyrometallurgical operations already have been using process modelling for years to obtain better operational results. The challenge to be tackled is the accessibility of the virtual plant from the developer, typically an R&D engineer, towards all levels within an organization. An example of a simple smelting operation will illustrate the different steps to take from capturing data to defining the user reports for operators, plant managers and purchasing departments. They all need to take decisions on the same process, so it is only logic that they rely on the same knowledge basis.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 12 Gas/Solid II

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Tuesday PM | Room: Ontario |
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*Session Chairs:* Ron Schonewille, Glencore; Mika Muinonen, Dalhousie University

**4:10 PM**
**Reduction in GHG Emissions of Steel Production by Direct Injection of Renewable Biocarbon**: *Ka Wing NG*[1]; Louis Giroux[1]; Ted Todoschuk[1]; [1]Natural Resource Canada

Integrated steel production is a GHG intensive process. In order to reduce the environmental impact of the industry, feasibility of substituting fossil fuel by renewable biocarbon is investigated. It was estimated that replacing of pulverized coal injection (PCI) by biocarbon in blast furnace ironmaking has the potential to reduce direct CO2 emission by 25%. Careful selection of suitable solid biocarbon is essential to achieve the desirable GHG reduction while maintaining the productivity of the process. A systematic evaluation of biomass pyrolysis technology was conduction and the performance of resultant biocarbon in blast furnace ironmaking was evaluated. A techno-economic model was developed to assist biocarbon industry to produce suitable product for steel industry. It also facilitate the steel industry in selection of suitable solid biocarbon for replacement of PCI.

**4:35 PM**
**Preparation of Ferronickel from Nickel Laterite Ore via Semi-molten Reduction Followed by Magnetic Separation**: Xueming Lv[1]; Lunwei Wang[1]; Zhixiong You[1]; Jie Dang[1]; Xuewei Lv[1]; Guibao Qiu[1]; *Chenguang Bai*[1]; [1]Chongqing University

The process of rotary kiln-electric furnace (RKEF) is the main method for producing ferronickel from nickel laterite ore. However, this process was characterized by energy intensive as it involves several high temperature steps. Therefore, a novel process was proposed to directly produce ferronickel from nickel laterite ore by semi-molten reduction, which was expected to be realized in rotary hearth furnace (RHF). The RHF process was able to shorten the flow sheet, decrease the reaction temperature as well as reduce energy consumption. In this study, the influence of roasting parameters on reduction of nickel laterite ore was firstly investigated. Then, the high temperature wettability of refractory materials by the molten slag was also studied with the sessile drop method. The results revealed that qualified ferronickel product can be obtained via semi-molten reduction followed by magnetic separation, while the erosion effect of molten slag on refractory materials need further consideration.

**5:00 PM**
**Hydrogen Assisted Magnesium Reduction of TiO2**: *Zhigang Fang*[1]; Yang Xia[1]; Ying Zhang[1]; Hyrum Lefler[1]; Pei Sun[1]; [1]University of Utah

Titanium metal production has been a focus of the research community around the world for several decades. The strong affinity of titanium to oxygen makes the conventional Ti metal production by either the Kroll or the Hunter process energy-intensive. A new approach is designed to prepare high-purity Ti metal powder from commercial purified TiO2. Pure TiO2 is subjected to Mg reduction, followed by a de-oxygenation process using Mg. Both the Mg reduction and the deoxygenation processes are carried out in hydrogen atmosphere. It can be shown that hydrogen destabilizes Ti-O system and enables Mg to reduce oxygen content in Ti to extremely low levels. The processes are also conducted in molten salt medium. It has been successfully demonstrated that this two-step hydrogen assisted Mg reduction process, i.e. the reduction plus deoxygenation, can produce low oxygen Ti metal powder with oxygen content as low as a few hundred ppm.

**5:25 PM**
**Thermodynamic Modeling of the Solid State Carbothermic Reduction of Chromite Ore**: Christopher Pickles[1]; *Omid Marzoughi*[1]; [1]Queen's University

Chromium has a wide range of applications, including as an alloy addition in various steels and also as a corrosion resistance coating. Carbothermal reduction of chromite ore (FeCr2O4) in a submerged arc furnace is an important industrial process for extracting chromium, but the energy consumption is excessive. It is suggested that one area for future research is the low temperature carbothermic solid state reduction of chromite to produce an intermediate product, which can subsequently be upgraded to ferrochromium. In this regard, a thermodynamic model has been developed to investigate this process and the effects of temperature, carbon additions and ore composition on the recovery of chromium and the grade of the ferrochromium, have been studied. Further development of the model may allow it to be applied to the simulation of other processes for the recovery of chromium from chromite ores.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 9 Modelling Fundamentals - Thermodynamic and Other Physiochemical Properties Modelling

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Tuesday PM | Room: Governor General III |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chairs:* Sergei Decterov, École Polytechnique de Montréal; Evgueni Jak, Pyrosearch, The University of Queensland

**2:00 PM Invited**
**Thermodynamic Modeling of Liquid Phases for Metallurgical Applications**: *Sergei Decterov*[1]; [1]École Polytechnique de Montréal

Several liquid phases of different nature can form in various metallurgical processes. Among such liquids are molten oxide (slag), molten sulfide (matte), molten salt, metallic liquid and a mixture of impure arsenides and antimonides of iron, cobalt, nickel, or copper (speiss). The mutual solubility of these liquids under industrial conditions can be fairly small, e.g. slag – matte, or substantial, for example between metal and speiss or between matte and molten alkaline salts. Furthermore, these liquids can be completely miscible under certain conditions, which are normally far from industrial practice. Accurate thermodynamic modeling of the liquid phases is important for understanding and simulation of various metallurgical processes, but describing all these liquids as one solution phase with multiple miscibility gaps is too complex and not practical. The complex approach to thermodynamic modeling of various liquids and corresponding challenges will be discussed.

**2:25 PM**
**The FactSage Thermodynamic Computer Package - Recent Developments**: *Christopher Bale*[1]; Arthur Pelton[1]; Gunnar Eriksson[2]; [1]Ecole Polytechnique; [2]GTT-Technologies

The FactSage computer package consists of calculation and manipulation modules with access to databases of thermodynamic and physico-chemical properties of thousands of compounds and hundreds of multicomponent solutions of metals, oxides, salts, sulfides, etc. This paper presents a summary of recent developments in the FactSage software and databases for calculating complex chemical and phase equilibria of interest in metallurgy and materials science.

**2:50 PM Invited**
**Thermodynamics and Kinetics as Key-sciences for Understanding and Controlling Steelmaking Operations: A Constant Preoccupation for ArcelorMittal Global R&D**: *Jean Lehmann*[1]; Fayssal Oudich[1]; Pascal Gardin[1]; [1]ArcelorMittal

Thermodynamics remains one of the basic sciences for understanding and controlling steelmaking operations. But for it to be really effective, it needs appropriate models to represent accurately the properties of the different phases appearing along the steelmaking process. The last developments made in this domain at ArcelorMittal Global R&D concern the slag and the steel phases. For the first one, it consisted in building and assessing a new model in collaboration with CSIRO Melbourne and for the second ones, in reassessing conventional models against literature and in-house experimental data. These models are implemented in the in-house software CEQCSI to make them easily usable by any ArcelorMittal researcher or operator. These models are also used as the thermodynamic “backbone” of kinetic models especially for simulating slag/metal reactions in continuous casting mold.

**3:15 PM Invited**
**Multicomponent Thermodynamic Databases for Complex Pyrometallurgical Processes**: *Denis Shishin*[1]; Peter Hayes; Evgueni Jak; [1]The University of Queensland

In the pyrometallurgical production and recycling of metals, using complex concentrates with high level of impurities, extracting value from variable recycled materials and increasing throughput by improving stability of operation give competitive advantages. To achieve these, computerized systems are increasingly used for operation control, planning and feasibility studies. These predictive tools have high requirements: accurately and simultaneously describing, as a function of process conditions, the partitioning of many elements, the heat balance, and phase equilibria, i.e. precipitation of solids. Recently, computational power and sophisticated mathematical models for solutions (e.g. quasichemical, compound-energy and other) allowed the systematic development of large internally consistent thermodynamic databases, which meet those criteria. The development of the gas-slag-matte-metal-speiss-solids Cu2O-PbO-ZnO-Al2O3-CaO-MgO-FeO-Fe2O3-SiO2-S-(As-Bi-Sb-Sn-Ag-Au) FactSage database from binary, ternary, up to multicomponent systems using integrated approach with experimental studies is described. Its application is to industrial practice is demonstrated.

**3:40 PM Break**

## Part C-1: Hydrometallurgy 2018 – Electrolytic 2 and Extraction/Processing 5

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

| | |
|---|---|
| Tuesday PM | Room: Confederation I |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM**
**EMD Deposition on $Mn_2O_3$/Ti Anode for Manganese Recovery from Zinc Electrowinning Solutions**: Yuuki Yoshida[1]; Kenji Kawaguchi[1]; *Masatsugu Morimitsu*[1]; [1]Doshisha University

This paper reports the preparation of $Mn_2O_3$ coated titanium electrodes by thermal decomposition method and the anodic deposition of electrolytic manganese dioxide on the $Mn_2O_3$/Ti anode. The conductivity of the electrode and the polarization resistance for Mn(II) oxidation in sulfuric acid solutions were strongly affected by thermal decomposition temperature, and the electrode prepared at 350 °C worked well for EMD deposition. The anodic current density, the bath temperature, the Mn(II) concentration, and the electrolysis time were investigated to know their influences on the crystallographic structure and current efficiency of EMD. We present the most favorable electrolysis conditions to produce EMD on the $Mn_2O_3$/Ti anode and show a possibility to recover manganese from zinc electrowinning solutions.

**3:20 PM**
**A Hybrid Energy Storage System Combining Zn Deposition and Cu Leaching in One Setup**: *Kashif Mairaj Deen*[1]; Edouard Asselin[1]; [1]Department of Materials Engineering, University of British Columbia

Both Zn electrowinning and leaching of Cu from CuFeS2 are energy intensive processes. What, if we could combine these two processes in one setup? We are proposing a hybrid flow cell which uses zinc sulfate solution separated from a CuFeS2-activated carbon slurry by a membrane. During charging Zn deposits on the negative electrode while CuFeS2 oxidizes to Cu2+ on the positive electrode. An added advantage of this setup is the partial release of supplied energy at the expense of deposited Zn in the discharge cycle. In 50 charging/discharging cycles, about 20 % Cu was extracted from synthetic CuFeS2 with a ~60 % efficiency (Coulombic). The designed cell has about 50 % energy efficiency with an ability to supply back about 100 Wh/kg of specific energy.

**3:45 PM Break**

**4:10 PM Invited**
**Extraction of Rare Metals from Residues and By-products of Metallurgical Processes by Hydrometallurgical Treatment**: *Christiane Scharf*[1]; [1]Helmholtz-Zentrum Dresden-Rossendorf, Helmholtz-Institut Freiberg für Ressourcentechnologie
In the field of metallurgy, hydrometallurgical processes are widespread. They are used in the processing of the common metals Al, Mg, Cu and Zn but also in the winning of the rare metals such as Ge, In, Ga, Re and rare earth. Especially in the winning of metals, which are not enriched in natural mineral deposits hydrometallurgy plays a major role. By the circular flow in continuous hydrometallurgical processes the rare metals accumulate in certain mass flows. Also the treatment of residues from different metallurgical processes will be of particular importance, because of the possible selectivity of hydrometallurgical processes to extract valuable metals.The unit operations leaching, SX and EW, reduction and refining to well-defined materials respectively are the common steps in hydrometallurgy. Concrete examples are the hydrometallurgical processing of chrome containing slags (www.chromic.eu) and the leaching and SX of rare earth (https://www.hzdr.de/db/Cms?pNid=3534) containing raw materials.

**4:35 PM Invited**
**Separation of Rare Earths Using Diglycolamide Extractants**: *Bruce Moyer*[1]; Derek Brigham[1]; Vyacheslav Bryantsev[1]; Lætitia Delmau[1]; Ross Ellis[1]; Alexander Ivanov[1]; Santa Jansone-Popova[1]; R. Scott Herbst[2]; Kevin Lyon[2]; Mitchell Greenhalgh[2]; [1]Oak Ridge National Laboratory; [2]Idaho National Laboratory
The Critical Materials Institute (CMI) funded by the US Department of Energy has been developing technologies toward reducing the supply risk for five rare earth elements (REEs). One of the technical grand challenges in this endeavor is the separation of REEs from one another, owing to the small differences between the ionic radii of the adjacent trivalent REE metal ions across the series and feeble ligand-field effects. The family of diglycolamide extractants, first developed for nuclear applications, has emerged as highly effective for REE separations with avoidance of acid-base consumption. Using traditional distribution methods augmented by EXAFS structural analysis and DFT and MD computational modeling, fundamental understanding of how these ligands bind and extract REEs with unusually strong selectivity among the light REEs has emerged. Process chemistry for carrying out REE separations has been developed and demonstrated in countercurrent mixer-settler flowsheet tests.

**5:00 PM**
**Development of an Iron Solvent Extraction and Aluminium Precipitation Process for the Recovery of Poly-Alumino–Ferric Sulphate Coagulant From Acid Mine Drainage**: *Brian Mwewa*[1]; Sehliselo Ndlovu[1]; Geoffrey Simate[1]; [1]University of the Witwatersrand
The wastes generated from coal and metal mines, such as acid mine drainage (AMD) are an environmental concern. However, opportunities are available to recover valuable resources from AMD. This approach combines creating revenue with environmental sustainability. This study examines the potential of producing a poly-alumino-iron sulphate coagulant from AMD solution, via iron (III) solvent extraction (SX) followed by aluminium precipitation processes. The extraction of iron from an AMD solution by Cyanex 272 in kerosene has been studied under different conditions such as pH, temperature, contact time and O/A ratio. The stripping of iron using sulphuric acid has also been evaluated. The iron SX step was followed by the precipitation of aluminium from the raffinate solution using calcium hydroxide at a pH of 5. The dissolution of the aluminium precipitate using the stripping solution from the iron SX process to produce the poly-alumino-ferric sulphate coagulant has also been evaluated.

**5:25 PM**
**Determination of Distribution Ratios in Liquid-liquid Extraction of Hydrometallurgical Process Solutions using ICP-MS and Radiotracer Techniques**: *Hans Lerum*[1]; Svetlana Sand[1]; Dag Øistein Eriksen[1]; Eddy Walter Hansen[1]; Grethe Wibetoe[1]; Jon Petter Omtvedt[1]; [1]UIO
Liquid-liquid extraction is a commonly used method in extraction of metals from hydrometallurgical process solutions. Studies of hydrometallurgical processes require determination of distribution ratios which involves accurate determination of the concentration of metals of interest, preferably in both aqueous- and organic phases. The high concentration of dissolved material often found in hydrometallurgical process solutions challenges most quantitative detection methods. In the present work, liquid scintillation spectroscopy, high resolution gamma spectroscopy and inductively coupled plasma mass spectrometry were used. The advantages and shortcomings of the techniques for determination of distribution ratios will be discussed.

## Part C-1: Hydrometallurgy 2018 – Extraction/ Processing 6

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

Tuesday PM
August 28, 2018

Room: Provinces II
Location: Westin Ottawa

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM**
**Pilot Plant Commissioning and Operations for Copper Sulfide In Situ Indirect Bioleaching**: Theodore Ineich; Jan Kwak[1]; Mark Damhuis[2]; Bart Zaalberg[2]; Doris Hiam-Galvez[1]; *Wickus Slabbert*[1]; [1]Hatch; [2]Zeton
The “BIOMOre” project aims to prove the technical feasibility of indirect in situ bioleaching of sulfide minerals contained in a deep underground deposit, by bringing together the disciplines required to make a success. The underground location in Poland was provided by project partner KGHM inside an operating copper mine. Key components of this project were the design and construction of a pilot plant, and its operation in an underground environment. This project also included a ~250 t (100 $m^3$) fragmented rock reactor hydraulically connected to the pilot plant. The pilot plant consisted of several tanks and pumps, a fluidised bed ferric iron generating bioreactor containing immobilised acidophilic iron oxidation biomass, and all the required instrumentation and utilities. Before the bioleaching phase could start, the rock reactor had to be flushed continuously firstly with water to remove chloride salts that are corrosive and also harmful for the bacteria used in the bioreactor, and secondly, with sulfuric acid solution to react with the carbonates present in the ore matrix. This presentation summarizes the design, construction, commissioning, and operation of the pilot plant.

**3:20 PM**
**The Dewatering Behaviour Of Transformed Ferri-oxyhydroxide Precipitates Formed Under Moderate Temperature And Varying Fe(III) Concentrations**: *Cledwyn Mangunda*[1]; Jochen Petersen[1]; Alison Lewis[1]; [1]University of Cape Town

Mining operations generate Acid Rock Drainage (ARD) that poses a significant threat to the natural environment. ARD treatment using Ca(OH)2 leads to the precipitation of a sludge dominated by FeOOH. This sludge has poor dewatering tendencies and is deposited in landfills with potential for metal remobilization. This study investigated the dewatering behaviour of a precipitate formed during elevated temperature treatment of a primary, pre-settled sludge from the neutralisation of aqueous acidic Fe2(SO4)3 and Ca(OH)2 solutions in an MSMPR reactor. The resulting treated precipitates were analysed for micro-properties, with results showing that an increase in the secondary reactor temperature from 25ºC up to 50ºC led to an increase in mean particle size, a decrease in the number of particles and improved dewatering behaviour. This was ascribed to the attainment of a circumneutral pH, surface charge decrease which favoured agglomeration and a change in micro-structure that allowed for better water passage.

**3:45 PM Break**

**4:10 PM**
**The Hydrothermal Reaction and Kinetic for Enargite**: *Gerardo Fuentes*[1]; [1]Retired

The stoichiometry and kinetic of the hydrothermal reaction of enargite in copper sulphate solutions was investigated in the range 140–300 °C, and particle size under 15 and 50 microns. The stoichiometric experiment was performed at 300°C, using one gram of sample (96% enargite, 4% tennantite) and 100 mL of copper sulphate solution (10 gpl) at 1.2 pH. Enargite reacted completely after 80 min. A solid product was obtained and characterized by XRD. The main product was chalcocite (M) and some traces of djurleite and chalcocite (Q). Tennantite did not react under this conditions. The kinetic experiment were conducted at 140°C, 190°C, 250°C and 300°C. From fitted data and Arrhenius equation the calculated activation energy (Ea) was 51 kJ/mol. According to the hydrothermal transformations studied, the reactivity of different phases found in the copper concentrates was bornite > chalcopyrite > covellite > sphalerite > pyrite > enargite > tennantite.

**4:35 PM**
**In Situ Precipitation of Scorodite in Atmospheric Leaching of Enargite**: *Fazel Jahromi*[1]; Ahmad Ghahreman[1]; [1]Queen's University

Enargite, known as one of the major arsenic containing copper minerals, with approximately 19% arsenic, introduces challenges to typical processing options. In most hydrometallurgical processing methods, arsenic remediation occurs after the copper recovery in an autoclave or in a stepwise neutralization process. In this study, the in-situ precipitation of scorodite was investigated during an atmospheric leaching process in the presence of carbon-based catalysts and chloride media. The effective parameters of initial ferric addition, temperature, catalyst addition, and oxygen sparging rate were studied and the ferric behaviour was monitored during the scorodite precipitation. The most influential parameters on efficient scorodite precipitation are found to be: initial ferric addition, catalyst to concentrate ratio, and temperature. A 99% scorodite precipitation yield was achieved in this process.

**5:00 PM**
**Kinetics of Arsenic Release from Orpiment**: *Seyed Mohamadjavad Mirazimi*[1]; Wenying Liu[1]; [1]University of British Columbia

Exposure of mining waste rocks containing arsenic to water and air can cause arsenic release to receiving waters and soils. preventing arsenic release from its minerals which is known as source control is the most preferable option for mining companies. To implement an appropriate source control strategy, it is necessary to have knowledge on the fundamental processes that determine the dynamics of arsenic release from its bearing minerals and waste rocks. These processes include waste rock hydrology, geochemical reactions, and microbial activities. In this research, orpiment (As2S3) which is a common arsenic mineral in gold and copper mines was used as the arsenic-bearing mineral. Concentration of dissolved oxygen, pH and temperature were considered as leaching parameters. A kinetic equation describing the effect of these parameters on arsenic release was calculated.

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## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Tuesday PM

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

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| Tuesday PM | Room: Provinces I, sponsored by Purolite |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**2:50 PM Introductory Comments**

**2:55 PM**
**Separation and Purification of Value Metals from Aqueous Chloride Solutions by Solvent Extraction**: V. I. Lakshmanan[1]; R. Sridhar[1]; *Jonathan Chen*[1]; Darcy Tait[1]; R. DeLaat[1]; M.A. Halim; [1]Process Research Ortech Inc.

The demand for elements such as nickel, cobalt, titanium and gold in various applications has increased significantly. Innovation to recover these elements now plays a major role in metallurgical processes as established technologies have challenges in treating the types of ores that are available while meeting the increasingly stricter environmental regulations. Alternative chloride based processes have been developed that can be used to recover the value elements from the available feed stocks with potentially lower environmental impact. Chloride-based hydrometallurgical processes have several advantages, including higher leachability of complex ores/tailings and relative stability of chloro-complexes of the metals. Process Research ORTECH Inc. (PRO) has developed mixed-chloride process flowsheets, where innovative solvent extraction process steps are used for the separation of nickel, cobalt titanium and gold from their respective chloride solutions. This paper will discuss the potential aqueous chloro-chemistry of these metals and separation reaction mechanisms involved in the solvent extraction process.

**3:20 PM**
**Clean TeQ Sunrise Project – A Novel Hydrometallurgical Flowsheet to Produce Battery-Grade Cobalt and Nickel Sulphates**: *Sunil Jayasekera*[1]; [1]Clean TeQ

Sunil Jayasekera1, Simon Donegan1, Tim Harrison1, Ronald Molnar2 and Michael Robart3 1Clean TeQ Holdings Limited, Australia 2MetNetH2O, Canada, Consultant to Clean TeQ 3SGS Canada Inc., Canada Clean TeQ is developing its Sunrise Project located in New South Wales, Australia utilising its Clean-IX® technology. The DFS currently underway, assesses the economics of producing high purity nickel and cobalt sulphates for lithium-ion battery market. The study also includes the production of scandium oxide.Clean TeQ has developed a novel hydrometallurgical process flowsheet for direct treatment of its laterite ore to produce battery-grade nickel and cobalt sulphate crystals. The process encompasses pressure acid leaching of the ore followed by resin-in-pulp and the processing of the eluate through solvent extraction to generate nickel and cobalt tenors suitable for crystallisation. This paper discusses the results of a pilot plant campaign conducted at SGS Lakefield, which generated on-spec nickel and cobalt sulphates from Sunrise ore.

**3:45 PM Break**

**4:10 PM Invited**

**Utilization of CYANEX® 936 Reagent for Lithium Extraction in LiSX™ Process**: *Jonathan Lipp*[1]; Laurent Cohen[2]; [1]Tenova Advanced Technologies Ltd.; [2]Solvay

Lithium demand is growing exponentially with the transition of the automotive industry toward electric vehicles. Traditionally lithium production has relied on solar evaporation for natural brine processing and ore beneficiation techniques for spodumene operations. Only recently has solvent extraction been applied to lithium processing. Tenova Advanced Technologies (TAT) and Solvay have collaboratively introduced CYANEX® 936, a new extractant used in TAT's lithium solvent extraction process (LiSX™). This paper present test results (laboratory and pilot scale) and demonstrate the benefits of this process and reagent: lower capital investment and operational expenditures, faster time to market, higher product quality, reduced water consumption and virtually 100% lithium recovery. Additionally, LiSX™ and CYANEX® 936 can be applied to all lithium containing solutions and be implemented at various stages in new or existing operations. The process also offers the versatility to produce directly any lithium salt, thus accommodating any changes in battery chemistries.

**4:35 PM**

**Recovery of Palladium from Spent Catalysts – A Critical State-of-the-Art**: *Ana Paiva*[1]; [1]Universidade de Lisboa

The high economic value and hardly replaceable technological properties of the platinum-group metals (PGMs), plus their growing scarcity in the Earth's surface, justify the crucial importance of developing recycling practices for PGMs end-of-life materials. Examples of top devices relying on the use of PGMs are automotive and industrial catalysts, and electrical and electronics equipments.This communication critically describes the most recent research about the use of solvent extraction to recover one PGM, palladium, from spent catalysts. Some groups focus on the development of schemes involving commercial extractants, while others prefer to design specific molecules to efficiently and selectively recover palladium from these specific complex leaching solutions. Examples of extractants proposed for the former schemes are Alamine 308, TBP and LIX84I; on the other side, sulfur-containing diamides, thioamides, thiocarbamates and dithioethers have recently been developed. Ionic liquids have to be mentioned too.

**5:00 PM**

**Unique Hydrometallurgical Process for Copper-Anode Slime Treatment**

**at Saganoseki Smelter and Refinery**: *Takahiro Furuzono*[1]; Atsushi Fujimoto[1]; Tomohisa Takeuchi[1]; Kazuaki Takebayashi[1]; [1]Pan Pacific Copper Co., Ltd.

Saganoseki Smelter and Refinery of Pan Pacific Copper Co., Ltd. started treating copper-anode slimes using a unique hydrometallurgical process in 1997. Precious metals and rare metals in the copper-anode slimes are dissolved into an aqueous solution of hydrochloric acid by oxidation leaching, which is termed wet-chlorination. Gold is extracted efficiently from the chlorination liquor by dibutyl carbitol in the solvent-extraction stage. Gold is reduced by oxalic acid from gold-loaded dibutyl carbitol, and recovered as gold powder. The gold powder is cast directly into granules or ingots of more than 99.99% purity without electro-refining. The plant was designed to process 132 tons of copper-anode slimes per month and has a current capacity of 200 tons per month as a result of several enhancements. Compared with a conventional process, the hydrometallurgical process provides some advantages, in particular, a higher product quality, a shorter gold-retention time, and a reduction in environmental load.

## Part C-3: Processing of Critical Metals – Critical Materials, Niobium, and Lithium

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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| Tuesday PM | Room: Governor General I |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM**

**Critical Materials Traceability: More Important than Metallurgy**: *John Goode*[1]; [1]J.R. Goode and Associates Metallurgical Consulting

Half of neodymium and praseodymium production, key ingredients in permanent magnets, is produced illegally. About 60% of cobalt production, critical in Li-ion batteries and other applications, comes from central African states, and much of it produced illegally. Tantalum, important in modern electronics, is primarily sourced from central African states and again illegally. Illegal mineral production, as exemplified here, can fund conflict. Furthermore, it is typically conducted with scant regard for human rights and environmental standards. It also leads to depressed prices which in turn limits the possibility of legitimate producers entering the market. A system of traceability and cooperative supply chain participants can limit the production of illegitimate material and thereby improve conditions in the country of origin and reduce downward pressure on prices. This paper discusses traceability options.

**3:20 PM**

**A Process Flowsheet for the Extraction of Niobium, Titanium and Scandium from Niocorp's Elk Creek Deposit**: *Niels Verbaan*[1]; Mike Johnson[1]; Tassos Grammatikopoulos[1]; Eric Larochelle[2]; Scott Honan[3]; Kelton Smith[3]; Rick Sixberry[3]; [1]SGS Minerals Services; [2]SMH Process Innovation; [3]NioCorp Developments Ltd.

NioCorp is developing the niobium/scandium/titanium Elk Creek carbonatite resource deposit. The carbonatite phase contains significant niobium (0.71% Nb2O5), titanium (2.68% TiO2) and scandium (72 g/t) and is composed predominantly of calcite, dolomite and ankerite. Niobium is mostly (80%) contained in the pyrochlore and the balance in various Fe-Nb-Ti oxides, which also hosts the titanium. Scandium is distributed homogeneously throughout the ore mineral assemblage.The process flowsheet recovers separate niobium, titanium and scandium products. Scandium is extracted from whole ore hydrochloric acid leach solutions through solvent extraction, and is further refined through a re-leach and precipitation process. Scandium leach residues are treated in a sulphuric acid sulphation process to recover separate niobium and titanium precipitates. Both hydrochloric acid and sulphuric acid reagents are recycled within the flowsheet.This paper will discuss key bench and pilot test results and will present a conceptual flowsheet developed by the project team for NioCorp at SGS Minerals.

**3:45 PM Break**

**4:10 PM**
**Recycling of Li-Ion and Li-Solid State Batteries: The Role of Hydrometallurgy**: *Francois Larouche*[1]; George Demopoulos[2]; Kamyab Amouzegar[3]; Patrick Bouchard[3]; Karim Zaghib[3]; [1]McGill University/Hydro-Québec; [2]McGill university; [3]Hydro-Québec
Since their commercialization in the early 1990's, lithium-ion batteries (LIBs) have become ubiquitous for powering a myriad of portable electronics. Their usage now extends to the automotive industry and stationary energy storage market. With an average life of 6.2 years and the strong demand, the volume of spent LIBs has increased exponentially making recycling mandatory. Currently, recycling/recovery of spent LIBs is limited in comparison to all other types of batteries. The current processes focus mainly on the recovery of the most valuable metals such as cobalt and nickel, leaving lithium and phosphate in a low value end-product. It is necessary that new advanced recycling technologies are developed for the recovery of spent LIBs both from an economic and environmental perspective. In this paper, the current R&D status of LIBs recycling is reviewed with the emphasis placed on hydrometallurgical processing opportunities for Li-ion and Li-solid state batteries.

**4:35 PM**
**Hydrothermal Production of Lithium Metal Silicate Powders with Controlled Properties for Application to Li-Ion Batteries**: *Yan Zeng*[1]; George Demopoulos[1]; [1]McGill University
Lithium metal silicates (Li2MSiO4, M = Fe or Mn) composed by earth abundant and nontoxic elements are important cathode materials for Li-ion batteries. In contrast to solid-state or sol-gel methods, hydrothermal synthesis conducted in pressure reactors is a favorable processing route as it provides the potential for scalable production at low cost and environmentally benign. However, the key is to control the precipitation reaction to obtain powders with desired properties meeting battery specifications. Through systematic study, we found that Li2MSiO4 with tunable size from nano- to micro-range can be produced by adjusting precursor concentrations, temperature and reaction time. Under optimum condition, high purity and low defect Li2MSiO4 was successfully produced and examined as LIB cathode. The use of complexing agents promoted the formation of unique hollow particles made via self-assembling of elongated crystals. A four-step formation mechanism is proposed based on extensive characterizations with synchrotron XRD, HR-TEM, SEM, and Mössbauer.

**5:00 PM Invited**
**Production of Purified Lithium Salts with a One-Stage Solid Phase Extraction (SPE) System**: *Richard Hammen*[1]; [1]IntelliMet LLC
Processes are needed to rapidly and cost-effectively produce highly pure lithium salts for the rechargeable battery sector. Lithium purification is an engineering challenge, due to the low concentrations of lithium compared to sodium, potassium, magnesium, calcium, and transition metal ions commonly occurring in lithium brine resources. We report a SPE process that rejects sodium and potassium, while binding lithium and other ions. Lithium is then harvested by selective elution from the SPE column. The rapid equilibration kinetics of the various ions with the SPE matrix enables these separations to occur in minutes in one column stage with compact units. The ion capture and displacement kinetics will be shown. The resultant engineering parameters and projected capital/operating costs are modeled and described.

**5:25 PM**
**Electrochemical and Frequency Assisted Separation Methods for Lithium-7 Enrichment From Liquid Media**: *Prashant Sarswat*[1]; Jaron Wallace[1]; Michael Free[1]; [1]University of Utah
Isotopes are critical to a variety of applications including physical science analyses, medicine, and national security. Current isotope separation technologies are relatively inefficient, capital and labor intensive, and often produced by a limited number of suppliers. Lithium is found naturally in two isotopes, $^6$Li with about 7.5% abundance, and $^7$Li which makes up the balance of 92.5%. Each of these isotopes is important to the nuclear industry. $^7$Li is often used in the form of lithium hydroxide which is used to control pH in pressurized water reactors. One common technology for lithium isotope separation involves the use of mercury, which is an environmental concern. Hence, a reliable and environmentally friendly technique is needed to produce $^7$Li. In this study the authors discuss a variety of results, including computational isotope dispersion and actual isotope ratio after enrichment using frequency assisted electrochemical and other methods.

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## Part D: Sulfide Flotation – Recent Advances in Flotation Equipment

*Program Organizers:* Ronel Kappes, Newmont Mining Corporation; Tarun Bhambhani, Solvay

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| Tuesday PM | Room: Quebec |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Tarun Bhambhani, Solvay

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**2:00 PM Introductory Comments**

**2:10 PM Keynote**
**Beyond the Limits of Flotation: Recent Advancements in Coarse and Fine Particle Sulfide Flotation**: *Michael Mankosa*[1]; [1]Eriez Magnetics
Flotation is used almost exclusively for sulfide mineral recovery. Unfortunately, existing equipment is constrained to an optimum size range of approximately 15-150 microns. Recent developments have extended the range of applicability while improving process kinetics. The introduction of fluidized bed flotation has substantially raised the upper size limit. Test work conducted at multiple pilot plants around the world has shown that particles as coarse as 600 microns, with a mineral surface expression as low as two percent, can be successfully recovered using fluidized bed flotation. Likewise, high-kinetics flotation processes have reduced the lower limit of applicability while simultaneously reducing the required energy input. Combining these two technologies provides a new paradigm in plant design which reduces net power consumption per ton of ore processed while increasing the effective particle size range of flotation. Results from extensive laboratory-, pilot- and full-scale testing of both technologies in multiple applications will be presented.

**2:55 PM**
**Enhanced Selectivity and Lower Costs for Copper Flotation Applications**: *Glenn Dobby*[1]; [1]Woodgrove Technologies Inc
The Staged Flotation Reactor (SFR) has been developed by Woodgrove Technologies over the past several years to address two deficiencies in conventional flotation equipment, which are inefficient use of equipment volume, and generally poor recovery of collected particles in the froth phase. As the name implies, the SFR approach designs specific sections of the flotation device to target particle recovery and froth recovery independently. The result is flotation equipment that consumes 80-90 percent less air, and up to 50 percent less power than conventional flotation machines. In addition, selective separation of floating species, e.g. copper sulfide from pyrite, is significantly enhanced. This presentation will review key features of the equipment design, and will describe pilot testing and full scale results from installations at several copper concentrators.

**3:20 PM**

**Managing the Bubble**: *Ben Murphy*[1]; [1]Outotec

Since mechanical flotation cells started finding commercial application there has been a lot of focus on how to scale-up these units to achieve the desired result. Much of this scale-up has revolved around how to get the correct pulp volume. As the flotation cells developed successful geometries were identified and these proportions were fixed so when scale-up occurred they got larger. As a result of this process we now how much larger froth surfaces on these float cells which on the larger units has led to operational inefficiencies. This has been compounded by falling head grades globally, especially on large projects. This presentation will focus on the importance of the froth zone to performance and why optimizing launder and crowding design are critical to the success of any flotation operation.

**3:45 PM Break**

**4:10 PM**

**Prediction of Plant Scale Overall Recoveries for Mach Reactor Enhanced Flotation Systems by Utilizing a Validated Simulation Technique**: *Adrian Singh*[1]; Martyn Hay[2]; [1]Gold Ore; [2]Eurus Mineral Consultants

Previous studies well illustrate the positive effects of cavitation, pico-bubbles and high energy input on the flotation of valuable fines. Bubble aging and the importance of generating both pico-bubbles and flotation-sized bubbles within the same device has also been noted by other researchers. The Mach Reactor technology efficiently incorporates all of these aspects into its design. Plant scale Mach Reactor technology is capable of slurry throughputs of up to 2500m3/h. Whereas much emphasis has been placed on semi-pilot testing and the understanding of the effect of the Mach Reactor on grade/recovery and kinetic curves, very little has been done thus far on the prediction of overall full scale plant recoveries using this data. This paper illustrates how a validated simulation technique can be used to easily and accurately predict full scale plant performance from semi-pilot data.

**4:35 PM**

**A Reliable Solution for Pumping Mineral Froth with Challenging Froth Volume Factors**: *Dave Soper*[1]; Jessica Allendes[1]; [1]Weir Minerals

Pumping mineral froth has always been a challenge, often magnified by incorrect pump selection and suction tank design, manifesting from insufficient information on the froth volume factor. The limits of the flotation process are being continually stretched to increase recovery and improve efficiency, often leading to an increasing and more changeable froth volume factor. In these complex conditions, traditional froth pumps can fall over. Warman pumps have solved the problem with a new technology called the 'Continuous Air Removal System' (CARS), which can reliably operate in these more challenging, variable conditions whilst maintaining pumping performance, high efficiency and excellent wear life. The enhanced froth pumping technology is designed for Warman heavy duty horizontal froth pumps and is successfully operating in a number of Gold, Phosphate, Potash, Copper, Molybdenum, Silver, Zinc, Lead, Coal and Oil Sands applications around the world.

**5:00 PM**

**Effect of Microwave Pre-treatment on the Flotation of Low Grade Ultramafic Nickel Ores**: *John Forster*[1]; Erin Bobicki[1]; [1]University of Toronto

As known high-grade nickel sulphide deposits are depleted, and with no new deposits being found, it is necessary to develop better techniques for the processing of low-grade ultramafic nickel ores. However, these ores difficult to process as they are predominantly comprised of serpentine, an anisotropic mineral. Serpentine increases the viscosity of ore slurries, slime coats the valuable nickel-bearing mineral pentlandite, and dilutes the concentrate through the formation of bubble-fibre aggregates that report to the froth. A new method of processing ultramafic nickel ores is proposed where microwave pre-treatment is used to convert the serpentine gangue to olivine prior to beneficiation. The effects of microwave pre-treatment on grinding and flotation are presented and energy considerations are discussed.

## Pyrometallurgy Keynote – Wednesday AM

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| Wednesday AM | Room: Governor General III |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Gerardo Alvear Flores, Aurubis AG

**8:00 AM Introductory Comments**

**8:10 AM Keynote**
**The Rebirth of Tuyere Bath Smelting and Converting: Pipe Dream or Reality?**: *Joel Kapusta*[1]; [1]BBA, Inc.
As flash and TSL furnaces were adopted at a faster pace for smelter modernizations than Noranda/Teniente/QSL vessels, sometimes replacing them, the decline of tuyere bath smelting seemed inevitable in early 2000s. Nevertheless, in the last 10 years, new developments in SKS/BBS "bottom blowing technologies" appeared to have made great headways in China. And since 2012, a growing number of smelters seriously consider retrofitting sonic injectors to intensify their processes and achieve their SO2 abatement goals. Is this trend of renewed interest in tuyere bath smelting/converting sustainable? Can we speak of a rebirth of tuyere bath smelting/converting? Will the SKS/BBS be adopted outside China soon and how fast? Will sonic injectors be retrofitted widely and at what pace? In my lecture, I will explore historical facts and discuss what I believe will be the necessary conditions for this renaissance to be successful in Western economies and not just a pipe dream.

**8:45 AM Panel Discussion**

**9:30 AM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 11 Complex Metallurgy

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Wednesday AM | Room: Governor General II<br>Sponsored by Hatch |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Gerardo Alvear Flores, Aurubis AG

**9:50 AM**
**Recent Developments in the South African Platinum Smelting Industry**: *Rodney Jones*[1]; [1]Mintek
The South African producers of platinum group metals (PGMs) are going through an economically challenging period, with many of them struggling to operate profitably in a time of depressed metal prices and rapidly rising costs. There have been several mergers and sell-offs between companies, and even a few smelter plant expansions. This paper will review recent developments in PGM smelting, and will provide a current overview of the South African PGM industry from a pyrometallurgical perspective.

**10:15 AM Invited**
**Ust-Kamenogorsk Metallurgical Complex : A Silent Achiever**: Alistair Burrows[1]; Turarbek Azekenov[1]; [1]Kazzinc Ltd
Situated in the oblast of East Kazakhstan, the Ust-Kamenogorsk Metallurgical Complex has spent the past 30 years renovating and remodeling itself as a modern polymetallic sulfide smelting facility, and a regional centre of excellence for custom smelting. Along the way there have been changes to ownership, introduction of new technologies, investments in expanded capacity, environmental improvements, and addition of new metal products and by-products to the site's repertoire. These changes have been gradual and incremental, but taken together they represent a significant contribution to placing Kazakhstan's sulfide smelting industry on a sustainable foundation for enduring success in the international custom smelting market. In achieving these changes, a workforce that was historically isolated from much of the world now has recognised expertise, internationally competitive skills, and confidence to embrace the future. Further improvements in energy efficiency, environmental compliance and polymetallic processing capabilities are challenges that UKMC stands ready to face.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 12 Contributions of Peter Hayes to Sulfide Smelting I

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Wednesday AM | Room: Quebec<br>Sponsored by Hatch |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Jürgen Schmidl, RHI Magnesita

**9:50 AM**
**Trace Metal Distributions in Nickel Slag Cleaning Furnace**: Niko Hellsten[1]; *Pekka Taskinen*[1]; Ari Jokilaakso[1]; Hannu Johto[2]; [1]Aalto University; [2]Boliden Harjavalta Oy
To capture efficiently the valuable trace metals from nickel slag using electric furnace, it is important to study their distributions between the slag and metallic phases in the furnace. It is impossible to calculate these distributions without experimental measurements. Therefore, in this work, selected trace metal distributions and phase equilibria between K2O and MgO containing iron-silicate slags and a metallic Ni-Fe-Cu alloy in nickel slag cleaning furnace conditions were studied. The experimental method developed and applied during the work, involved a modified quenching technique that included equilibration of the samples in semi-sealed quartz ampoules in an inert atmosphere and metallic Fe saturation. The use of quartz ampoule prevents the escape of volatile elements from the sample during equilibration. Chemical compositions of the phases and the trace elements were analysed by EPMA and laser ablation-ICP-mass spectrometry methods. From the measured compositions, the trace metal distribution coefficients can be calculated.

**10:15 AM Invited**
**Sulphation Roasting of High Arsenic Copper Concentrates**: Igor Wilkomirsky[1]; *Roberto Parra*[1]; Jorge Etcheverry[2]; Fernando Parada[1]; Eduardo Balladares[1]; [1]Universidad de Concepción; [2]CODELCO División Ministro Hales
The sulphation roasting of high arsenic copper concentrates seems to be an attractive option allowing the Cu recovery by leaching the calcines produced, and capturing the arsenic by volatilization. A laboratory study in batch conditions (tests with less than 10 g of enargite bearing concentrates), confirmed the concept. A second experimental step was developed in a continuous fluidized bed reactor of 8 cm of diameter. The results in this case didn't confirm the process hypothesis such less than 60% of the arsenic volatilized and the rest remains in the calcine as copper arsenate, soluble in the leaching step. The explanation is based in the mechanism of chemical transformation that occurs in the fluidized bed, where at any moment the material in the bed is a calcine completely transformed and the arsenic volatilized has the possibility to be oxidized and to react with copper and iron oxides to form soluble arsenates.

**10:40 AM**
**Case Study on the Application of Research to Operations – Calcium Ferrite Slags**: *Stanko Nikolic*[1]; Denis Shishin[2]; Peter Hayes[2]; Evgueni Jak[2]; [1]Glencore Technology; [2]PYROSEARCH - Pyrometallurgy Innovation Centre

The Top Submerged Lance (TSL) technology, developed in the 1970s, is now widely used for the processing of a range of materials. TSL technology for continuous converting was first patented in the 1990s. The process is based on the use of calcium ferrite slag. Although this slag system had been applied elsewhere the phase equilibria had not been thoroughly investigated. This lead to a collaboration between the Process Technology group of Mount Isa Mines, now part of Glencore, and the Pyrometallurgy Innovation Centre (PYROSEARCH) at the University of Queensland.Through multiple research programs this complex system was successfully investigated. The results were then implemented within thermodynamic modelling tools. This combined new knowledge was then applied to the design and industrial implementation of the TSL continuous converting technology, ISACONVERT™. This paper describes the key findings of the research and how this was applied to the industrial implementation of the technology.

**11:05 AM**
**Kinetics of Oxidation of Pyrrhotite**: *Anastasia Alksnis*[1]; Bo Li[1]; Richard Elliott[1]; Mansoor Barati[1]; [1]University of Toronto

Pyrrhotite is an iron deficient, low nickel content sulfide mineral that is commonly associated with pentlandite, a nickel-rich sulfide; and are both main components of the nickel ore mined in Sudbury. Pyrrhotite tailings generated in the concentration of Ni ores are stored in tailing reservoirs and presents serious environmental risks including acid mine drainage. This study investigated the potential of converting pyrrhotite into a valuable resource through the use of fluidized bed roasting, in which the mineral will be oxidized to produce iron oxide and SO2 gas. These products can then be used to create iron for high-grade steel and elemental sulfur. Thermogravimetric analysis of Sudbury pyrrhotite was performed to study the oxidation kinetics, supporting the feasibility of this process. Further, energy and materials balance was carried out to establish the basic parameters of a possible roasting process.

**11:30 AM**
**Formation Mechanism of Ferronickel Alloy due to the Reaction Between Iron and Nickeliferous Pyrrhotite at 850–900 °C**: *Feng Liu*[1]; Mansoor Barati[1]; Sam Marcuson[2]; [1]University of Toronto; [2]Independent Consultant

A thermal upgrading process by which nickel value can be concentrated in a ferronickel alloy is a possible alternative to treat Sudbury pyrrhotite (Po) tailings with nickel content of 0.5–1.5 wt%. The basis of this process is precipitation of Ni from Po at high temperature once Fe/S ratio in the iron-deficient Po is shifted towards stoichiometric or near stoichiometric FeS (troilite) either by the addition of iron and/or the removal of sulfur. For the iron addition route, the reaction between elemental iron and nickeliferous pyrrhotite to produce ferronickel alloy and Ni-depleted iron sulfide phase plays a critical rule. In this paper, the formation mechanism of ferronickel alloy was investigated using the diffusion couple technique to better understand the nickel diffusion behavior in the iron and sulfide phases.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 13 High Temperature Processing

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Wednesday AM | Room: Ontario |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Graeme Goodall, XPS-Glencore

**9:50 AM**
**Characterization of Coarse and Fine Residues from a Sludge Site of an Integrated Steelwork in Peru**: *Mery Gómez-Marroquín*[1]; [1]Universidad Nacional de Ingenieria

Nowadays one of the most important worldwide steelmaking industry issues are the benefits of recycling or provision of the particulate wastes generated by blast furnaces, LD / BOF converters and electric arc furnaces–EAF. The experimental methodology in this work comprised the characterization of materials from a sludge site, mainly the coarse and fine sludges generated at a primary wet LD dedusting system. Were utilized chemical analysis, Atomic Absorption, X-ray Diffraction, Optical Microscopy, and Scanning Electron Microscope-SEM. From this characterization were suggested the following technological routes: a) the production of coarse – fine residues composite briquettes, to be used as burden in ironmaking reactors; b) the production of coarse – fine self-reducing briquettes, complemented by a carbon resource in their composition, to be used as an alternative cooling material for the liquid steel temperature control and as burden in reactors demanding fast iron metallization

**10:15 AM**
**Production of Ferromanganese Alloys from Silicomanganese Sludge and an Iron Source**: *Maria Wallin*[1]; Kai Erik Ekstrøm[1]; Gabriella Tranell[1]; [1]NTNU

Millions of tons of sludge from different metallurgical processes are produced worldwide annually, and the environmental impact of landfilling these often hazardous sludges stresses the need to understand their role as valuable resources. The current work explores the potential of producing a saleable low-phosphorous ferromanganese alloy by utilizing sludge from the silicomanganese industry together with an iron source. The aim of the project is to explore the feasibility and practical challenges related to reduction and dissolution of manganese and silicon from the sludge to liquid metal and slag. Parameters such as ratio of input material as well as the effect of adding limestone and coke to the mixture were explored by thermodynamic calculations and adapted experimentally. Results show that a ferromanganese alloy, in fact, can be formed, while silicon and calcium forms a complex slag that captures a significant amount of impurities.

**10:40 AM**
**Study on the High Porosity Refractory Bricks Made from Mining Waste**: *Youngjae Kim*[1]; Hyunsik Park[1]; Minseuk Kim[1]; [1]Korea Institute of Geoscience And Mineral Resources

Due to environmental concerns, utilization of mining waste and by-products of extraction process has been paid attention. Approximately 120 million tons of red mud; a bauxite residue of Bayer process, is annually produced. However, due to its high alkalinity, the remediation and utilization of red mud is limited. Gold tailing; discharged after the floatation process, is one of the problematic mining wastes since it contains residual cyanides. Recently, in the high temperature metallurgy process, thermal insulation brick with low thermal conductivity has attracted significant attention for enhancing the energy efficiency. In the present study, we suggest the utilization of gold tailing and red mud for the high porosity refractory bricks.

**11:05 AM**

**New Paradigms for Iron Ore Pelletization**: *Surendra Kawatra*[1]; [1]Michigan Tech University

In recent years, there have been several efforts to develop binder mixtures for iron ore pelletization. Some efforts have been fruitful, while others have encountered failure. For example, adding corn starch to bentonite is effective, while adding fly ash to bentonite is not. When binders are made with fly ash, a pozzolanic reaction occurs, but no such reaction occurs when bentonite and corn starch are used together. The authors analyzed which binders can be mixed, and which binders will succeed. The authors confirmed this analysis with several laboratory and plant studies. This paper presents this critical analysis, along with various combinations of binders for making Iron Ore Pellets.

**11:30 AM**

**Optimal Conditions of Controlling Direct Reduction in Smelting Reduction Ironmaking**: *Sung-Mo Jung*[1]; Yang-Sub Shim[2]; [1]Pohang University of Science and Technology; [2]POSCO

In two stage-smelting reduction process, less pre-reduced iron ore can induce direct reduction in a melter-gasifier, which can increase coal consumption. In this case, the portion of direct reduction might be determined by the reducibility of Pre-Reduced Iron ore (PRI) and the reactivity of coal with CO2. PRI was made into pellets, and its reducibility was measured in several conditions. Coal was carbonized in melter-gasifier condition, and then its reactivity with CO2 was evaluated at various temperatures in an atmosphere containing CO2. The direct reduction occurring in a melter-gasifier was highly feasible because the PRI pellet was reduced more slowly than unreduced iron ore, and the char reacted more actively than coke. The direct reduction rate in a melter-gasifier was roughly estimated as the product of the CO2 content in the ascending gas. The reaction rate constant of coal with CO2 and its minimization of the direct reduction were discussed.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 14 Gas Metals Kinetics

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Wednesday AM | Room: Governor General III |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chairs:* P. Chris Pistorius, Carnegie Mellon University; Mansoor Barati, University of Toronto

**9:50 AM**

**Influence of Manganese on Dissolution of Graphite in Manganese Iron Alloys**: *Hamideh Kaffash*[1]; Merete Tangstad[1]; [1]NTNU

Ferromanganese is a ferroalloy with high manganese content which finds many uses for example as deoxidizer in steelmaking industry. A variety of carbonaceous materials are being used during the production of ferromanganese. However, there is very little data on the dissolution rate of carbonaceous materials in Mn containing metals. In this paper, the kinetic analysis of different Fe-Mn alloys carburization reactions is discussed. Dissolution rate of graphite in pure iron and four different alloys with 10%wt, 40wt%, 60wt% and 85wt% manganese at 1823K was studied. Results showed that the dissolution rate of carbon from graphite increased with increasing time for all alloys. The dissolution rate constant increased with the increasing manganese content from 7.4×10-3 cm/s for 0%Mn to 2.6×10-2 cm/s for 85%Mn.

**10:15 AM**

**Kinetics of Decarburization and Manganese Loss During AOD Processing of High Manganese Steels**: *Aliyeh Rafiei*[1]; Ken Coley[1]; [1]McMaster University

Argon oxygen decarburization (AOD) is considered as a candidate process to produce high manganese steels. In this study, the kinetics of decarburization and manganese losses of Fe-(5-25%)Mn-(0.6-2%)C melts was investigated by bubbling a mixture of Ar+O2 gas through a submerged nozzle at 1600°C. The influence of experimental variables such as gas flow rate and Ar/O2 ratio were determined. The rate of decarburization in the initial period was constant and independent of carbon content of the metal and only dependent on the oxygen supply rate. After the initial period, the rate gradually decreases with decreasing of carbon content. A kinetic model was developed to predict the rate of decarburization and manganese loss as a function of manganese and carbon concentration.

**11:05 AM**

**Experimental Investigation of Pyrometallurgical Treatment of Zinc Residue**: Minna Rämä[1]; Ari Jokilaakso[1]; *Lassi Klemettinen*[1]; Justin Salminen[2]; Pekka Taskinen[1]; [1]Aalto University; [2]Boliden Kokkola Oy

The iron leach residue from the hydrometallurgical zinc production contains many valuable or harmful metals that should be removed in order to obtain a stable and reusable product. After a short thermodynamic pre-study, industrial jarosite leach residue samples have been processed in laboratory scale experiments under oxidizing and reducing conditions at elevated temperatures. The kinetics of the smelting of the residue is studied. First, the pretreated material is melted and oxidized in order to produce a melt of metal oxides. Next, the oxide melt is reduced in a CO-CO2 atmosphere. Target of the reducing step was to produce a clean slag and a liquid metal or speiss phase that collects the valuable metals, such as silver. The purpose was to investigate the optimal processing time and conditions for these two steps, and releasing the metal values either to speiss or flue dusts for a further treatment.

**10:40 AM**

**Aluminothermic Reduction of Vanadium Pentoxide for Production of 60Al-40V Master Alloy**: *Kalenda Mutombo*[1]; [1]CSIR

An exothermic mixture consisting essentially of vanadium pentoxide (V2O5), Al and flux was processed in a water cooled copper vessel. The mixture constituents were in such proportion to produce an exothermic reaction, and capable of reducing V2O5 to vanadium which is absorbed by an extra amount of aluminum. A light optical microscope, a scanning and X-ray diffraction analysis were used to investigate the reduction process of V2O5 to vanadium and formation of pre-alloyed 60Al-40V. The effect of the flux constituents on the separation of the molten alloy and slag was evaluated. The fluidity of the melt increases with the CaF2 content. Increasing the CaF2 content decreased the melting point of the melt, however increasing the CaO content increases the slag temperature.The produced pre-alloyed contained about 60% of Al and about 40% V. The phase analysis revealed the presence of Al23V4 (hcp), Al3V and Al8V5 (bcc) phases.

**11:30 AM**
**Dynamic modelling of molten slag-matte interactions in an industrial flash smelting furnace settler**: *Nadir Khan*[1]; Ari Jokilaakso[1]; [1]Aalto University
Depleting copper resources and advancing technologies have challenged industries to develop more viable, adaptable and cost efficient processes using also secondary raw materials in copper production. This study is targeting to that goal by dynamic modelling of flow and heat transfer coupled with chemical kinetics in an industrial scale flash smelting furnace settler using commercial CFD software Ansys Fluent. First, different physical phenomena occurring inside the settler, for example, settling and separation of the slag/matte phases, and heat transfer between slag/matte phases and settler walls are studied. Secondly, reaction kinetics between matte and slag, and between slag/matte and settler walls, and impurity element distribution will be studied. This would also include phase changes phenomena due to these reactions and the flow of the reaction gases inside the settler. Settling of polydispersed droplets, their coagulation, breakage, and WEEE particle behavior are further targets of the modelling work.

## Part C-1: Hydrometallurgy 2018 – Extraction/ Processing 7

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Wednesday AM | Room: Confederation I |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**
**Solubility of Rare Earth Salts in Sulphate-Phosphate Solutions of Hydrometallurgical Relevance**: Thusitha Bandara[1]; *Gamini Senanayake*[1]; Devindri Perera[1]; Sunil Jayasekera[2]; [1]Murdoch University; [2]Murdoch University; Clean TeQ Holdings Limited
The solubility of rare earth (RE) salts in aqueous solutions depend on many factors including the type of cations and anions in solution, their concentrations, temperature and the type of solid precipitated. Experiments were conducted using anhydrous La2(SO4)3 and Ce2(SO4)3.8H2O as solids and lanthanum(III) perchlorate prepared by dissolving La2O3 in HClO4 solutions as RE-sources. Solutions of H2SO4, H3PO4 and their mixtures in the presence or absence of Na+, Ca2+, Fe(III) or Al(III) as perchlorates served as test solutions. Saturated solutions and precipitated solids were assayed and characterized using standard techniques to show that the La(III) and Ce(III) ions precipitate as hydrated sulphates, phosphates or double salts with sodium, depending upon the solution composition. The change in solubility of RE-salts with solution composition and temperature is the result of the composite effect of changes in solubility products (pKSP) of salts, pKa of acids and other equilibrium constants for ion-association.

**8:30 AM**
**Speciation and Extraction of Ru Species in Hydrochloric Acid Media**: *Tomoya Suzuki*[1]; Hirokazu Narita[1]; Takeshi Ogata[1]; Tohru Kobayashi[2]; Hideaki Shiwaku[2]; Tsuyoshi Yaita[2]; [1]National Institute of Advanced Industrial Science and Technology; [2]Japan Atomic Energy Agency
In the well-known refining processes for platinum group metals (PGMs), Ru is recovered by distillation as RuO4. However, the distillation complicates the processes because of requirements for neutralization, oxidation of Ru, and heating. Although solvent extraction of Ru would result in the simplified refining processes, there has not been any effective extraction systems of Ru. In this study, in order to obtain knowledge for developing efficient extractants for Ru(III), we have investigated Ru(III) species in HCl by X-ray absorption fine structure and UV-Vis spectroscopies, and Ru(III) extraction properties using an amide-containing tertiary amine extractant.

**8:55 AM**
**Electrochemical Co-deposition of Cobalt and Manganese using 1-Butyl-3-Methylimidazolium Trifluoromethanesulfonate Ionic Liquids**: Min Li[1]; Zhongning Shi[1]; Zhaowen Wang[1]; *Ramana Reddy*[2]; [1]Northeastern University; [2]The University of Alabama
The electroreduction of Co(II) and Co(II)+Mn(II) in air and water stable 1-butyl-3-methylimidazolium trifluoromethanesulfonate (BMIMTfO) ionic liquid was studied using cyclic voltammetry at 363 K. Reduction of Co(II) ions to Co is possible in the ionic liquid. Mn(II) cannot be reduced alone, but Co-Mn can be codeposited from the ionic liquid. Electrodeposition of Co-Mn coatings were investigated at various cathodic potentials (-1.2 to -1.5 V) in BMIMTfO containing CoCl2 (0.20 mol L-1) and Mn(TfO)2 (0.10 mol L-1) using constant potential electrolysis experiments on copper. The electrodeposits were characterized using scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), and X-ray diffraction (XRD) techniques. The Mn content in the Co-Mn alloy coatings varies from 9.86 to 29.6 wt% with the applied cathodic potential.

**9:20 AM Break**

**9:50 AM**
**Pressure Oxidation of Enargite Concentrates Containing Gold and Silver**: Kimberly Connor-Mills[1]; *Corby Anderson*[1]; [1]Colorado School of Mines
Most of the copper produced worldwide comes from sulfide minerals, and a majority of production is through smelting as opposed to the use of hydrometallurgical methods. As easily-accessed sulfide mineral deposits are depleted, producers must mine the more complex sulfides, which are more difficult to process. The concentrates from these sulfides contain various impurities, like arsenic, in copper minerals such as enargite and tennantite. These minerals are present in many copper orebodies. Copper producers worldwide are required to meet increasingly stringent environmental regulations for gaseous, aqueous and solid waste emissions to the atmosphere. As a result of these regulations, difficulties may be encountered with conventional smelting technology when treating minerals with elements such as arsenic. Conventional smelting/converting technology has a limited capacity and capability to treat arsenic-contaminated concentrates because of the risk of atmospheric pollution and copper cathode quality. When treated pyrometallurgically, arsenic minerals tend to react easily forming volatile oxides or sulfides or an impure copper product. Many globally significant copper properties have copper sulfide mineralogy high in arsenic present as enargite, Cu3AsS4. The enargite may contain significant amounts of contained precious metals. Development of a selective hydrometallurgical approach to efficiently treat copper concentrates containing large amounts of arsenic would eliminate the issue of atmospheric pollution and may be relatively easily integrated into existing pyrometallurgical operations. In order to evaluate an economic hydrometallurgical process to treat enargite, a background understanding of copper processing, arsenic behavior and enargite mineralogy is essential.

**10:15 AM**
**Emulsion Mediated Low Temperature Pressure Leaching of Base Metals from Mixed Sulfide Minerals through Enhanced Oxygen Mass Transfer**: *Shivendra Sinha*[1]; Devabrata Mishra[1]; Kamla Kanta Sahu[1]; Archana Agrawal[1]; [1]NML Jamshedpur, India

Total pressure oxidation (TPOX) is widely outreached leaching practice of base metals from sulfide minerals, wherein high temperature (T ~ 200 oC) and oxygen pressure (pO2 ~ 25 Bar) are required. These aggressive conditions intensify the oxygen mass transfer and therefore facilitate metal dissolution. However, challenging-cum-negative aspects of such practice are energy and material intensive requirements and high oxygen demand. Herein, the present study explores the novel emulsified medium for enhancement of oxygen mass transfer, which assists faster metal dissolution at significantly low temperature and pressure. It was possible to achieve quantitative dissolution (>98%) of Cu, Ni and Co from mixed sulfide minerals at T ~95 0C and pO2 ~ 2 Bar using an emulsion of 2.5 % (v/v) n-Hexadecane in dilute sulfuric acid. In addition, n-Hexadecane was found to be inert, stable and immiscible thus can be easily recovered and recycled in subsequent leaching stages.

**10:40 AM**
**Assessment of Gold and Sulphide Mineral Associations in a Pressure Oxidised Leached Residue**: *Mark Aylmore*[1]; Martin Wells[1]; Kelly Merigot[1]; William Rickard[1]; Zakaria Quadir[1]; David Saxey[1]; Brigitte Seaman[2]; [1]Curtin University; [2]Newcrest Mining

Refractory sulphidic gold ores require some oxidation process to render gold locked in sulphide minerals available for subsequent cyanidation treatment to recovery the gold. It is well known that gold bearing pyrites can exist in various forms (blocky,fractured/porous,framboidal, disseminated pyrite) with varying As and Au tenor and crystallinity. In this study the quantity of Au, chemical zonation and crystallinity of sulfide minerals and their elemental associations in both concentrate feed and cyanide leached oxidised residue was evaluated from Newcrest's Lihir pressure oxidation circuit. This work is part of an investigation assessing whether Au bearing sulphides can be preferentially oxidised over gold barren sulphides and potentially reduce operating costs.The properties of the different pyrites and elemental compositions were used to assess the reactivity of the different sulphides under oxidative leach conditions. The location and form of residual atomic Au distribution in a leach residue sulphide grain was examined.

**11:30 AM**
**SX-EW Circuit Crud Treatment Sustainable Solution Using Centrifugation Technology**: *Tore Hartmann*[1]; [1]GEA Westfalia Separator Group GmbH

All commercial solvent-extraction plants in the SX-EW circuit produce the formation of crud. Crud is a solid-stabilised emulsion which most commonly accumulates at the aqueous/organic interface in the settlers of solvent-extraction stages. It is caused by a variety of substances entering the SX circuit, ranging from wind-blown dust, entrained solids from the leaching, impurities in the plant solutions, and even insects attracted by the lights in the solvent-extraction plant. While a thin layer of crud at the aqueous/organic interface can aid coalescence of fine droplets, excess crud can interfere with phase separation and severely reduce the efficiency of the settlers. The 3 phase decanter centrifuges are used as state of technology to treat the crud. This paper should indicate the latest control characteristic to process cleanest organic back to the settlers and indicate the payback time for the investment of this advanced technology.

**11:05 AM**
**A New Process Recovering Al2O3 and Na2O from Red Mud**: *Zheng Shangguan*[1]; Wenmi Chen[1]; Junxia Du[1]; [1]Central South University

Bayer red mud is treated by hydrothermal process and obtained solution is carbonized thoroughly.Then the solid Al(OH)3 is sent to Bayer process again,spent liquor is purified and causticized with lime milk to produce caustic soda and light CaCO3 for sale.The benefit is about 300 yuan RMB for treatment of one ton of Bayer red mud.

## Part C-1: Hydrometallurgy 2018 – Extraction/ Processing 8

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Wednesday AM | Room: Provinces II |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**
**Equipment Selection for Chloride Circuits: Challenges and Opportunities**: G.R. Waters[1]; G.B. Harris[2]; [1]CGIS; [2]NMR360 Inc.

NMR360 is developing a suite of chloride-based metals extraction processes, with the first commercial operation scheduled for commissioning late in 2018. It is critical, therefore, that with the introduction of any new technology, that the circuits do not suffer from mechanical failures which will compromise the operation. Although chloride leaching is at atmospheric pressure and relatively low temperature, the main challenge is preventing corrosion, since the high proton activity makes even a small amount of acid behaves as though it were concentrated. An additional challenge in concentrated chloride circuits is the potential for solids precipitation. In this context, therefore, correct valve selection is crucial, and NMR360 has partnered with CGIS to ensure that the Severe Service Valves (SSVs) needed will perform over and above the definitions of the Manufacturers Standardization Society (MSS) of the Valve and Fittings Industry. This paper outlines what the minimum requirements are for SSVs in chloride leaching applications, drawing on five decades of industry experience from one of Canada's leading valve experts.

**8:30 AM Invited**
**FLSmidth's Hydrometallurgical Pretreatment Process for Refractory Gold Ores/Concentrates**: Gary Roy[1]; David Chaiko[1]; *Michael Woloschuk*[1]; [1]FLSmidth

Today, approximately 15-20 per cent of the world's current gold production involves refractory ores that must be pre-treated prior to downstream recovery by cyanidation. As the gold deposit head grades continue to decline, they are also becoming increasingly more complex to treat. For many undeveloped gold deposits, either the head grade is too low to be economically processed, or the reserve life is too short to deliver an adequate return on investment due to the high capital intensity and high operating costs of existing refractory pretreatment processing technologies, such as roasting and total pressure oxidation. FLSmidth has been pioneering a mechano-chemical pre-treatment process to oxidize refractory sulfide gold ores/concentrates under atmospheric pressure and at temperatures much lower than traditional roasting or autoclave pretreatment technologies. This mechano-chemical pre-treatment approach shows great potential for processing refractory gold ores and concentrates that would otherwise not be economic to develop or process.

**8:55 AM**

**Materials for Design and Construction of Hydrometallurgical Equipment**: *Kevin Lambrych*[1]; Joy Bennett[1]; Lisa Adkins[1]; [1]Ashland

Hydrometallurgical equipment used to extract and refine copper, nickel, cobalt, and rare earth metals is exposed to extremely corrosive chemical environments. These systems must be constructed from materials that are durable against corrosion, meet mechanical requirements, and perform economically over the life of the mineral processing plant. In several recent large hydromet projects fiber reinforced plastic (FRP) has been shown to provide equal if not improved durability relative to alternative materials of construction. This paper will compare corrosion performance and cost of plant equipment fabricated with corrosion resistant alloys, rubber lined steel, and FRP made with Epoxy Vinyl Ester thermoset resins. Case histories for FRP piping, storage tanks, extraction vessels, and electrowinning cells combined with laboratory based corrosion studies will be reviewed to demonstrate how FRP materials are selected for hydrometallurgical equipment.

**9:20 AM Invited**

**New Process for Treatment of Cyanidation Effluent to Recover Cyanide and Metals**: *Qiankun Wang*[1]; [1]SPS-Hydromet

Cyanidation has been practiced worldwide for extracting gold and silver from ores. A key issue for this process is how to treat the cyanide effluent/tails in an environmentally friendly and economically viable way. SPS-HYDROMET has developed a new process for treatment of cyanide effluent. In this process, cyanide effluent is subjected to chemical precipitation under alkaline conditions to concentrate cyanide and metals into a small amount of solids. The cyanide precipitate formed is further treated to regenerate cyanide which is recycled to cyanidation for reducing net cyanide consumption, and to recover metals as salable by-product. After the chemical precipitation treatment, cyanide in the effluent is reduced to ~ 1 mg/L, for further polish removal or discharge to a polish pond. An evaluation conducted indicates that this process is economically more viable as compared with existing cyanide destruction methods.

**9:45 AM Break**

**10:15 AM**

**Understanding Cyanidation of Silver from Batch and Continuous Medium Temperature Pressure Oxidation Generated Residues**: *Robert Seaman*[1]; [1]Teck Resources

Pressure oxidative treatment of whole ores and/or mineral concentrates is used to leach or liberate metals of value for downstream recovery. Silver, when present, is often lost in processing, precipitating as a cyanide-insoluble jarosite in the residue. Depending on pressure oxidation conditions, the degree of silver loss to jarosite can vary dramatically. Batch testwork is often performed to define that loss, and then assess the implications at a continuous scale. When a silver-insoluble anion, iodide, is dosed prior to oxidation, there is a marked improvement in silver recovery from batch-generated residue; however, that benefit is not consistently seen in continuous testwork. This paper focusses specifically on CESL pressure oxidation conditions with respect to the impact on silver recovery, and discusses limitations of the batch testing process as well as means of overcoming these limitations to better predict silver recovery in the scale up from bench to continuous system operation.

**10:40 AM**

**Chloride Assisted Leaching of Gold in Thiosulfate Solutions**: *Gamini Senanayake*[1]; [1]Murdoch University

The rate of leaching of gold in thiosulfate solutions depends on the nature of oxidant, availability of other cations and co-ligands. This paper considers the role of chloride as a co-ligand in thiosulfate solutions which facilitates the gold dissolution. Evidence based on electrochemical measurements and the dissolution of colloidal gold is presented.

**11:05 AM Invited**

**Effect of DO, Free Cyanide and Mineralogy on Gold Cyanidation Mechanism; an Electrochemical and Surface Analysis Study**: Rina Kim[1]; Ahmad Ghahreman; Michel Epiney[2]; [1]Queen's University; [2]Air Liquide Canada

There are many factors which affect the gold cyanidation mechanism – mineral composition, free cyanide and dissolved oxygen (DO) concentrations, heavy metal additions, etc. This study combines electrochemistry and surface analysis methods to examine the effectiveness of the above factors on gold cyanidation process.Three gold ore samples were used in this study. Sample 1 was a pyrite concentrate, contained mercury and silver. Sample 2 also contained sulfide minerals, including galena. Sample 3 contained pyrite with sphalerite and galena. In the case of samples 1 and 2, the presence of heavy metals enhanced gold cyanidation kinetics, though the addition of higher DO was not effective on improving the kinetics. Sample 3 showed an opposite behavior: the kinetics was not enhanced by galena, because of its relatively small amount, however, the use of higher DO made improvement in the gold leaching kinetics, which was connected to the pyrite and sphalerite oxidation.

**11:30 AM Invited**

**Measuring Potential in a Pressure Oxidation Autoclave: The Development of a Robust In-situ Oxidation/Reduction Potential Sensor**: *Jing Liu*[1]; Edouard Asselin[1]; [1]The University of British Columbia

Pressure Oxidation (POX) leaching is typically operated at high oxygen partial pressures and high temperatures in an autoclave. The conditions prevalent in the autoclave are critical to the success of downstream processing and ultimate gold recovery. POX is usually controlled by parameters including particle size, pressure, temperature, density and pH of the slurry. All of these parameters together provide an oxidative condition, which is quantified by the oxidation/reduction potential (ORP) of the slurry. This work focused on developing a novel and robust Quasi Reference Electrodes (QRE) to measure the in-situ ORP of POX processes. It is confirmed that there is a one-to-one relationship exists between the ORP and R values. R is the ratio of anodic and cathodic characterization currents when an overpotential is imposed on the working electrode vs. the reference electrode through potentiodynamic polarization. It also resulted in proof of concept: the pre-calibrated ORP sensor and measurement system we developed works under a wide variety of POX conditions.

## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Wednesday AM

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

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| Wednesday AM | Room: Provinces I, sponsored by Purolite |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**8:00 AM Introductory Comments**

**8:05 AM**
**Ion Exchange Technology in Hydro-Metallurgy's Future**: John Rossiter[1]; *Gordon Rossiter*[1]; [1]Ionex Separations
Advances in Continuous Countercurrent Ion Exchange (CCIX) using simulated moving bed technology has penetrated several industries where the advantages have been routinely practiced over the past 30 years. The advantages of CCIX include improved separation efficiency, purer product, higher product strength, increased productivity. Many industries have benefited from significant cost benefits with the adoption of CCIX SMB technology. Hydromet can also reap the advantages of this technologyMany observers view CIX as a series of fixed beds and fail to appreciate the value of the SMB CCIX technology. Paper is set to change that by explaining the differences and some of the novel techniques used in the SMB CCIX and how they have proved beneficial compared to traditional ion exchange in both the purification and production of concentrated products of high purity. The new generation equipment and techniques, is there to solve some of the industries toughest challengers.

**8:30 AM**
**Separation of Lead from Chalcopyrite Using Resin-in-Pulp**: *Weng Fu*[1]; Sabrina Lao[2]; Yepeng Ding[1]; James Vaughan[1]; [1]University of Queensland; [2]McGill University
In this study, Resin-in-Pulp (RIP) technology is used to separate Pb from a chalcopyrite slurry. Solvent-impregnated resin, Lewatit® VP OC 1026, which contains di(2-ethylhexyl)phosphoric acid (D2EHPA) in a macroporous polystyrene matrix was used as the functional group exhibits selectivity for Pb over Cu. Adsorption pH, kinetics, as well as resin and CuSO4 concentrations were investigated. The results show that the kinetics of Pb and Cu loading are fast, reaching the adsorption equilibrium within 30 min. The equilibrium pH of 2 was chosen as optimum pH for operation in order to achieve high a Pb extraction rate and extent as well as selectivity for Pb over Cu. High Cu(II) concentration in solution results in Pb(II) requiring a larger amount of resin for the same degree of extraction. Regeneration and reuse tests show that the loss of adsorption capacity happens in the 1st and 2nd cycles and then the adsorption capacity stabilises for the 3rd cycle.

**8:55 AM Invited**
**Ion Exchange Resin - Pilot and Resin Testing**: *Donald Downey*[1]; [1]Purolite Corporation
Pilot Testing Ion Exchange Resin (IEX) can go from very simple beaker testing to complicated column testing. Space velocities regenerate quantities, loading capacities, ion leakage all terms that get accumulated together to prove or disprove a resin(s) ability to load a single or set of specific ions. Not getting all the resin's operating parameters correct will disqualify the results. Laboratory test for capacity, moisture content, bead size, metals fouling, etc. – What does it all mean? At last count, there were over twenty-five separate ion exchange resin tests (analyses) that were available to end users. Standard testing procedures identify the resin properties but more specific procedures can be used to identify problems with equipment operation. Then, there is the cost to consider; simple cation resin testing (moisture content, total capacity and bead integrity) is in the $200/sample range. However, add to this Chatillon, HIAC particle size, metals and % regeneration test procedures and the lab work can increase to over $1000/sample. In this paper, the author will explain the "must-do" pilot and test procedure and why they are important and the key to understanding how resin does ion exchange.

**9:20 AM Invited**
**Antimony and Bismuth Control in Copper Electrolyte by Ion Exchange**: *Katerina Kryst*[1]; Phillip (Rocky) Simmons[1]; [1]Eco-Tec Inc.
Antimony and bismuth are two of the elements that need to be removed from copper electrolyte to ensure a trouble free operation as well as to maintain copper cathode purity. One method to control these impurities is the use of aminophosphonic ion exchange resins. Antimony is present as both Sb(iii) and Sb(v). Sb(v) is very difficult to remove from these resins, requiring excess amounts of highly concentrated hydrochloric acid. In industry this affinity of Sb(v) for the resin causes a buildup of Sb(v) and degrading resin performance due to continual reduction of resin capacity. A new method for regeneration of aminophosphonic resins loaded with Sb(v) has been developed, which utilizes catalytic regeneration of the resin. Ion exchange can then be utilized for continual control of Sb and Bi in copper electrolyte.

**9:45 AM Break**

**10:15 AM Invited**
**Development and Screening for Resins to Recover REE and Scandium from Different Sources**: *Mikhail Mikhaylenko*[1]; [1]Purolite Ltd
Natural and technogenic sources of rare earth elements and other rare and scattered metals are remarkable for their chemical diversity. The pregnant solutions going to processing for the valuable metals have very complex compositions. Both the targeted elements and competing impurities are present in the solutions in different chemical forms. Thus processing of such materials demands application of different technological tools addressing numerous specific tasks on the way to the final product.Screening work was undertaken to identify the best resins among development and commercial products addressing typical cases of hydrometallurgy of scandium and REE. The cases outline typical sources of scandium and REE, such as streams of TiO2 production, extracted phosphoric acid, barren uranium solutions and some others. Specially designed ion exchange resins can represent such tools.

**10:40 AM Invited**
**Green Chemistry Principles Applied to the Selective Separation and Purification of Specialty Metals Using Molecular Recognition Technology**: *Steven Izatt*; Ronald Bruening; Neil Izatt[1]; Reed Izatt; [1]IBC Advanced Technologies, Inc.
Green chemistry principles will be discussed and examples will be given of the use of Molecular Recognition Technology (MRT) to selectively separate specialty metals such as cobalt, nickel, bismuth, rhenium, molybdenum, indium and germanium from various primary and secondary feed streams. Recovery of these metals has numerous advantages including (i) conservation of valuable resources, (ii) prevention of environmental damage, and (iii) elimination of capital and operating expenses due to re-processing or disposal of metal-bearing streams.

**11:05 AM**
**Breakthrough in Uranium Recovery from Saline Liquors by Ion Exchange**: *Karin Soldenhoff*[1]; James Quinn[1]; Tomasz Safinski[1]; Keith Bowes[1]; Merrill Ford[1]; [1]Australian Nuclear Science & Technology Organisation (ANSTO)
Recovery of uranium in conventional ion exchange circuits, using strong base or weak base resins containing quaternary or tertiary amine functional groups, is based on an anion exchange mechanism. In saline liquors, chloride competes with uranium for the active resin sites and reduces resin loading . This results in significant negative impacts on the IX process in terms of plant throughput and operating costs. In this paper we present the results of a study on the recovery of uranium from an acidic in-situ leach liquor containing approximately 9 g/L chloride. A range of resins were tested, and a high capacity strong base resin was identified with significantly enhanced loading compared to conventional resins. Other process relevant criteria such as loading kinetics and elution efficacy are also discussed. The process developed was successfully tested during a recent ion exchange pilot plant operated in conjunction with a field-leach trial.

**11:30 AM Invited**
**The Use of Ion Exchange to Improve Revenue via the Removal of Impurities**: *Johanna Van Deventer*[1]; Yoshinari Mori[1]; [1]Purolite
For some time now, ore bodies around the world have been declining in grade, whilst increasing in complexity. The level of impurities relative to the valuable metal is steadily increasing, posing new challenges to existing operations. Ion exchange is widely used in the hydrometallurgical industry for both primary recovery of metals and the removal of impurities. The superior selectivity of ion exchange resins makes them exceptionally suitable for the removal of target impurities to very low levels, thereby saving operating costs, increasing the value of the final product and significantly improving revenue. Examples of impurities that are successfully removed via ion exchange include iron, antimony and bismuth from copper electrolyte, copper and zinc from cobalt electrolyte, nickel from cobalt electrolyte. In the copper electrolysis process, antimony, bismuth and arsenic tend to form slimes which are dispersed in the electrolyte. These slimes contaminate the cathode and/or decrease the quality of the copper deposition. To avoid these problems, chelation resins have been used to remove the impurity metals from the copper sulphate solution. The ion exchange process in this application is very simple, using standard ion exchange equipment and acid regeneration. This paper will address a few of these examples in more detail.

## Part C-3: Processing of Critical Metals – Cobalt, Vanadium, Lithium, and Scandium

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

Wednesday AM
August 29, 2018

Room: Governor General I
Location: Westin Ottawa

*Session Chair:* To Be Announced

**8:00 AM Break**

**8:25 AM Introductory Comments**

**8:30 AM**
**Extraction of Cobalt and Nickel from a Pyrrhotite Rich Tailings Sample via Bioleaching**: Rory Cameron[1]; *Ben Yu*[2]; Chris Baxter[2]; Andriy Plugatyr[2]; Rolando Lastra[1]; Mauro Dal-Cin[2]; Patrick Mercier[2]; Nancy Perreault[2]; [1]CanmetMining; [2]National Research Council Canada
The growing use and acceptance of electric vehicles (EV), as evidenced by the record sales of over 750 thousands vehicles and a current global EV stock of 2 million vehicles, is putting pressure on sourcing raw materials such as cobalt, and to a lesser extent, nickel. Global supply is poorly diversified, with 50-60% of global cobalt production sourced solely from the Democratic Republic of Congo (DRC). One potential source for cobalt and nickel are low-grade nickeliferous pyrrhotite tailings, of which 50-100 million tonnes are present in the Sudbury area alone. This paper presents the extraction of cobalt and nickel from this material using a combination of flotation and bioleaching technologies. The findings of a high-level techno-economic analysis of the proposed processing flowsheet are presented.

**8:55 AM**
**Vanadium Extraction from Low Concentrated Iron Bearing Sources by a New Method**: *Benedikt Nowak*[1]; Raffael Stastny[2]; Herbert Weissenbaeck[1]; [1]SMS Group Process Technologies GmbH; [2]SMS group Process Technologies GmbH
For sources with an iron-to-vanadium ratio of far above 1, it is proposed to leach in acid and to oxidize under autoclave conditions. Experimentally it could be shown that free HCl prevents the precipitation of both iron and vanadium. If the initial concentration of free HCl is an order that can be consumed by the ferrous-to-ferric oxidation, also vanadium will co-precipitate as iron-vanadium-oxide. By means of setting the right HCl concentration, an iron-to-vanadium ratio of close to 1 can be reached, whereas the liquid remainder is almost vanadium free. Further processing of this filter cake by conventional technologies such as caustic leaching and precipitation with ammonia, salt roasting, or reduction with aluminum yields common marketable products.

**9:20 AM**
**Recovery of Lithium from the Great Salt Lake Brine**: *Raja Shekhar Marthi*[1]; York Smith[1]; [1]University of Utah
Lithium is one of the key components for future electric vehicle batteries and energy storage. The future availability of lithium to meet demands remains in question. Around 60% of lithium resources exist in the form of continental brines. Traditional methods use precipitation and have found limitations in lithium extraction due to interference of Mg in high Mg/Li brines. Thus, highly selective adsorbents in the form of spinel structured delithiated lithium manganese oxide have demonstrated promising results. However, due to the small particle sizes, it is economically difficult to recover the adsorbents and thereby limiting industrial applications. In our work, LiMn2O4 ion sieve was synthesized and immobilized simultaneously on diatomaceous earth. Fundamental adsorption studies were carried out in lithium buffer solutions to understand the nature of adsorption and kinetics. The adsorbents were also tested for recycling stability as well as with Great Salt Lake brine samples.

**9:45 AM Break**

**10:15 AM Invited**
**Crystallization of a Pure Scandium Solid Phase from Solvent Extraction Strip Liquors**: Edward Peters[1]; Carsten Dittrich[2]; Serif Kaya[2]; *Kerstin Forsberg*[1]; [1]KTH Kungliga tekniska högskolan; [2]MEAB Chemie Technik GmbH
Scandium (Sc) has unique properties and is one of the most valuable elements in the periodic table. Scandium can be used in solid oxide fuel cells and to form high strength aluminum alloys of value for e.g. the aerospace industry. Scandium is often grouped together with the rare earth elements (REE). Scandium can be found in bauxite residues, so called red mud. It is possible to extract and enrich scandium from red mud by leaching and solvent extraction. Scandium can then be recovered from the pregnant strip liquor by crystallization. The strip liquor will however still contain certain impurity elements. In the present work a method for obtaining a pure scandium solid phase by direct crystallization from the strip liquor is presented. The impurity incorporation has been studied by performing seeded crystallization experiments under controlled conditions.

**10:40 AM Invited**

**Innovative and Sustainable Valorization Process to Recover Scandium from Canadian Bauxite Residue**: Gisele Azimi; *John Anawati*[1]; Sable Reid[1]; [1]University of Toronto

Bauxite residue is an environmentally hazardous waste product of alumina manufacturing, produced worldwide in large quantities. This material contains 50-100 ppm of scandium, a critical material for the production of stronger, weldable, corrosion resistant, and heat tolerant aluminum products. Aircraft manufacturers are particularly interested in Al-Sc alloys because the ability to employ weldable structures could reduce aircraft weights by 15–20%. Because of its abundance and low cost, bauxite residue has the potential to be used as an efficient feedstock for valorisation processes to recover its scandium content, while in turn degrading this hazardous waste. Here, we developed an efficient process to recover scandium from Canadian bauxite residue with high extraction yields (above 90%), using industrially scalable and economical techniques. This process employs a modified version of sulfuric acid leaching and subsequent impurity removal by selective precipitation. Kinetic reaction and materials characterisation studies were conducted to describe the leaching mechanism.

**11:05 AM**

**Extraction of Scandium (Sc) using a Task-Specific Ionic Liquid Protonated Betaine bis(trifluoromethylsulfonyl)imide [Hbet][TF2N].**: *Godfrey Mawire*[1]; Lizelle van Dyk[1]; [1]University of Witwatersrand

The extraction of scandium from its oxide with a task specific ionic liquid [Hbet][TF2N] offers potential advantages like lower energy consumption, recycling of the extractant and reduced environmental impact compared to conventional methods. In this paper, the influence of reaction temperature, solid to liquid ratio and water to ionic liquid ratio on the extraction of scandium from a synthetic scandium oxide (Sc2O3) system was studied. The influence of investigated parameters on leaching was very significant as approximately 98% scandium was extracted from its oxide after 72 hours. Furthermore, the ionic liquid also selectively extracted 47% scandium after 48 hours from a mixture of pure metal oxides containing oxides of tantalum, niobium, and scandium. The research demonstrated the potential of [Hbet][TF2N] to selectively extract scandium from columbite processing tailings and other scandium bearing ores like Ixiolite and tantalite which predominately contain tantalum and niobium.

**11:30 AM**

**Development of Scandium-Recovery Process from Titanium-Smelting Residue**: *Kota Nakashima*[1]; Yoshifumi Abe[1]; Hidenori Okamoto[1]; Akira Yoshimura[1]; Matsuhide Horikawa[2]; Seiichiro Tani[2]; [1]JX Nippon Mining & Metals Corporation; [2]Toho Titanium Co., Ltd.

The residue from a titanium smelting process contains scandium. However, the scandium is discarded as in the residue, because there was not so suitable process existed for recovering the scandium from the residue. To use any discarded resource effectively is an important issue for preserving the earth environment and achieving the sustainable development of society. JX Nippon Mining & Metals has been developing scandium recovering process from the residue of a titanium smelting process since 2015. The process consists of the following technologies: (i) Concentrating scandium by classification or neutralization. (ii) Selective leaching of scandium. (iii) Removal of impurities. (iv) Solvent extraction scandium with D2EHPA. (v) Purification. (vi) Roasting. We have established a process to produce Sc2O3 from the residue by optimizing and combining these technologies. This paper will introduce the results of bench scale tests and the flowsheet of scandium recovering process developed by JX Nippon Mining & Metals.

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## Part C-3: Processing of Critical Metals – Rare Earth Elements

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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| Wednesday AM | Room: Les Saisons |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**8:00 AM Introductory Comments**

**8:05 AM Invited**

**Fundamental Understanding of the Flotation Surface Chemistry of Rare Earth Minerals**: *Courtney Young*[1]; Avimanyu Das[1]; [1]Montana Tech

Montana Tech has been engaged in fundamental research on the processing of critical materials for more than a decade. Efforts include examining novel reagents for the flotation of Rare Earth Minerals (REMs). For this paper, results for a collector, salicyl hydroxamic acid (SHA), are presented. Various REMs were examined and include oxides (RECs), carbonates (RECs) and phosphates (REPs). A suite of Rare Earth Elements (REEs) were studied particularly involving several that were light (LREE), middle (MREE) and heavy (HREE). Differences are attributed to lattice spacing, solution chemistry, coordination number and REE ionic diameter. SHA adsorption follows an ion-exchange process that leads to chemisorbed or surface-precipitated states, depending mostly on atomic spacing and pH. Many effects are directly attributed to lanthanide contraction; however, results should be applicable to other REM/collector systems.

**8:30 AM Invited**

**The Simulation and Preliminary Studies on Bear Lodge Ore Flotation**: *Hao Cui*; Corby Anderson[1]; [1]Colorado School of Mines

Rapid technological development causes an increase of demand of rare earth. Ancylite, a strontianite rare earth carbonate, is a significant source of rare earth bearing minerals. In this research essential aspects of the magnetic separation and flotation processes are presented. Based on an optimization of the variables and flotation simulation, a flowsheet is proposed. Furthermore, the economic feasibility for obtained processing conditions is analyzed.

**8:55 AM**

**Efficient Recovery of Neodymium from Neodymium-Iron-Boron Magnet**: Jiakai Zhang[1]; Feixiong Zhang[1]; Brittny Carter[1]; Gisele Azimi; [1]University of Toronto

Much waste electrical and electronic equipment contain considerable amount of rare earth elements (REEs); however, the current level of REE recycling from them is very limited (< 1%). Neodymium-iron-boron (NdFeB) magnets, used at both small- and large-scale from computer hard disk drives and small tools to wind turbines and cars, are a good example of such waste materials that contain high content of neodymium and dysprosium. These elements are considered critical metals because they are the main building block of green technologies that will enable the GHG emissions reduction target. Thus, it is critical to develop efficient, robust, and cost effective processes to recycle these elements from this class of electronic waste materials. Here, we performed a through characterization of N52 NdFeB magnet to identify its composition, crystal structure, and morphology. Furthermore, we then developed an efficient hydrometallurgical process to extract Nd and Dy with high efficiency (more than 95%).

**9:20 AM**
**Recovery of REEs from End-of-Life Permanent Magnet Scrap Generated in WEEE Recycling Plants**: Sebastiaan Peelman[1]; Prakash Venkatesan[1]; Shoshan Abrahami[1]; *Yongxiang Yang*[1]; [1]TU Delft
Nd-Fe-B permanent magnets are the best available magnets used in many technology applications. However, at their end-of-life (EoL) most of the magnets and the contained REEs are lost during the recycling of the bulk metals. The REEs are classified as most critical raw materials in the Europe Union, and recycling of the REEs from EoL products will reduce their criticality and contribute to the REE sustainability. Various technological routes have been reported, but most of the methods are effective for highly concentrated magnets or magnet scrap, which is greatly dependent on expensive pre-dismantling processes. This paper presents various innovative metallurgical solutions to the effective REE recovery from current industrial practice for WEEE recycling, including the ferrous scrap from WEEE shredder products and shredder residues from computer hard disk drives. Both hydrometallurgical and combined hydro- and pyrometallurgical flow-sheets are developed after demagnetization and physical upgrading.

**9:45 AM Break**

**10:15 AM**
**A Comparison Between Batch and Continuous Processes in Impurity Removal from REE Water Leach Solution by Lime and Limestone Neutralization**: *Farzaneh Sadri*[1]; Zhi Yang[1]; Ahmad Ghahreman[1]; [1]Queen's University
After water leaching of the acid baked REE concentrate, impurities such as Fe, Al, Th, and Cu are removed by neutralization with different reagents such as NaOH, Mg(OH)2, MgCO3, CaO, and CaCO3. Among all the said chemicals, lime (CaO) and limestone (CaCO3) are the preferred reagents due to their low costs. However because of calcium sulfate dihydrate (gypsum) precipitation, they are not so common in industry. One of the disadvantages of gypsum precipitation in this process is the adsorption of REE to the precipitates and loss of a proportion of REE to gypsum, which is hard to recover. In this paper, batch and continuous conditions in the impurity removal process by limestone are investigated and the differences between these two processes are examined. Based on the experiments, REE uptake by gypsum significantly increases in continuous process and different gypsum morphologies are observed.

**10:40 AM**
**Innovative Coupled Hydrometallurgical and Pyrochemical Processes for Rare Earth Recycling**: *Eugen Andreiadis*[1]; Vincent BLET[1]; [1]CEA, Atomic Energy and Alternative Energies Commission
Rare earth elements (REE) are regarded today as highly critical raw materials but currently lack suitable recycling processes. A combined hydro- and pyrometallurgical process aimed at REE recovery from used NdFeB permanent magnets was recently developed by the CEA. The process integrates the physicochemical treatment of magnets, followed by a solvent extraction step for the recovery and intra-REE separation using a selective extractant. A subsequent pyrometallurgical treatment via molten chloride salt electrolysis allowed the isolation of pure Dy or Nd metals. Techno-economic assessment and life-cycle analysis were equally conducted. Following this first successful technical demonstration, a new project has been launched in collaboration with industrial and academic partners for the recovery of REE from end-of-life nickel-metal-hydride batteries. The project aims at evaluating from an experimental and techno-economics perspective different processes converging at the production of value-added products such as cermet materials for catalysis applications, purified REO concentrates or metallic alloys. This paper will illustrate some of the main insights of this project.

**11:05 AM**
**REE recovery from the fern D. dichotoma by acid oxalic precipitation after direct leaching with EDTA**: *Baptiste Laubie*[1]; Zeinab Chour[1]; Ye-Tao Tang[2]; Jean Louis Morel[1]; Marie-Odile Simonnot[1]; Laurence Muhr[1]; [1]University of Lorraine; [2]Sun Yat-Sen University
The fern Dichranopteris dichotoma is a rare earth elements (REEs) hyperaccumulator, which naturally grows on former mine tailings in China. It accumulates up to 0.35% of REEs in its aerial parts. Different hydrometallurgical processes were developed to recover these elements directly from the biomass or from ashes after combustion. The first process consists in using a resin to enhance the extraction and to purify REEs by several elution steps. A solution with 75% of the REEs at 81% purity is finally obtained, with aluminium as the main impurity. For the second process, selective extractions of REEs from ashes are performed by different leaching steps. In that case, aluminium is isolated. The upscaling of these processes will allow the agromining development to recover REEs from secondary ressources.

## Hydrometallurgy Keynote – Wednesday

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| Wednesday PM | Room: Confederation I |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:00 PM Introductory Comments**

**2:05 PM Keynote**
**Minimizing the Hydro in Hydrometallurgy**: *Gretchen Lapidus-Lavine*[1]; [1]Universidad Autonoma Metropolitana-Iztapalapa
One of Society's major concerns with hydrometallurgical processing is the large amount of water that is quintessential to its nature. This is especially troubling in arid areas, where the population struggles to procure potable water for their daily needs. For that reason, it has become our responsibility to conceive, design and implement processing schemes that not only use as little water as possible, but recycle streams within the plant itself and minimize waste that exits its perimeter. With this in mind, the conference will center on the importance of selecting the appropriate chemical systems and integrating material balances to avoid reagent overkill and to detect impurity accumulation. The three "R"'s (reuse, recycle and recovery) of aqueous solutions within the processes are emphasized. Examples of processes for the recovery of lead, copper, precious and PG metals from minerals and waste materials will be presented.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 13 Cont. Sulfide Smelting Operations - Bath Smelting

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Governor General II<br>Sponsored by Hatch |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Joel Kapusta, BBA, Inc.

**2:00 PM**
**Two-step Copper Smelting Process at Dongying Fangyuan**: *Zhi Wang*[1]; [1]Dongying Fangyuan Nonferrous Metals. Co., Ltd.
Dongying Fangyuan Nonferrous Metals Co., Ltd has developed a new technology to produce anode copper from concentrate through only two furnaces. This new technology is called Two-Step Copper Smelting Process, with patent No. 201410237182.4. This paper presents the commercialized application of the Two-Step Copper Smelting Process and its operating conditions. The key features of the Fangyuan Two-Step Process are as follows: 1) feed materials including concentrates and flux are mixed without pretreatment and fed into Submerged Lance Smelting Furnace (SLS); 2) high grade white metal (WM) produced by the SLS is transferred via launder into one of the two Submerged Lance Converting and Refining Furnace (SLCR); and 3) the two SLCRs blow alternatively to maintain continuous operation of the whole production chain. The new smelter started operation in October 2015 with a processing design capacity of 1.75 Mt/a of mixed feed and has been operating for 30 months.

**2:25 PM**
**ISASMELT™ - Flexibility in Furnace Design**: *Stanko Nikolic*[1]; Ben Hogg[1]; Paul Voigt[1]; [1]Glencore Technology
One of the keys to success in process development is incremental scale-up, allowing for potential problems to be identified and rectified. The ISASMELT™ top submerged lance (TSL) process was developed to maturity using this method. by Mount Isa Mines, now Glencore. Commercialization only occurred once the process had been proven on each scale and as a result the ISASMELT™ technology now operates successfully around the world. An important parameter in the evolution of the technology has been the furnace campaign life. The initial commercial scale furnaces had minimal water-cooling. Although this led to shorter campaign lives, an extended development program resulted in the achievement of four-year campaign lives, without any water cooling. In tandem to the refractory designs Glencore Technology, supplier of the TSL technology, has progressed cooled copper lining designs for application to both the ISASMELT™ and ISACONVERT™ furnaces allowing for ultimate flexibility in the lining choice.

**2:50 PM Invited**
**Investigation of Oxygen Bottom Blown Copper Smelting Process**: Qinmeng Wang[1]; *Xueyi Guo*[1]; [1]Central South University
The oxygen bottom blown copper smelting process (Shuikoushan process or SKS process) is a new technology which has been widely applied in the copper production in China. In this work, based on SKS smelting mechanism and theory of Gibbs free energy minimization, a computational thermodynamics model for this technology has been established. The calculated results from the model agree well with the actual industrial data, indicating that the model can be used for the predictions under different operating conditions. The tendencies of the key parameters (such as Cu losses and $Fe_3O_4$ content in slag) and the distribution ratios of the minor elements (such as Pb, Zn, As, Sb and Bi) can be predicted by adjusting the oxygen/ore ratio charged into the bottom blown copper smelting furnace. The model can be used to monitor and optimize the industrial operations of the oxygen bottom blown copper smelting process.

**3:15 PM**
**Top Submerged Lance Furnace Lining Cooling System Upgrade**: Allan MacRae[1]; *Brandon Steinborn*[2]; [1]MacRae Technologies, Inc.; [2]Freeport McMoRan Inc.
Freeport-McMoRan Inc. operates an IsaSmelt furnace for the smelting of copper concentrate at the Miami Smelter in Claypool, Arizona. In May 2017, the furnace was restarted after incorporating newly designed copper cooling elements from just above the tap hole to the underside of the roof. The objective of the improved cooling design was to extend campaign life by eliminating existing failure mechanisms with the wall refractory. In addition to upgraded bathline coolers and complete coverage of the gas offtake transition, or ‘kettle’ with plate coolers, a novel arrangement of coolers was installed in the remaining freeboard area. The shell required significant cutting and re-stiffening, as well as extensive modification of the cooling water piping. Based on performance observed to date, it is expected that smelter throughput will be increased due to extended IsaSmelt refractory campaign life.

**3:40 PM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 14 Pyrometallurgy General

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Quebec<br>Sponsored by Hatch |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Baojun Zhao, The University of Queensland

**2:00 PM**
**Application Study on the Technology of Reducing Cu in Discarded Slag**: *Bian Ruimin*[1]; Zhi Wang; Wei Chuanbin[1]; Zhao Baojun[1]; [1]Dongying Fangyuan Nonferrous Metals Co., Ltd
Under the conditions of smelting temperature 1200°C and 1250°C,settling time 30min and 60min and Fe/SiO 1.7-1.9, new slag cleaning furnace is used to study the effect of flux, vulcanizing agent and reductive agent, etc on the result of slag cleaning. According to the study and analysis, we find that when adding $SiO_2$, $B_2O_3$ or $CaF_2$ into original copper smelting slag, settlement and separation of matte can be enhanced. Addition of FeS has almost no effect on recovery of Cu. But, it is able to react with oxygen to produce the heat required. In addition, it can also reduce the dissolution of Cu in the spinel and slag. Under the optimized comprehensive technical conditions, when the ratio of oxygen to natural gas is controlled at 1.6, Cu content in discarded slag can reach to 0.26%.

**2:25 PM Invited**
**Thermodynamic Consideration of Copper Matte Smelting Conditions with Respect to Minor Element Removal and Slag Valorization Options**: *Eric Klaffenbach*[1]; Gerardo Alvear Flores[1]; Bart Blanpain[2]; Muxing Guo[2]; [1]Aurubis; [2]KU Leuven
Valorization of slag from metallurgical industrial processes becomes more and more important as utilization of these material may help optimizing and reducing the use of natural resources such as rock and sand in further applications. In view of this objective, metallurgical processes have to be analyzed in order to adjust the slag composition so that it will meet expected requirements of potential users of these resources. This paper describes fundamental thermodynamic calculations performed with the aim of reviewing the slag chemistry and element partitioning associated with the flash smelting process to understand the impact of operating process parameters. The thermodynamic calculations show that an increase of the matte grade leads to higher deportment of Pb, Zn and As to the slag.

**2:45 PM**

**Optimizing Smelter Uptime through Digital Asset Management**: Bien Ferrer[1]; Lucy Rodd[1]; Adi Dhora[1]; Richard MacRosty; Chris Walker[1]; Mohamed Alhashme[1]; [1]Hatch

There is a strong incentive in most operations to improve safety, reduce downtime and extend campaigns of furnaces and related equipment. This effort can be enhanced through advances in monitoring technology for hot pyro-metallurgical vessels combined with advanced data analysis techniques and on-line predictive models. These are complemented by systematic development of an asset management framework Asset Criticality Assessments, FMECAs and the development of Asset Management Strategies and Plans. These tools are supplemented by effective reliability modeling of the project which allows for identification of key reliability and availability opportunities. A successful RAM model is an invaluable tool to make design decisions as it allows for the quantification of opportunities in terms of NPV rather than poor indicators of overall value such as CapEx or other qualitative measures.This paper introduces a methodology to close the gap between data gathering and evidence-based decision-making using a data-centric approach to asset management.

**3:10 PM Invited**

**Reducing Refining Cycle Times to Extend Anode Furnace Campaign Life at Kennecott Copper**: Jun Enriquez[1]; Ryan Walton; Adrian Deneys[2]; Allen Chan[3]; Bryan Bielec[3]; Viktor Kilchyk[3]; [1]Rio Tinto/Kennecott Utah Copper; [2]Praxair, Inc.; [3]Praxair Inc.

Kennecott Utah Copper aims to extend anode furnace campaigns to more than three years. As part of that goal improvements are sought on anode-furnace tuyere-area refractory performance. Kennecott and Praxair developed high pressure nitrogen refining for the Oxidation Stage which shortened anode furnace fire refining cycles by up to two hours per cycle. Future developments include optimizing the Reduction Stage's steam-gas reforming and achieving coherent jet tuyereless refining.

**3:35 PM Break**

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 15 Process Control and Modelling II

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Governor General II |
| | Sponsored by Hatch |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Roberto Parra, Univ. de Concepción

**4:10 PM Invited**

**Smelting Mechanism in the Reaction Shaft of a Commercial Copper Flash Furnace**: *Jun Zhou*[1]; [1]Tongling Nonferrous Metals Group Holdings Co., Ltd

Water-quenched samples were taken from a commercial flash furnace at three levels along its reaction shaft during operation at high feed rate. The samples were subjected to a series of analysis and observation. Such processes in reaction shaft as oxidation, desulfurization, melting, slag and matte formation and etc., variations of particle size along axial and radical direction of the shaft are investigated. The following smelting mechanism called as "Multi-particle and multi-phase fusion model" is proposed: (1).Fragmentation and collision of concentrate particles take place simultaneously in reaction shaft with particle size growing up. Collision produces large-size "unit melt" falling into the settler. (2). In the settler reaction layer below the shaft, weak bath smelting reactions will take place, producing the final matte and slag and separating into two layers. (3) The processes in the shaft are all progressive along its whole height. The predominant reaction in the shaft is oxidation.

**4:35 PM**

**Progressing Towards Furnace Modernization by Utilizing Comparative Analysis of Acousto Ultrasonic-Echo (AU-E) Monitoring: Case Studies**: *Afshin Sadri*[1]; Mitchell Henstock[1]; Peter Szyplinski[1]; Wai Lai Ying[1]; [1]Hatch

Acousto Ultrasonic - Echo (AU-E) is a technique developed to provide accurate measurements of the refractory lining wear in operating smelters based on the principles of stress wave propagation. The objective of the system is to provide feedback for the continuous optimization of the overall smelter operation. In some cases, the AU-E refractory lining measurements have allowed clients to extend their smelter campaigns and operate safely for several years beyond their planned reline schedule. In other cases, AU-E results inform clients of serious issues within their furnace allowing them to shut down their smelters ahead of predicted failures and possible disasters. This paper presents the results of several smelter AU-E inspections of the hearth and sidewall. These case studies demonstrate how the AU-E results were used to positively affect the smelter operation.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Topic 16 Contributions of Peter Hayes to Sulfide Smelting II

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Quebec |
| | Sponsored by Hatch |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Stefan Steinlechner, Montanuniversitaet Leoben

**4:10 PM Invited**

**Total Sulphur Capture in a Novel Pyrometallurgical Process to Produce Copper from White Metal**: Igor Wilkomirsky[1]; *Roberto Parra*[1]; Eduardo Balladares[1]; Fernando Parada[1]; [1]Universidad de Concepción

The copper production by the classical route of smelting and converting is facing increasing challenges to diminish their environmental impacts. $SO_{2(g)}$ fugitive emissions represent the most important concern considering the wide use of Peirce Smith converters, a robust reactor, but with intrinsic limitations.We present a proposal for a new process that can be part of the classical pyrometallurgical route for the treatment of copper concentrates, by replacing the conversion of matte or white metal by enriched air injection. This process is based in the reduction of $Cu^{+1}$ from the melt by use of C and the capture of S by its association with Na or Ca in a slag type phase where also the Fe can be retained. We present in this paper the physical chemistry justification with the experimental results that allowed to define a process to produce Cu with this new approach.

**4:35 PM**
**Distribution of Copper, Gold and Silver during the Conversion of Copper Matte Considering Addition of Printed Circuit Boards Scrap for Copper Smelters in Chile**: Kevin Flores[1]; Camila Pizarro[1]; Julio Ossandon[1]; *Leandro Voisin*[1]; [1]University of Chile

By 2016 Chile reached the second worldwide pyrometallurgical production of metallic copper from mineral sources with about 8.6% (1.49 million tons) considering the seven local batch smelters. Scrap of Printed Circuit Boards (PCB) are also produced in a small scale and exported by government recycle companies.In this study, different amounts of PCB scrap, together with white metal and converting slag, provided by local recycle companies and copper smelters, respectively, were melted under controlled neutral atmosphere at 1250°C inside a high purity alumina crucible in a laboratory scale furnace in order to determine the distribution of valuables copper, gold and silver between the equilibrated molten phases. Quenched samples from each phase were analyzed by SEM and ICP techniques. The results are the first approach that allow to identify and clarify the added value to treat PCB scrap together with copper matte during the smelting stage for copper smelters in Chile.

**5:00 PM**
**Kinetics of Roasting of a Sphalerite Concentrate**: *Omid Marzoughi*[1]; Mohammad Halali[2]; Davood Moradkhani[3]; Christopher Pickles[1]; [1]Queen's University; [2]Sharif University of Technology; [3]University of Zanjan

In this study, the effects of the two main parameters, time and temperature, were investigated in the zinc sulfide roasting process at the Bafgh mining complex in Iran, and the kinetics and the mechanisms of the roasting reaction were studied. The oxidation process was performed in a muffle furnace in air. The experiments were designed so that the effect of each parameter could be evaluated quantitatively. The results indicated that the highest oxidation percentage occurred at 950°C for 60 minutes. The reaction mechanism followed the shrinking core model, i.e., the rate controlling step was the chemical reaction between zinc sulfide and oxygen in the temperature range of 650-800°C with an activation energy of 105 kJ mol-1, and oxygen diffusion in the temperature range of 850-950°C with an activation energy of 51 kJ mol-1. In addition, the roasting behavior was studied using thermogravimetric (TG) and derivative thermogravimetric (DTG) techniques.

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## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 15 Minor Elements Recovery

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Les Saisons |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chairs:* Eli Ringdalen, Sintef; Pekka Taskinen, Aalto University

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**2:00 PM**
**Phase Equilibria and Thermodynamics of the Selenides in Ag-Au-Se System**: *Dawei Feng*[1]; [1]University of Science and Technology Beijing

In this project, the phase structures, phase equilibria and thermodynamics of the selenides in Ag-Au-Se system are systematically studied by combining key accurate experiment measurements, first-principles calculation and CALPHAD technique. A series of high-temperature selenides phase diagrams in the composition area of Ag-Au-Se are determined to reveal the variation of phase equilibria with composition and temperature. The phase structures of main ternary condensed phases are determined by X-ray diffraction, neutron diffraction and synchrotron X-ray diffraction experiments and first-principles calculations. The heat capacities, entropies, enthalpies of formation and Gibbs energies of some ternary compounds and solid solutions are obtained by calorimetry measurements and first-principles calculations. All experiment data are evaluated to optimize the thermodynamics of the selenides in Ag-Au-Se system with the aim of developing the phase diagram and thermodynamic databases of the selenides in Ag-Au-Se system, which lay the foundation of the study of multicomponent copper anode slime system.

**2:25 PM**
**High Temperature Characteristics of Slags Originating from the Production of Synthetic Tantalum Concentrate**: *Dominik Hofer*[1]; Stefan Luidold[1]; Frank Schulenburg[2]; Tobias Beckmann[3]; [1]Chair of Nonferrous Metallurgy; [2]H.C. Starck GmbH; [3]H.C. Starck Smelting GmbH & Co. KG

A broad spectrum of tantalum containing input materials can be processed for the production of synthetic tantalum concentrate ("SynCon"). The use of these low grade substances offers a secure alternative to mining of coltan in Central Africa. SynCon is produced in a multi-stage pyrometallurgical process, wherefore the melting behaviour of slags presents an important factor especially regarding the energy consumption and its optimisation. The characteristics of a slag comprising mostly Al2O3, CaO, SiO2 and MgO are influenced by the amount of other oxidic constituents which enfolds the main focus of this study. A hot-stage microscope is used to investigate the slag behaviour in a temperature range of 1000 to 1600 °C under reducing atmosphere (CO/CO2 gas). Sample analysis via REM/EDX sheds light on the phase composition. The experimental results are compared with thermodynamic calculations (FactSage) to get a better understanding of the process.

**2:50 PM**
**Extraction of Rare Earth Elements from Spent Rare Earth Magnets Using Ferrosilicon and Sodium Silicate Flux**: *Chompunoot Wiraseranee*[1]; Yusuke Kimura[1]; Rinat Mirvaliev[1]; Satoshi Okada[1]; [1]Mitsubishi Materials Corporation

Rare earth elements including neodymium and dysprosium play a very important role as the permanent magnets materials of the recent decades. With the attempt to recycle rare earth elements from spent magnets, the new extraction process was developed. By using Fe-Si liquid alloy and sodium silicate flux, an oxygen potential of the Si/$SiO_2$ system at 1300–1400°C has been kept at the values at which rare earth elements were oxidized and iron remained in a metallic phase. From experiments, rare earth elements dissolved into the molten flux to form $Na_2O$-$SiO_2$-$RE_2O_3$ slags, while iron dissolved into Fe-Si liquid alloys. Recovery efficiencies of both rare earth elements and iron of 99% were achieved. Furthermore, rare earth elements could be effectively extracted from the slags by a hydrometallurgical method. From this process, pure rare earth oxides and recyclable Fe-Si alloys were obtained as main products.

**3:15 PM**
**Recovery of Nickel and Vanadium from Heavy Oil Residues using DC Plasma Smelting**: *Timothy Johnson*[1]; [1]Tetronics International

Relentless increases in demand for nickel and vanadium for uses such as steelmaking, catalysts and battery materials, plus the growing financial and environmental costs of their primary extraction, have led to much interest in potential secondary sources of these metals. The presence of such metals in heavy fuel oils, bitumen and related materials offers both opportunities and challenges for potential extraction methods, especially with the growing production and importance of metal-rich fossil fuels around the world. For several decades, Tetronics' DC plasma smelting technology has been used for the recovery of metals such as nickel and chromium from stainless steel melt dusts and other wastes in compact, environmentally friendly and efficient plants. This paper will explore the suitability of DC plasma smelting as part of a wider flowsheet with feed preparation and aluminothermic reduction techniques for smaller-scale extraction operations based on this important niche secondary source of these key metals.

**3:40 PM Break**

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 16 Gas/Solid III

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Ontario |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Leili Tafaghodi, University of British Columbia

**2:00 PM**

**Iron Segregation Roasting Processes**: *Patrick Kerr*[1]; Thomas Etsell[2]; Qi Liu[2]; [1]MINEPROMET; [2]University of Alberta

Iron segregation is pre-dated by copper and nickel segregation processes for which the experimental methodology and reaction chemistry were established. Iron segregation roasting offers a potential extraction solution for processing oxide deposits with complex mineralogy or waste streams such as Minette type iron deposits, nickel laterites, ilmenite, red mud, electric arc furnace (EAF) dust, mill scale and slag. After subsequent magnetic separation, one is left with a high grade metallic iron powder which can be marketed for powder metallurgy or briquetted to serve as a direct reduced iron (DRI) product. The non-magnetic product is typically concentrated oxides including rutile, alumina, silica, or oxides of V, P, and rare earths, etc. that may be economically recoverable with subsequent processing. Testwork performed by the authors shows promising results that may aid in future development of the process.

**2:25 PM**

**Simulation of Commercial Hematite Pellet Reduction in a Fixed Bed**: *Reza Beheshti*[1]; [1]KTH

In the present study a model for future use in the modelling of moving bed direct reduction reactors have been developed. The model of a fixed bed reactor for the production of sponge iron from hematite incorporates both heat- and mass-transfer, as well as the chemical reduction rate. The model consists of three 1D time dependent models (mass transfer in (1) pellet and (2)bed as well as(3)heat transfer in bed). The three-stage shrinking core model is adopted and modified as the kinetics model for gas–solid reactions in pellets. The equations were solved by finite element modeling using the COMSOL Multiphysics® 4.3b. The model results were compared to the experimental data obtained from a lab scale reactor in the temperature range 1123-1273 K. The H2/CO ratio of the reducing gas was in all cases varied from 0.8-2.0. The model well simulates the thermal gravity experimental data with an average 1.3% error.

**2:50 PM**

**Assessing High-pressure Oxy-fired Flash Metallization of Iron Ore via Thermodynamics, Kinetics and Phase Characteristics**: *Marc Duchesne*[1]; Mohammad Asiri[1]; Robin Hughes[1]; Bruce Clements[1]; [1]Natural Resources Canada

CanmetENERGY is developing a process by which iron ore is transformed to liquid iron in a pressurized entrained-flow reactor fed with oxygen and natural gas. This process bypasses the need for ore pelletization/sintering and some of the metal refinement in traditional blast furnace operations. The reduction reaction would occur in a pressurized environment to increase the partial pressure of reactants, reduce the size of equipment, and ease the burden of CO2 capture. This process intensification involves high temperatures (1500-2000°C) and pressures (up to 100 bar) not typically used in iron production. To assess the feasibility of this process, thermodynamic equilibrium simulations were performed. These were followed by thermogravimetric analysis to verify iron ore reduction kinetics. Properties of the expected liquid iron and slag phases, such as density, interfacial tension and viscosity, were determined.

**3:15 PM**

**Towards a Microwave Metal Extraction Process**: *Christopher Pickles*[1]; [1]Queen's University

Microwave processing is a relatively new technology and has been successfully applied in a number of industries. However, in the field of metal extraction there is a paucity of success stories despite considerable hype in the early years. Selective heating, lowered reaction temperatures and higher energy efficiency were some of the possibilities that have been investigated. Even with over almost two decades of research and even some pilot plant studies, microwave metal extraction remains essentially a laboratory technique. In this paper, the research performed over the last few decades will be reviewed and some reasons for the lack of success in developing microwave metal extraction processes will be discussed. Based on the knowledge gained from these experiences, a more informed view of microwave heating can lead to the realization that there is still some untapped potential for this heating technique in metal extraction processes.

**3:40 PM Break**

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 17 Slag/Metal

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Governor General III |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chairs:* Katsunori Yamaguchi, Waseda University; Dennis Shishin, University of Queensland

**2:00 PM**

**The Influence of Aluminum on Indium and Tin Behavior in Secondary Copper Smelting**: *Katri Avarmaa*[1]; Pekka Taskinen[1]; [1]Aalto University

Aluminum and copper are large volume metals in electronic appliances, while tin and indium exist as common minor elements. All of these non-ferrous metals are aimed to be separated and recycled from the end-of-life electronics into non-ferrous scrap fraction(s), and further through pyrometallurgical and/or hydrometallurgical processes to pure metals. Depending on the mechanical pre-treatment processes, aluminum and copper liberation from each other varies. This study focuses on the influence of alumina on indium and tin distributions between copper alloy and iron silicate slags with 0, 10 and ~17 wt% of $Al_2O_3$. The experiments were executed with an equilibration-quenching-EPMA technique in an oxygen pressure range of $10^{-9}$-$10^{-5}$ atm at 1300 °C. The distribution coefficient of indium remains constant as a function of alumina in slag, while that of tin increases. Nevertheless, oxygen pressure has clearly more significant influence on the behavior of both the metals in the smelting conditions.

**2:25 PM**

**Behavior of Nickel as a Trace Element and Time-dependent Formation of Spinels in WEEE Smelting**: *Lassi Klemettinen*[1]; Katri Avarmaa[1]; Pekka Taskinen[1]; Ari Jokilaakso[1]; [1]Aalto University

For better understanding and maximal value utilization of the WEEE smelting process, the behavior and distribution of different trace elements must be known. In this study, the behavior of nickel as a trace element was studied in an equilibrium system with metallic copper – spinel saturated iron silicate slag with 3.5 wt-% $K_2O$ – iron aluminous spinel. The experiments were conducted in alumina crucibles at 1300 °C, in oxygen pressure range of $10^{-10}$ – $10^{-5}$ atm. A time series of 15 - 60 min experiments was also conducted for investigating the formation rate of the primary spinel phase in the system. The results show that the distribution coefficient of nickel between metallic copper and liquid slag changes from approximately 70 to 0.5 along the increasing oxygen pressure range. However, most of the nickel deports into the spinel phase. The spinel formation was investigated mainly based on visual observations from SEM-images.

**2:50 PM**

**The Distribution of Sn between $CaO-CuO_x$- $FeO_y-SiO_2$ Slag and Copper Metal at 1300 \176 C**: *Amy Van den Bulck*[1]; Stuart Turner[2]; Muxing Guo[1]; Annelies Malfliet[1]; Bart Blanpain[1]; [1]KU Leuven; [2]Aurubis Belgium RDI

In Europe, 50% of the copper originates from recycling and impurity levels are increasing in these copper feeds. After pyrorefining, these impurities remain in the anode copper, which leads to problems in electrorefining. The distribution of tin between copper and slag has been investigated for conditions relevant to copper converting. Unlike previous studies, this work focuses on the behavior of tin relevant to fire refining conditions, which are essential for anode refineries. In this study, liquid Cu-1Sn and $CuO_x$- $FeO_y-SiO_2$ slag, with $Al_2O_3$ and CaO additions, were equilibrated at 1300 \176 C in vacuum sealed $SiO_2$ ampoules. After metal-slag equilibration, the samples were quenched in water. The composition of the slag and Cu metal was investigated with Electron Probe X-ray Microanalysis. The distribution coefficients of Sn between slag and Cu metal were determined as a function of slag composition.

**3:15 PM**

**Gaseous Reduction of Mn ores in CO-CO2 atmosphere**: *Trine Larssen*[1]; Merete Tangstad[1]; Ida Kero[2]; [1]Norwegian University of Science and Technology; [2]SINTEF

The efficiency in production of manganese ferroalloys is dependent on the gaseous reduction of the higher manganese oxides in the ores used as raw materials. The materials, descending down the furnace, will meet the furnace gas that contains significant amounts of CO(g) and reduce in subsequent steps, the last step being reduction of Mn3O4 to MnO. This step may to varying extent occur at temperatures exceeding 800°C, i.e. in the active region of the Boudouard reaction. The gas reduction of Assmang and Comilog manganese ores were investigated in CO-CO2-atmosphere at temperatures up to 1000°C. It was seen that decreasing raw ore size correlates to a lower reduction temperature and increasing reduction rate. Similar effect was observed with increasing CO-content in the gas atmosphere. Further, it was found that Comilog ore obtained a complete prereduction at 600°C, whereas reduction of Assmang ore was not complete at 1000°C for the majority of the experiments.

**3:40 PM Break**

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## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 19 Slag

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

Wednesday PM
August 29, 2018

Room: Ontario
Location: Westin Ottawa

*Session Chair:* Fumitaka Tsukihashi, University of Toyko

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**4:10 PM**

**Operational and Environmental Opportunities of the Na2O-SiO2-FeOx Slag System**: *Joseph Grogan*[1]; Camille Fleuriault[1]; Apratim Biswas[1]; [1]Gopher Resource

Non-ferrous furnace slag systems are often based around FeO-SiO2 or CaO-SiO2-FeOx chemistries. A less common slag system is that of Na2O-SiO2-FeOx. This paper presents experimental data on these sodium based slags, contrasting them with other compositional types. These sodium based slags are shown to have a low viscosity, low melting temperature, low density, and a good ability to accept impurities. A benefit of these traits is good phase segregation and a low metal loss via slag entrainment. Leaching susceptibility of these various slag compositions is described using the USEPA Method 1311 TCLP.

**4:35 PM**

**Optimization of Slag Composition in View of Iron Recovery and Dephosphorization in EAF Process**: *Jung Ho Heo*[1]; Joo Hyun Park[1]; [1]Hanyang University

Undesirable selection of electric arc furnace (EAF) operating conditions lead to heavy financial losses and longer operation time. The proper control of slag composition is a dominant factor affecting yield of iron as well as dephosphorization efficiency. Thus, the addition of fluxing additives (e.g. lime and dolomite) and reducing agents (e.g. carbon and aluminum) should be carefully controlled. Moreover, thermophysical properties of slags are strongly affected by the changes in slag composition. Therefore, the main purpose of this study is to improve the EAF operations in commercial meltshop with the aim of higher yield of iron as well as higher dephosphorization during EAF process by optimizing not only additive fluxes but also reducing agents. The FactSageTM7.0 thermochemical software was employed to simulate the influence of basicity (%CaO/%SiO2), viscosity, and melting point of the EAF slag on (FeO) content in tapping slag and final [P] content in molten steel.

**5:00 PM**

**A New Pyrometallurgical Recycling Technique for Lead Battery Paste without SO2 Generation — A Thermodynamic and Experimental Investigation**: *Yun Li*[1]; Yongming Chen[2]; Chaobo Tang[2]; Shenghai Yang[2]; Lassi Klemettinen[1]; Minna Rämä[1]; Xingbang Wan[1]; Ari Jokilaakso[1]; [1]Aalto University; [2]Central South University

An innovative lead recycling process from scrap lead-acid battery paste is presented. The novelty in the process is avoiding SO2 generation and emission by using reductive sulfur-fixing technique. Iron-bearing secondary wastes produced from metallurgical industry were utilized as sulfur-fixing agent to capture sulfur in the form of FeS(s) instead of generation of SO2(g). Na2CO3 molten salt was added to the smelting system to speed the reactions and improve valuable metals' recovery and sulfur-fixation efficiency, even at low temperature. Also, this process can simultaneously co-treat various lead and iron-bearing wastes. Some precious metals, such as Au, Ag etc., contained in iron-bearing wastes can be recovered at the same time. The feasibility and reliability of this process was investigated thermodynamically and experimentally with the help of HSC 9.0 database and XRD and SEM-EDS analysis. A possible reaction mechanism and path in PbSO4-Fe2O3-Na2CO3-C smelting system was also clarified.

**5:25 PM**

**Understanding Viscosity-structure Relationship of Slags and its Influence on Metallurgical Processes**: Tae Sung Kim[1]; Jung Ho Heo[1]; Jin Gyu Kang[1]; Jin Sung Han[1]; *Joo Hyun Park*[1]; [1]Hanyang University

The viscosity is one of the most critical properties of slags and thus it's influence on the physicochemical phenomena in metallurgical processes has been issued for last decades. The viscosity of ferrous- and non-ferrous metallurgical slags can be understood via structural investigation with spectroscopic methodologies including x-ray photoelectron spectroscopy, infrared- and Raman spectroscopy, and solid state nuclear magnetic resonance spectroscopy, etc. Therefore, the reaction kinetics such as desulfurization in ladle metallurgical furnace, smelting reduction of FeO and MnO in electric arc furnace is strongly dependent on the viscosity of the slags. The rates of oxide (inclusion and refractory) dissolution into the slags and fluxes are governed by the viscosity. Alternatively, the structure of aluminosilicate melts also affects the thermochemical properties such as sulfide capacity, etc. The present paper will review these diverse applications of the viscosity-structure relationship to ferrous- and non-ferrous metallurgical processes.

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## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Session 20 Ferroalloys

*Program Organizers:* Evgueni Jak, PYROSEARCH, Pyrometallurgy Innovation Centre; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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| Wednesday PM | Room: Governor General III |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chairs:* Oleg Ostrovski, University of New South Wales; Merete Tangstad, Norwegian University of Science and Technology

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**4:10 PM**

**Reduction of Manganese Ore Pellets in a Methane-containing Atmosphere**: *Richard Elliott*[1]; Mansoor Barati[1]; [1]University of Toronto

Current methods for producing low-carbon manganese alloying materials for the steel industry are energy intensive and costly. To enable wider implementation of high Mn steel alloys, a novel solid-state Mn ore reduction strategy is therefore being investigated. This solid-state process, modelled on existing Direct Reduced Iron technology, employs a methane-containing atmosphere to reduce Mn ore pellets to a metal carbide. These pellets may then be smelted, yielding a Mn-rich master alloy. It is well established that CH4 is a suitable reductant for Mn ore powders; however, the reduction behaviour of industrially relevant Mn ore pellets by CH4 is poorly understood. The present work reports the results of a reduction kinetics study undertaken to address this knowledge gap. The results of this study identify the optimum conditions to achieve maximum rate and extent of reduction, and form the basis of a predictive mass and energy balance model of the process.

**4:35 PM**

**Kinetics of Reduction-carburization of Synthetic $(Fe,Mg)(Cr,Al)_2O_4$ Solid Solutions by $Ar$-$CH_4$-$H_2$ Gas Mixtures**: *Vincent Canaguier*[1]; Leiv Kolbeinsen[1]; [1]NTNU, Norwegian University of Science and Technology

Methane is increasingly considered as a promising reductant for metal oxides, including chromite. To assess the possibilities of such reduction route, the gas-solid reactions between $Ar$-$CH_4$-$H_2$ gas mixtures and synthetic chromites are studied between 950 and 1050°C. The influence of Mg and Al additions to the reduction-caburization of $(Fe,Mg)(Cr,Al)_2O_4$ solid solution is investigated thermodynamically, structurally and kinetically. The product phases are examined by x-ray diffraction (XRD), scanning electron microscopy (SEM), and electro probe microanalysis (EPMA). The reaction rate is derived from real-time exhaust gas measurements and post-reaction product analyses such as oxygen analysis. Kinetic models are proposed based on the product phase morphologies and confronted with the empirical data.

**5:00 PM**

**Manganese Reductive Alloying: Novel Laboratory Data & Analysis**: *Brian Jamieson*[1]; Mansoor Barati[2]; Kenneth Coley[1]; [1]McMaster University; [2]University of Toronto

Production of 3rd Generation Advanced High Strength Steel (AHSS) requires high manganese contents, which can be a challenge to achieve. Hundreds of experiments have been performed in the authors' laboratory, reacting synthetic slags rich in manganese oxide (MnO) with high silicon iron alloys. This data has been analyzed and modelled to determine reduction mechanisms, rate determining steps, and mass transfer coefficients. Analysis of the results has been used to rationalize apparently contradictory findings in the literature. The model developed in this work has also been used to define optimum reduction conditions.

**5:25 PM**

**CFD Modeling of Reactors for the Direct Reduction of Ring of Fire Chromite**: Kevin Watson[1]; *Tanai Marin-Alvarado*[2]; Dogan Paktunc[3]; Graeme Goodall[4]; [1]Kingston Process Metallurgy Inc.; [2]M4Dynamics; [3]Natural Resources Canada; [4]XPS-Glencore

Natural Resources Canada (NRCan) was directed through Budget 2015 to undertake a significant effort to support the development of Ontario's "Ring of Fire" (RoF) chromite deposits. In 2016, NRCan sponsored a techno-economic review of technologies suitable for producing ferrochrome from RoF chromite. That work identified direct reduction of chromite has an attractive technology that warranted further investigation. In the present work, a detailed literature review of direct reduced iron technologies was conducted. From the review two reactor types were chosen as being potentially suitable for direct reduction of chromite. CFD models of these reactors were then developed using the COMSOL multiphysics modeling platform to investigate the impact of reactor design and process operating conditions on the chromite reduction process. This paper will provide a summary of the literature review; the CFD modeling methodology and results; and the implications for RoF chromite.

## Part C-1: Hydrometallurgy 2018 – Extraction/ Processing 10

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Wednesday PM | Room: Provinces II |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM Invited**

**Extraction of the Surface-coated Metals from Waste Acrylonitrile Butadiene Styrene Plastics in an Ammoniacal Solution**: Minji Jun; Tae Gyun Kim; *Jae-chun Lee*[1]; Rajiv R. Srivastava; Min-seuk Kim[1]; [1]Korea Institute of Geoscience and Mineral Resources (KIGAM)

Leaching of the surface-coated metals from waste acrylonitrile butadiene styrene plastics (WABSP) has been investigated in the ammoniacal solution. The leaching of the WABSP sample (typically containing metals such as 4.1 wt.% Cu, 1.3 wt.% Ni, 0.03 wt.% Cr) efficiently dissolved copper and nickel, leaving unleached chromium as the fine particles. The results indicate that the anions of different buffer media for metal leaching follow the order: CO32- > Cl- > SO42-. A declined leaching with the high NH4OH–(NH4)2CO3 ratio (8:1) and a steep rise in extraction at the higher pulp density in solution revealed the influence of anion (CO32-) and cation (Cu2+) present in the system. The leaching performed in carbonate solution by maintaining the total NH3 concentration of 5.0 M at a ratio, of 4:1 for NH4OH–(NH4)2CO3, 200 g/L pulp density, 20 °C temperature and 400 rpm agitation speed in 120 min, yielded the maximum extraction (>99%) of copper and nickel. The study reveals a plausible recovery of the surface-coated metals from the WABSP without altering the properties of polymer material that can be recycled separately.

**3:20 PM**

**Hydrothermal Process to Convert Hematite in Red-Mud to Magnetite**: *Sumedh Gostu*[1]; Brajendra Mishra[1]; [1]Worcester Polytechnic Institute

Red-mud a residue generated from the Bayer's process to treat Bauxite ore is subjected to a hydrothermal process. Jamaican Red-mud (~60 wt % Hematite) is leached in oxalic acid: 95 oC, 15 % solids, 2.5 h, 550 rpm, 2.5 M oxalic acid solution. 100 % conversion of hematite in red-mud to ferric oxalate was obtained while Calcium and REE's separated as undissolved oxalates, constituting the residue. The ferric oxalate was subjected to reduction using iron powder/scraps to obtain solid ferrous oxalate precipitate. The precipitation process was optimized varying time, temperature and Fe+3/Fe. Aluminum and Titanium remained in the pregnant leach solution. Ferrous oxalate was subjected to a thermal treatment in N2 atmosphere (low PO2) to obtain a high purity saleable magnetite.

**3:45 PM Break**

**4:10 PM**

**Comparative Evaluation of Sulfuric and Hydrochloric Acid Atmospheric Leaching for the Treatment of Greek Low Grade Nickel Laterites**: Christiana Mystrioti[1]; *Nymphodora Papassiopi*[2]; Anthimos Xenidis[2]; Konstantinos Komnitsas[2]; [1]Technical University of Crete; [2]National Technical University of Athens

Greece is the only EU country with extensive nickel laterite deposits. Since the 1960s, the Greek laterites are treated for ferronickel production via a pyrometallurgical route. Currently, due to the rising cost of energy and the decreasing grade of mined laterites the pyrometallurgical treatment became economically marginal and for this reason alternative treatment processes are under investigation. Potential applicability of hydrometallurgical treatment, using either H2SO4 or HCl, under atmospheric pressure conditions, was investigated in the present work. The laterite used contained 22.4% iron, 13.2% magnesium, 0.88% nickel and 0.06% cobalt. The investigated parameters were temperature (65-90oC), acid concentration (1-4 N) and solid to liquid ratio (10-30% w/v). High Ni extractions, almost 100%, were achieved with both acids. As far as Co extraction is concerned, HCl was found to be more efficient compared to H2SO4. The maximum achieved Co extraction was about 37% with H2SO4 and 96% with HCl.

**4:35 PM Invited**

**Novel Process for Comprehensive Utilization of Iron Concentrate Recovered from Zinc Kiln Slag**: *Zhiyong Liu*[1]; Huan Ma[1]; Zhihong Liu[1]; Qihou Li[1]; [1]Central South University

A novel process, including hydrochloric acid leaching, iron powder replacing, sulphide precipitation and spray pyrolysis, was proposed to treat iron concentrate recovered from zinc kiln slag for comprehensive utilization. Treated by solution of 6 mol/L hydrochloric acid at 60°C, the leaching rates of Ag, Pb, Cu, Fe and Zn reached 99.95%, 99.34%, 95.07%, 89.44% and 57.92%, respectively. More than 98% Cu and Ag were recovered from the leach liquor when stoichiometric ratio of iron powder was 1.25 times of the theoretical value. More than 96% Pb and Zn was removed with three times of theoretical consumption of FeS, and the concentration of impurities of the final solution was less than 500 mg/L. Fe2O3 powder, which was spherical with mean size of 12 μm and purity of 99%, was prepared with final solution at above 700°C.

**5:00 PM**

**Hydrolytic Precipitation of Nanosized $TiO_2$ Phases for use as Photocatalytic Sorption Media in Effluent Treatment**: *Konstantina Chalastara*[1]; George Demopoulos[1]; [1]McGill University

Mixed phase titanium dioxide ($TiO_2$) nanoparticles synthesized through hydrolysis of $TiCl_4$ solution at different conditions, namely concentration, pH, and residence time are characterized and evaluated as photocatalysts. The process is operated in a continuous stirred-tank reactor, CSTR giving blends of anatase, brookite, and rutile nanoparticles that were further evaluated to find the optimum mixture for a photocatalytic sorption material. The titania nanoparticles are first characterized in terms of photocatalytic activity under UV light illumination using an organic model compound (methyl orange) and after that are tested for removal of toxic selenate and selenite species from simulated effluent waters.

## Part C-1: Hydrometallurgy 2018 – Extraction/Processing 9

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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| Wednesday PM | Room: Confederation I |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**2:50 PM Introductory Comments**

**2:55 PM**
**Activation and Deactivation Effects of Lead on Gold Cyanidation**: *Rina Kim*[1]; Ahmad Ghahreman[1]; Michel Epiney[2]; [1]Queen's University; [2]Air Liquide Canada
The addition of lead to a gold leaching reactor can effectively accelerate or retard the gold cyanidation reaction. This study explored the lead effect on the gold dissolution kinetics using cyclic voltammetry (CV) experiments. It was illustrated that the gold leaching kinetics in the cyanide solution enhanced with the addition of lead salt in the low overpotential region (–0.35 V vs. Ag/AgCl). The similar behavior was observed in the presence of ore containing 0.25% galena. In contrast, the gold oxidation kinetics retarded at –0.35 V (vs. Ag/AgCl) in the presence of silicate and lead-bearing mineral under certain conditions. Likewise, the lead addition was not functional for the high sulfur ore. This was attributed to the oxidation of the sulfides to the elemental sulfur, which subsequently formed a passivating layer on the gold surface. The results were evidently affirmed by the electrochemical tests and X-ray photoelectron spectroscopy (XPS) analysis.

**3:20 PM Invited**
**Australian Hydrometallurgy Research and Development**: *James Vaughan*[1]; Weng Fu[1]; Hong Peng[1]; Will Hawker[1]; Peter Hayes[1]; Dave Robinson[1]; [1]University of Queensland
Australia is a major miner of ore that requires hydrometallurgical processing. According to the 2016 US Geological Survey Minerals Commodities Summaries, the country is 1st for aluminium (bauxite) and lithium, 2nd for gold, zinc and cobalt, 4th for nickel and silver, and 6th for copper mining, not to mention its wealth in coal and iron ore. In this paper, examples of recent Australian hydrometallurgical activities are summarised. Then, selected research projects from the University of Queensland hydrometallurgy research group are profiled. The projects profiled are related to fundamental aspects of processing bauxite with organics and reactive silica as well as the development of a synergistic hydro- and pyrometallurgical process for copper. The process context and motivation for the research is introduced, key results are highlighted with the associated relevant references.

**3:45 PM Break**

## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Wednesday PM

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

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| Wednesday PM | Room: Provinces I, sponsored by Purolite |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

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**2:50 PM Introductory Comments**

**2:55 PM**
**Ion Exchange Removal of Copper Impurity from Silver Nitrate Electrolyte**: *Sami Virolainen*[1]; Mikhail Maliarik[2]; Olli Holopainen[1]; Tuomo Sainio[1]; [1]Lappeenranta University of Technology; [2]Outotec Oyj
An ion exchange process for removal of copper from concentrated silver nitrate electrolyte was designed. Suitable ion exchange resin was chosen based on single-column experiments with synthetic nitrate electrolyte containing ca. 85 g/L silver and 40 g/L copper at pH 3.5. 2-(aminomethyl) pyridine functional chelating resin (CuWRAM) was observed as the best choice among several tested commercial resins. With this resin, a process was designed based on additional experiments and process simulations, which were done utilizing developed mechanical ion exchange model. The process is capable of purifying ca. nine bed volumes of electrolyte under a day. In addition, experimental results indicate that silver losses to the copper eluate are minimal.

**3:20 PM**
**Selective Separation of Iron from Simulated Nickel Leach Solutions Using Ion Exchange Technology**: *Rene Silva*[1]; Yahui Zhang[1]; Kelly Hawboldt[1]; Lesley James[1]; Wesley Saunders[1]; [1]Memorial University of Newfoundland
The separation of Fe(III) from simulated Ni(II) solutions using different ion exchange resins was studied. The resins tested included cation exchangers with sulfonic and carboxylic groups and chelating resins with iminodiacetic, aminophosphonic, and mixed sulfonic and phosphonic groups. The dosage of resins was varied from 0.1 to 0.5 g/mL to study the impact of resin type and dosage on iron separation from simulated nickel leach solution containing 25 g/L Ni(II) and 25 g/L Fe(III) at pH 1.5. Also, the effects of different metal ion concentration, Fe(III):Ni(II) ratios in solution, pH, and adsorption times were investigated. Experimental results demonstrate that all the chelating resins selected favored the adsorption of Fe(III) over Ni(II) with high Fe(III) loading. Soft cation exchange resins also favored the adsorption of Fe(III) over Ni(II), but no remarkable Fe(III) loading was observed. In contrast, strong cation exchange resins did not show adsorption preferences. The most efficient separation was observed using resin with aminophosphonic groups at resin dosage of 0.2 g/mL, having a Fe(III) adsorption over 94% and Ni(II) adsorption below 5%.

**3:45 PM Break**

**4:10 PM**

**Recovery of Copper Nanoparticles from AMD by Cementation with Iron and SDS**: *Giuseppe Granata*[1]; Chiharu Tokoro; [1]Waseda University

In this work, we studied the recovery of copper from AMD by cementation with iron powder. Aiming to control the size of copper particles within the nanoscale, we tested the use of the anionic surfactant sodium dodecyl sulfate (SDS). We tested three levels of concentration (0.2, 0.4 and 0.6 M) and temperature (25, 50 and 75°C). The activation energy of cementation was also assessed by fitting the experimental data with the Arrhenius equation. The concentration of dissolved metals was determined by inductively-coupled plasma spectrometry (ICP/AES). The cemented product was characterized by X-ray diffraction (XRD) and scansion electron microscopy (FE-SEM) to determine phase composition, particle size distribution and morphology. Under all investigated conditions, the cementation reaction was found to be a diffusion-controlled process. Without surfactant, the activation energy was 18 kJ/mol. In the presence of SDS the activation energy increased up to about 35 kJ/mol. Whether using SDS or not, the particle size of the copper product was strongly affected by the cementation temperature. Without SDS, the cemented product aggregated into micro-sized clusters of about 15 µm at 25°C, 2-3 µm at 50°C and 1 µm at 75°C. The addition of SDS determined a dramatic decrease of copper particle size up to the nanoscale. Under the best operating conditions, the particle size of copper was lower than 100 nm.

**4:35 PM**

**Keeping Mine-Water Membranes Clean**: *Steve Chesters*[1]; Max Fazel[2]; Phil Morton[2]; [1]Genesys International; [2]Genesys International Ltd. UK

Membrane technologies are capable of treating mine waste waters to produce clean permeate water for reuse and a concentrate stream that can be used for valuable metals recovery. In this paper the authors have researched and identified over 350 operational membrane plant in mines worldwide. Reverse Osmosis (RO) nano-filtration (NF) and ultra-filtration (UF) technology is increasingly being adopted. 69% of these plant are in gold and copper mines. In precious metal mines, waste water can be concentrated using membrane plant so additional metals can be recovered from barren liquor. Acid mine drainage (AMD) is increasingly treated and then reused or sent off site as a valuable resource for domestic and agricultural use. The wholesale adoption of membrane technology is hampered by the potential for rapid membrane fouling and calcium sulphate (gypsum) scale deposition. The authors have embarked on research project to investigate calcium sulphate scale formation at alakilne and acidic pH and in the presence of a variety of soluble metals. New techniques for preventing sulphate scale and to clean fouled membranes have been investigated and the results are presented.

## Part C-3: Processing of Critical Metals – Rare Earth Elements

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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| Wednesday PM | Room: Governor General I |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* To Be Announced

**2:50 PM Introductory Comments**

**2:55 PM**

**Early Separation of Cerium from Mixed Rare Earths: A Review of Methods and Preliminary Economic Analyses**: *John Goode*[1]; [1]J.R. Goode and Associates Metallurgical Consulting

There are at least a dozen methods of selectively removing cerium from a mixture of the rare earth elements including separation techniques based on the oxidation of cerium to the quadrivalent state. Several of these methods have been operated on a commercial scale, others have been tested and are part of proposed flowsheets. In this paper, we describe and compare the various methods. We also present a preliminary estimate of the impact of early Ce removal on separation plant capital and operating costs and the impact of more promising cerium removal options on overall project economics.

**3:20 PM**

**Oxidative Removal of Cerium from Rare Earth Elements Mixed Chloride Solution**: *Maziar Sauber*[1]; [1]Natural Resources Canada

ABSTRACT In order to prepare a more desirable feedstock for a rare earth elements separation refinery, cerium, a penalty element in the refinery feedstock, should be removed from a mixed rare earth elements chloride solution. In this study, calcium hypochlorite was used to oxidize cerium (III) to cerium (IV) which was then removed by precipitation. A factorial design of experiments was used to determine the effect of process variables such as temperature, pH, and oxidizer concentration on the oxidation of cerium (III) using both synthetic and real solutions. This proposed technology allows for low cost removal of cerium from mixed rare earth elements chlorides. KEYWORDSRare earth elements (REE), leaching, separation, solvent extraction, oxidation

**3:45 PM Break**

**4:10 PM**

**Alternatives to 2-Ethylhexyl Phosphonic Acid, Mono-2-Ethylhexyl Ester for the Separation of Rare Earths**: James Quinn[1]; *Karin Soldenhoff*[1]; Geoffrey Stevens[2]; [1]Australian Nuclear Science & Technology Organisation (ANSTO); [2]University of Melbourne

Solvent extraction technology using EHEHPA remains the backbone for industrial separations of rare earth elements. This process has some shortcomings, including a large plant footprint and high acid requirement for stripping of the heavy rare earths. In this work, we examine a number of alternative mixed solvent extraction systems: i) Mixtures of organo phosphonic and phosphinic acids such as EHEHPA/Cyanex 272 or Cyanex 572; ii) Ionic liquid mixtures of EHEHPA with quaternary ammonium chloride (Aliquat 336); and iii) Mixtures of carboxylic acids for yttrium/lanthanide separations. We discuss and compare the efficacy of these systems with reference to the Nd/Sm separation, which is of industrial significance. Based on the extraction chemistry and the use of modelling tools to define the counter-current solvent extraction circuit, we present a techno-economic analysis of a separation plant and discuss the impact of various solvent systems on the CAPEX and OPEX.

**4:35 PM**

**Production of Separated Rare Earth Elements (REE) from a Quebec Deposit**: *Jean-Francois Boulanger*[1]; Keven Turgeon[1]; Claude Bazin[1]; François-Olivier Verret[2]; Dominic Downey[3]; [1]Université Laval; [2]SGS Canada; [3]Mine Niobec

The production of rare earth elements from ore usually consists of three steps; the separation of a concentrate of REE bearing minerals; the cracking of the REE minerals to liberate the REE into an aqueous solution and the possible separation of REE into individual elements. This paper describes the results of laboratory tests conducted on a carbonaceous REE ore containing bastnaesite and monazite. The tests cover the whole processing sequence of beneficiation, preparation of the REE solution using a caustic leach followed by acid leach to break monazite and bastnaesite and liberate REE into an aqueous solution and the separation of the REE using solvent extraction. Details on the product quality and process performances (recovery and impurities removal) are given for each studied steps. The concentration and distribution of various radioactive elements are provided to assess this known problem of the processing of rare earth bearing ores. The paper also discusses the economic advantage of separating the REE rather than producing a mixed REO product to be sold to a refinery for REE separation. A mini-pilot plant version of the process is currently planned.

**5:00 PM**

**Separation and Purification of Rare-Earth Elements Based on Electrophoretic Migration (Part II)**: *Pouya Hajiani*[1]; [1]INNORD/Geomega

Rare earth elements (REEs) are critical materials in many leading-edge technology products. However, environmentally friendly REEs separation outside China has been remained a challenge. We have been working on a technique which uses emphasised variation of REEs electrophoretic mobility (Ui) in an electrical field for REE separation. In continuation of the results presented in IMPC 2016, this contribution summarizes the progress achieved in 2016 and 2017. The major goal was to increase the REEs concentration by a factor of 1000 and to attenuate the consequent drawbacks, specifically joule heating effect.A protic solvent was selected to replace water which has major impact on the complexation and buffer nature of the solution. Non-aqueous medium brings about 1000-fold drop in electrolytes' molar conductivity while Ui reduces by a factor 10. More over, a quasi-steady state electrophoretic separation method accompanied by a controlled counter-flow is adapted to improve separation efficiency per unit length.

**5:25 PM**

**Radionuclide Removal from Ore and REE-bearing Minerals by Leaching and Ion Exchange Separation**: *Nicolas Reynier*[1]; Laurence Whitty-Leveille[1]; Maxime Courchesne[1]; Cheryl Laviolette[1]; Jean-Francois Fiset[1]; Janice Zinck[1]; [1]Natural Resources Canada

The separation of radionuclides during rare earth element (REE) production is an important requirement for a developing Canadian REE mining industry. Separation of actinides from REE is often a big concern in the rare earth industry because of the need to manage the radioactive nuclides. A patented process developed for actinides extraction from radioactive wastes was applied to REE ore. Objectives were to optimize the process for REE leaching from ore, and separate radioactive impurities from sulphuric and nitric liquor by ion exchange (IX). Ore leaching was optimized using a surface response plan to ensure statistical significance. In optimized conditions, solubilization yields ranged 90-95% for Th, 60-75% for U, 48-55% for LREE, and 59-75% for HREE in sulphuric and nitric media. Both media were compared for radionuclides removal from rich REE-bearing minerals liquor by IX. Actinides separation ranged 92-97% for Th and 69-96% for U in sulphuric and nitric media.

## Last Call to Post Your Achievements: Extraction 2018 Poster Session – Posters - Monday

*Program Organizer:* Ahmet Deniz Bas, COREM

Monday AM
August 27, 2018

Room: Grand Foyer
Location: Westin Ottawa

*Session Chair:* Ahmet Deniz Bas, COREM

**M-1: Cyanide-free Treatment of Refractory Gold Ores - Process Simulation**: *Heini Elomaa*[1]; Pia Sinisalo[1]; Mari Lundstrom[1]; [1]Aalto University

As the environmental legislations and the general attitude against cyanidation have become stricter, there is an increasing interest to develop environmentally friendly cyanide-free processes for gold production. To prevent future environmental disasters and to observe the consumption of chemicals, waste waters and carbon dioxide formations in gold leaching plants, process simulation and life cycle analysis should be conducted to evaluate the development stage processes. This study presents the simulation of pressure oxidation and cyanide-free gold leaching from highly refractory gold ore using halogens. The processes are simulated by HSC-Sim 9. In the current status of the study, the simulated pressure oxidation consisted of autoclave leaching, counter current decantation and neutralization. The simulated gold leaching consisted of halogen leaching, gold recovery on silica and neutralization. The mineralogy of ore was mainly pyrite and arsenopyrite, having also dolomite, muscovite and quartz. The simulation results predicted 97.9% gold recovery.

**M-2: Effect of Matrix Complexity on the Quantification of Platinum Group Metals using Inductively Coupled Plasma Optical Emission Spectroscopy**: *Jihye Kim*[1]; John Anawati[1]; Gisele Azimi[1]; [1]University of Toronto

Platinum group metals (PGMs) are widely used in various industrial fields, particularly in the manufacture of automobile catalytic converters to reduce the emission of harmful gases. Given the fact that PGMs are getting depleted because of resource limitation and increasing demand, considerable effort has been devoted to extracting PGMs from low-grade ores and recycling them from secondary sources. However, one of the major challenges of extracting PGMs from these sources is that they contain a high concentration of other elements that can potentially hamper the accurate characterization of PGMs because of interferences. Here, we investigated the accuracy and precision of PGMs measurement in the presence of interfering elements using inductively coupled plasma optical emission spectrometry (ICP-OES), with an emphasis on the effect of analyte concentration, number and concentration of interferents, and interferent identity. A statistical approach was adopted to characterize how ICP-OES detection of PGMs is influenced by matrix parameters.

**M-3: Electrochemical Studies of Monoclinic and Hexagonal Pyrrhotite**: *CHAO QI*[1]; Jing Liu[1]; Mika Muinonen[2]; Julie Coffin[3]; Curtis Deredin[3]; Ravinder Multani[2]; Qingixa Liu[1]; [1]University of Alberta; [2]Expert Process Solutions; [3]Glencore Canada

Pyrrhotite, $Fe_{(1-x)}S$, is the major iron sulphide typically associated with economic Ni and Cu sulphide. In some Ni-Cu bearing deposits within the Sudbury Basin, an increasing amount of more floatable hexagonal pyrrhotite ($Fe_9S_{10}$) has been observed. Due to more stringent environmental standards for $SO_2$ emissions from smelting operations, there is a need to develop a fundamental understanding for the rejection of hexagonal and monoclinic pyrrhotite in the flotation process. In order to fulfill this purpose, hexagonal and monoclinic pyrrhotite were studied via micro-flotation, cyclic voltammetry (CV), auger electron spectroscopy (AES) and x-ray photoelectron spectroscopy (XPS). In this study, the flotation recovery curves of hexagonal and monoclinic pyrrhotite as a function of electrochemical potential and pH were established. It was discovered by CV studies that monoclinic pyrrhotite presented a higher oxidation rate compared to hexagonal pyrrhotite. In addition, their oxidation mechanism at various potentials was studied by AES and XPS.

**M-4: Froth Flotation of Ilesha (South West Nigeria) Placer Gold Ore Using Conventional and Locally-sourced Frothers and Collectors**: *John Ade Ajayi*[1]; [1]Federal University of Technology, Akure, Ondo State, Nigeria

The placer gold deposit in Ilesha gold field is finely disseminated and is amenable to amalgamation and cyanidation which are environmentally hazardous. There is a need for an alternative method of processing the ore and the favoured method is froth flotation which is environmentally friendly. However, the conventional flotation reagents are scarce and expensive. Hence, this work is aimed at enhanced and economic recovery of gold concentrate from Ilesha placer gold deposit using locally-sourced flotation reagents. Ilesha placer gold ore was panned and its chemical analysis, mineralogical assemblage and particle size analysis were carried out. MIBC and PAX were used as frother and collector respectively. For the locally-sourced flotation reagents, oils of groundnut and palm kernel, and potassium salts of groundnut and palm kernel oils were used as frothers and collectors respectively. The locally-sourced flotation reagents are potential substitutes for recovery of gold concentrate from Ilesha placer gold deposit.

**M-5: Fundamental Studies of the Surface Properties of Millerite under Different Pulp Potentials and Water Chemistry**: *Hua Zhao*[1]; Jing Liu[1]; Chao Qi[1]; Lori Kormos[2]; Julie Coffin[3]; Curtis Deredin[3]; Qingxia Liu[1]; [1]University of Alberta; [2]XPS (Expert Process Solutions); [3]Glencore Canada

Millerite (NiS) is found in along the margins of Cu rich orebodies in the Sudbury region along with varying amounts of pentlandite, chalcopyrite, and bornite. Recently with the emergence of higher millerite bearing ores in the Sudbury region, an understanding of the surface properties and flotation chemistry of millerite is becoming important for the successful depression of millerite from chalcopyrite in copper-nickel separation. In this study, the wettability and electrochemical properties of millerite were investigated using cyclic voltammetry (CV) coupled with FTIR and contact angle measurements under different pulp potentials and pH. In addition, the xanthate adsorption mechanism on millerite surface was elucidated by CV, FTIR, XPS, and contact angle measurements. Our research provides more insights on the role of pulp potentials, pH, and collector on millerite flotation.

**M-6: Heat Recovery from Slag through Air Atomization**: *Ayesha David*[1]; Mansoor Barati[1]; [1]Univ of Toronto

The heat contained in metallurgical slags represents a significant source of lost energy in processing operations. In 2015, molten blast furnace slags alone contained ~ 5x108 GJ of energy, most of which was lost. Additionally, metallurgical slags are underused in downstream applications such as concrete production. While many granulation technologies have been developed to take advantage of the inherent value of molten slags, none have shown definitive proof that heat recovery and idealized granulation can be performed simultaneously. This project's objective is to determine the feasibility of concurrent granulation and heat recovery by quantifying heat transfer during air atomization. A heat transfer model for a representative system is developed to quantify heat transfer from a granulated particle to the air within a heat recovery chamber, and to quantify the heat lost from the system during granulation.

**M-7: Rare Earths Extraction and Separation from Chloride Solutions Using Bis(2,4,4-Trimethylpentyl) Phosphinic Acid**: *Rajesh Kumar Jyothi*[1]; So-Hyun Kim[1]; Kyeong Woo Chung[1]; Jin-Young Lee[1]; [1]Korea Institute of Geoscience & Mineral Resources (KIGAM)

The importance of rare earth (RE) elements is growing due to their wide range of applications in clean energy, high-tech technologies and modern life. At the same time, sources of REs are very limited. The current study focuses on the aromatic diluents benzene, toluene and xylene to determine their suitability as well as their ability to improve the separation of light rare earth elements (LRE's). Bis(2,4,4-trimethylpentyl) phosphinic acid (tradename Cyanex ® 272) is used as an extractant and is dissolved the aforementioned diluents. Various experimental parameters, in this case the time effect, the influence of the pH, extractant concentration variations and the maximum loading capacity of the LRE under study associated with extraction with Cyanex ® 272 were examined. Finally, the potential for separating LRE's are calculated and a suitable diluent system is proposed.

**M-8: The AMBS Flotation Process for Copper and Gold Ores**: *John Jiang*[1]; Barun Gorain[2]; [1]AuTec Innovative Extractive Solutions Ltd; [2]Vedanta Resources

The Air-Metabisulfite (AMBS) process has been developed to treat complex copper, molybdenum and precious metals (gold, silver) bearing ores using brackish and sea water. This process was able to produce significantly better copper concentrate grades and higher recovery than possible using conventional lime and/or cyanide based processes for certain complex ores with high sulfide gangue minerals. The AMBS technology is now used commercially.This poster presents a summary of the findings from testing the AMBS technology on various ores types.

**M-9: The Effect of Additives on the Leaching of Ilmenite Concetrate**: *Khetho Daba*[1]; Ramakokovhu Munyadziwa[1]; Shongwe Mxolisi[1]; [1]Tswane University of Technology

Ilmenite (FeTiO3) is one of the sources of titanium dioxide and it constists of 36.8%Fe, 31.6%Ti and 31.6%O. Removal of iron and other impurities present in the ilmenite is the main focus as a way to free titanium dioxide. Ilmenite is processed using pyro-metallurgymethod which involves melting ilmenite in electric arc furnace to produce pig iron and titanium rich slag (95-97%TiO2). Titanium rich slag is then upgraded to 98-99.5%TiO2 by chloride or sulphate process. This method includes many processing stages which demand high capital investment and gases released are dangerous to environment. This present study examined the leaching using hydrchloric and sulphuric acid to produce high grade TiO2 (99.98%).Moreover,optimization of leaching conditions will be studied varying parameters such as acid concentration,temperature,solid ratio,agitation and residence time. The effects of additives such as ferrous chloride, phosphate, fluoride and etc. on the dissolution of iron and other impurities from ilmenite will be tested.

**M-10: Thiosulphate Gold Leaching Process and the Role of Thiosulfate Counter Cations on the Leaching Process**: *Uchitta Vashist*[1]; [1]Queen's University

There are serious concerns associated with the conventional cyanidation process due to extreme toxicity of cyanide. Thiosulfate is a less-toxic alternative lixiviants for effective gold leaching. This review elaborates on the chemistry of thiosulphate system which is rather complicated due to simultaneous presence of complexing ligands, Cu(I)- Cu(II) redox couple and thiosulphate decomposition reactions. Besides that, gold leaching is case-specific and depends on ore and solution chemistry. Leaching gold by thiosulphate is affected less by foreign counter cations in comparison with cyanidation. However, extraneous counter cation plays a major role on rate of the leaching process. In general, the gold dissolution rates decrease with increase in concentrations of the metallic ions. Decreased thiosulphate concentrations in the presence of the foreign ions also decreases gold dissolution. However, the effect of these cations is specific to the type of metal and solution conditions and can be elaborately understood by respective Eh-pH diagrams.

**M-15: The Cyclic Voltammetry Measurement of Redox Reactions for Gold in Acidic and Basic Media:** *Afolabi Ayeni1*; Shafiq Alam; Georges Kipouros; 1University of Saskatchewan

This poster presents the cyclic voltammetry measurement of redox reaction of gold in both acidic and alkaline solutions. The current and potential zones at which gold is reduced is investigated because of its importance in electrochemical evaluation of gold recovery. The solutions were prepared by reacting 0.1 and 0.5 M hydrochloric acid, sodium thiosulfate and sodium thiourea with 30 and 60 ppm gold concentration. These solutions with dissolved gold in 0.1 and 0.5 M of the three lixiviants were tested using potentiostat in cyclic voltammetry (CV) technique mode for possible measurement of reduction and oxidation reactions. Glassy carbon, saturated calomel (SC) and platinum wire mesh served as working, reference and counter electrodes, respectively. Comparative tests were carried out on 0, 30 and 60 ppm gold solution of the three lixiviants. The results show that no peak is observed in the case of the absence of gold in the solutions (0 ppm), 30 and 60 ppm gold in sodium thiourea and sodium thiosulfate, indicating no redox reaction or that CV is not a suitable technique to detect the peaks. However, appreciable cathodic and anodic peaks are observed for 30 and 60 ppm AuCl3 concentration in the acid solution. The redox reaction in the gold(III) chloride acid solution is found to be reversible because the ratio of oxidation peak current and reduction peak current is 1. The concentration of AuCl-4 on the surface of the working electrode at the reduction site for the AuCl3 concentrations using Nernst equation are 1.22× 109 and 2.44 × 109 ppm. It is inferred from this experiment that the reduction potentials are independent of concentration, while current is concentration dependent.

## Part A: Extractive Metallurgy Markets and Economics – Posters - Monday

*Program Organizers:* Luisa Moreno, Tahuti Global; Boyd Davis, Kingston Process Metallurgy Inc

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August 27, 2018

Room: Grand Foyer
Location: Westin Ottawa

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**M-11: The Effect of Magnesite on Removal of Metal Species and Sulphates in Acid Mine Solution**: *Karabo Tshoane*[1]; [1]Tshwane University of Technology

This study aims at investigating magnesite kinetics and its ability to attenuate metals and sulphates from AMD using a column reactor setup.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Posters - Monday

*Program Organizers:* Evgueni Jak, Pyrosearch, The University Of Queensland; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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**M-12: Chemical Reactivity and Thermal Stability of the Phosphate Binder used in Ceramic Foam Filters (CFFs)**: *Cathrine Solem*[1]; Massoud Hassanabadi[1]; Robert Fritzsch[1]; Ragnhild Aune[1]; [1]Norwegian University of Science and Technology (NTNU)

Filtration of liquid aluminium is widely used in the industry for refining purposes prior to casting, and Ceramic Foam Filters (CFFs) are often the filtration media. Following an incident with generation of phosphine gas after cutting used alumina based CFFs, the need for improved understanding for the chemical reactivity and thermal stability of CFFs was realised. In the present work, three CFF substrates with varying $AlPO_4$ contents were investigated. The substrates, as produced and in contact with pure aluminium, were heat-treated in a vacuum induction furnace and in a Simultaneous Thermal Analyser at 850°C in an inert gas atmosphere. Mass changes of ~1m% were registered for the substrates, and ~3-9m% together with a clear colour change when in contact with aluminium. Chemical analyses of the aluminium after heat-treatment revealed that phosphorus from the binder had been reduced to aluminium phosphide, making further phosphine generation possible if in contact with water.

**M-13: Metallurgical Processing: A Key Component of the Engineering Education at KU Leuven and in the Sustainable Materials Master Programme of EIT Raw Materials**: *Bart Blanpain*[1]; [1]KU Leuven

If we believe that developing and practicing sustainable metallurgy is important, education programmes containing metallurgical procsing should also be encouraged to take center stage. In this talk we will show the position and approach on metallurgical processing in the KU Leuven materials engineering curriculum and in the recently developed new master programme in Sustainable Materials with as partners the Universities of Leoben (MUL), Grenoble (INP), Trento, Milano-Bicocca and KU Leuven that is organised with the support of the EIT RawMaterials. Both highlights and challenges in setting up and running the programmes will be discussed.

**M-14: Production of Iron Nuggets from the Pudo Iron Ore using Carbonaceous Materials Generated from Charred Corn Cob and its Blends with Waste High Density Polyethylene**: *James Dankwah*[1]; Sylvester Agbo[1]; Pramod Koshy[2]; James Dankwah[1]; [1]University of Mines and Technology; [2]University of New South Wales

In this work the potential for producing high grade iron nuggets from the Pudo iron ore in the Northern Region of Ghana is investigated using carbonaceous materials generated from charred corn cob (CCC) and its blends with high density polyethylene (HDPE) as reductants. Reduction studies were conducted on composite pellets of Pudo ore containing CCC, HDPE and blends of CCC with HDPE. Reaction products were then characterised by SEM/EDS and XRD and the extent of reduction after 40 min was determined for CCC, HDPE and the blends. XRD and FTIR analyses showed that individual polymers retained their chemical structure in the generated carbonaceous materials after the melting-quenching process. It was further observed that iron nuggets can be produced from the Pudo iron ore using CCC, HDPE and their blends. The measured extent of reduction was up to 98.7% and the maximum was attained for CCC:HDPE blend ratio of 2:3.

## Part C-1: Hydrometallurgy 2018 – Posters - Monday

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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*Session Chair:* Ahmet Deniz Bas, COREM

**M-16: The Kinetic of Atmospheric Acid Leaching of Brazilian Lateritic Nickel**: Andre Santos[1]; Emily Becheleni[1]; Risia Papini[1]; Paulo Viana[1]; *Sonia Rocha*[1]; [1]UFMG

Atmospheric processing of nickel lateritic ores with low costs has been encouraged. In this work the kinetic of atmospheric acid leaching of a northern-Brazilian ore with 1.63% Ni and large amount of fine particles (d50 ˜ 0.075 mm and 40% below 0.038 mm) is presented. Chemical analysis showed a trend of Ni and Fe concentration in finer fraction (-0.075 mm) and Si and Mg in the coarsest one (-0.500+0.150 mm) associated to distinct mineral phases. Nickel is widespread in the mineral matrix. Distinct behaviors were observed as a function of particle size associated to the distribution of silicates and iron oxides in the ore. The kinetic modeling indicated that leaching is controlled by porous layer diffusion at 65 °C, but at 95 °C exhibits a mixed control by porous layer diffusion in initial minutes (60 min) and by chemical reaction or diffusion through the pore layer in final minutes (60-240 min) depending on metal evaluated.

**M-17: Dy Permeation through an Alloy Diaphragm Using Molten Salt Electrolysis**: *Hirokazu Konishi*[1]; Hideki Ono[1]; Hang Hua[1]; Tetsuo Oishi[2]; Kouji Yasuda[3]; Toshiyuki Nohira[3]; [1]Osaka University; [2]National Institute of Advanced Industrial Science and Technology; [3]Kyoto University

We have been developing a new process for the separation and recovery of rare earth metals using molten salt electrolysis and an alloy diaphragm.This new process was first applied to chloride melts, and the separation of Dy from Nd and Pr were investigated using Cu, Ni and Zn cathodic electrodes in molten LiCl-KCl-DyCl3-NdCl3 and LiCl-KCl-DyCl3-NdCl3-PrCl3 systems. The highest mass ratio of Dy/Nd+Pr in Dy-Nd-Pr-Ni alloy sample was found to be 50 at 0.65 V (vs. Li+/Li) for 1 h by ICP-AES. In this study, the investigation of Dy permeation through Dy alloy diaphragm using molten salt electrolysis was investigated. The Dy permeation experiment was conducted with electrolytic cells in molten LiCl-KCl systems at 723 K in order to confirm the theoretical feasibility of the present process.

**M-18: Reuse Opportunity of Ferrous Grinding Wwarf from Automobile Industry**: Myungwon Jung[1]; Junxiu Han[1]; *Brajendra Mishra*[1]; [1]Worcester Polytechnic Institute

This research focused on the recovery of iron from ferrous grinding swarf. Grinding swarf comprised metal grindings, oil residue, and ceramic particles. Metalworking fluids provide better grinding properties by lubricating and cooling the interface between tool and material; however, it covers metal grindings after its use, and it is undesirable since the oil burns explosively during smelting operations for metal recovery. Based on the initial characterization, the sample contained about 78 % of metallic iron and 16 % of oil residue by weight (dry basis). Thus, aqueous washing with detergents was evaluated to obtain oil removed ferrous grinding swarf at different operating conditions. In addition to the aqueous washing, oxidation of ferrous grinding swarf at elevated temperatures was also conducted to find an alternative way to reuse the waste material as a pigment.

## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Posters - Monday

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

Monday AM
August 27, 2018

Room: Grand Foyer
Location: Westin Ottawa

*Session Chair:* Ahmet Deniz Bas, COREM

**M-19: Separation of Uranium and Molybdenum from Alkali Leaching Solution of U-Mo Ore**: *Meifeng Zhi*[1]; [1]Beijing Research Institute of Chemical Engineering and Metallurgy

Separation of uranium and molybdenum from alkali leaching solution of U-Mo ore was studied. The process of acidification-solvent extraction-precipitation uranium and molybdenum was determined. The influence of solution acidity and phase ratio of acidic washing on separation of uranium and molybdenum were examined. The molybdenum extraction equilibrium curve was drew. The results show that the separation of molybdenum and uranium can achieve by acidizing the alkali leaching solution to pH of 2.5, solvent extracting molybdenum using tri-fatty amine and washing the loaded organic phase using sulfuric acid solution. The strip solution can directly precipitate ammonium molybdate, and the raffinate neutralized can directly precipitate uranium which meets the correlation standards.

**M-20: Lithium Solvent Extraction with a Beta-diketone Reagent**: *Ernesto Bourricaudy*[1]; Ronald Molnar[2]; [1]SGS Canada Inc.; [2]MetNetH2O Inc.

SGS Canada's Lakefield laboratories undertook an investigation of lithium solvent extraction from a chloride brine. The extract used was a commercially available beta-diketone reagent (Hallochem's Mextral 54-100) mixed with a liquid phosphine oxide (Solvay's Cyanex 923) in an aliphatic diluent. This work was carried out to expand on the successful results reported by workers from CSIRO in Australia using a beta-diketone reagent of similar chemical structure in a similar extractant mixture. The current report expands on some aspects of the data reported in the earlier study. Extraction with a more concentrated reagent mixture enabled higher lithium loading to be attained. The results of preliminary scrubbing and stripping tests are also reported.

## Part C-3: Processing of Critical Metals – Posters - Monday

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

Monday AM
August 27, 2018

Room: Grand Foyer
Location: Westin Ottawa

*Session Chair:* Ahmet Deniz Bas, COREM

**M-21: Challenges with the Use of Lime and Limestone for Impurity Removal in Rare Earth Elements Hydrometallurgical Treatment; A Fundamental Look**: *Farzaneh Sadri*[1]; Ahmad Ghahreman[1]; [1]Queen's University

Lime neutralization has a high efficiency in removal of dissolved heavy metals from the solution. After water leaching of the REE acid baked concentrate, different chemicals can be used to remove impurities from the solution, among which lime and limestone are the cheapest options. Although the application of lime and limestone to the impurity removal stage in hydrometallurgical treatment of REE ores could reduce the costs of operation, they are not widely in use; A proportion of REE is lost to gypsum while removing other impurities. An insight into the role of REE on the crystal morphology of gypsum is essential for a better fundamental understanding of the cation-assisted crystallization of calcium sulfate dihydrate. It is the scope of this poster to investigate the mechanism of the REE-loss in the said process and REE dopants effect on the crystallization of dihydrate in a Ca(OH)2–H2SO4 system.

**M-22: Impurities Analysis of a Magnetic Waste before Leaching and Extraction of Neodymium and Praseodymium: Elaboration of Fe-Nd Alloys**: *Mohammed Azzaz*[1]; Azzeddine Lounis[2]; [1]University of Science and Technology Houari Boumediene,; [2]University of Science and Technology Houari Boumediene,

The rare earths are becoming increasingly important in improving energy efficiency and developing clean technologies. This is due to their essential role in permanent magnets. Neodymium-iron-boron magnets are the most often used rare-earth permanent magnet. The objective of our work involves three steps: first we analyze the impurities from a magnetic waste.The second step includes extraction and determining the content of major elements. The third step involves producing an Nd-Fe alloy. The neutron activation (neutron flux of 3.4x1012n/$cm^2$/s), the SEM/EDX and DRX are used. We begin with an embrittlement of our material with hydrogen followed by acid leaching. The detected elements are: Ni, Al, Ti, Cu, Mn, In, Ta, Ce, Sm, Eu, Np, Yb, Gd, Lu. The analysis of the magnet by EDX shows that this sample contains Fe, Nd, Pr, and boron. The alloys are elaborated by ball milling.

**M-23: Influence of substrate properties on the selective leaching performance of Co from cemented carbides**: *Gregor Kuecher*[1]; Stefan Luidold[1]; Christoph Czettl[2]; Christian Storf[2]; [1]CD Laboratory for Extractive Metallurgy of Technological Metals; [2]CERATIZIT Austria GmbH

A lack of basic knowledge about the semi-direct recycling methods for hard metals hinders the application in industrial scale. However, advantages like reduced expenses and lower environmental impact draw interest at future potentials. Consequently, this report aims to offer insight into the influence of varying bulky hard metal substrates during their lixiviation in acidic media with an oxidant. The statistical software Modde 11 assisted in the development of a DOE for evaluation of the impact of average grain size, binder content and TaC on the leaching characteristics. The other experimental parameters exhibited constant conditions in preference. Among them remain temperature, solution concentration and amount, duration as well as substrate surface exposed to liquid volume. Eventually, response surface diagrams and factors of the computed model equation describe the effects of varying substrate qualities on leached binder metal and selectivity.

## Last Call to Post Your Achievements: Extraction 2018 Poster Session – Posters - Tuesday

*Program Organizer:* Ahmet Deniz Bas, COREM

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| Tuesday AM | Room: Grand Foyer |
| August 28, 2018 | Location: Westin Ottawa |

*Session Chair:* Ahmet Deniz Bas, COREM

**T-1: Challenges in the Top Submerged Lance Technology (TSL)-AUSMELT**: *Avinash Kandalam*[1]; [1]TU Bergakademie Freiberg

One of the high temperature process investigations in Virtuhcon's project is on Top Submerged Lance (TSL) Technology at INEMET, TU Bergakademie Freiberg. The advantages of this technology are high reaction rates, less space-time footprint, multiple functionalities, low installation costs etc. These outstanding properties lead the TSL to play a vital role in the pyrometallurgy. The furnace exhibits a highly turbulent, aggressive and splashing environment during the pyrometallurgical extraction processes. These remarkable process conditions caused a demand on process simulations over a decade and are moderately established. The simulation results have not been validated with experiments until now because of the TSL conditions. Understanding and proving the complex phase transformations, thermodynamics, hydrodynamics and kinetics of the system is a challenging task. This poster presentation depicts the experimental complications and possible solutions in TSL which will help to validate the simulation results and a better understanding of the whole process.

**T-2: Experimental Study of the Thermal Stability and Chemical Reactivity**
**of the Phosphate-Based Binders Used in Ceramic Foam Filters (CFFs)**: *Cathrine Solem*[1]; [1]Norwegian University of Science and Technology (NTNU)

Filtration of liquid aluminium is widely used in the industry for refining purposes prior to casting, and Ceramic Foam Filters (CFFs) are often the filtration media. Following an incident with generation of phosphine after cutting used alumina based CFFs, the need for improved understanding for the chemical reactivity and thermal stability of CFFs was realised. In the present work, three CFF substrates with varying $AlPO_4$ contents were investigated. The substrates, as produced and in contact with pure aluminium, were heat-treated in a vacuum induction furnace and in a differential scanning calorimeter with a thermogravimetric analyser at 850°C in an inert gas atmosphere. Clear colour changes were observed when heated with aluminium. Chemical analyses of the substrates after heat-treatment revealed that the thermal stability and chemical reactivity of the phosphate-bonded $Al_2O_3$-based CFF substrates can be questioned after being heated in contact with metal, but no $PH_3$ (g) was generated.

**T-3: Leaching of Flotation Tailings in the Córrego do Sitio II Business Unit, Anglogold Ashanti**: *Márcio Pereira*[1]; Marcus Magalhaes[1]; Vinicius Assis[1]; Guilherme Peixoto[1]; José Gregorio Filho[1]; [1]Anglogold Ashanti

The business unit of Mine I of Córrego do Sítio belongs to Anglo Gold Ashanti, located in Santa Bárbara city, Minas Gerais, Brazil. The ore mining is underground (sublevel stopping), and much of the gold refractory (about 98.5%) is contained in a sulfide matrix, especially arsenopyrite. Tests indicated that the leaching of the tailings from the flotation circuit, currently destined for the tailings dam, could mean an increased global recovery process. Characterization by technology MLA (Mineral Liberation Analyzer) showed that there is loss in the flotation stage on behalf of the gold that is very fine and free. Cyanidation testwork enabled the recovery of 50% of the remaining gold in the tailings. The project implementation revealed to be a technical and economically practicable alternative.

**T-4: Potential of Ion Exchange Resins for Lithium Extraction from Brine**: *Hiroki Fukuda*[1]; David Dreisinger[1]; [1]The University of British Columbia

There is great interest in lithium ion exchange technologies due to the advent of lithium ion batteries for mobile devices and electric vehicles. This study conducted batch tests of 27 ion exchange resins for lithium extraction from artificial brine, which is similar to brines in the South America. Some cation exchange resins, especially strongly cation exchange resins, showed good ability to adsorb lithium from lithium chloride solution. They recovered lithium at around 60–80% in terms of their capacity. For artificial brine, however, the selectivity for lithium was so low that the resins couldn't preconcentrate lithium. They used only about 1% of their capacity for lithium, and the rest of sites were used for other ions such as sodium, potassium, calcium and magnesium ions in brine. Therefore, in order to enhance the selectivity, this study additionally carried out tests with resins whose functional sites were modified.

**T-5: Promising New Depressant for Pyrite in Polymetallic Sulfide Flotation**: *Jordan Rutledge*[1]; [1]Silvateam

Compelling research has been performed with Silvateam reagents, specifically Benefloat, on a Peruvian polymetallic sulfide ore. The results from these on-site studies of the zinc rougher circuit show that Benefloat was an excellent depressant for both pyrite and silica. Subsequently, the zinc grade showed a dramatic increase. Surprisingly, the zinc recovery also increased with the addition of Benefloat, potentially indicating that the dispersive properties of the reagent may help to fully disperse the ore in solution. Benefloat shows great promise as a depressant and dispersant for polymetallic sulfide circuits.

**T-6: Separation of Uranium and Molybdenum in U-Mo Ore Alkaline Leach Liquor**: *Meifeng Zhi*[1]; Zujun Shu[1]; Zhiquan Zhou[1]; [1]Beijing Research Institute of Chemical Engineering and Metallurgy

Separation of uranium and molybdenum in the alkaline leach solution of a U-Mo ore was studied. A process of acidification-solvent extraction-precipitation uranium and molybdenum was determined. The influences of solution acidity and phase ratio of acidic scrubbing on separation of uranium and molybdenum were examined. The molybdenum extraction equilibrium isotherm was drawn. The results show that the separation of molybdenum and uranium can be achieved by acidifying the alkaline leach solution, solvent extracting molybdenum using trialkylamine at equilibrium pH 2.5, and scrubbing the loaded organic phase using sulfuric acid solution. The strip solution can directly precipitate ammonium molybdate. Uranium can be directly precipitated from the raffinate.

**T-7: Silver Recovery from the Electronic Wastes Using Thiourea Leaching and Cyclone Type Electrowinning Cell**
: *Jae-Woo Ahn*[1]; Hong-il So[1]; Joo-eun Lee[1]; In-hwan Jang[1]; [1]Daejin Univ

The recovery of silver from electronic wastes was studied with acidic thiourea leaching and electrowinning process. The thiourea leaching of silver from the electronic waste was carried out with 60 g/L solid/liquid ratio, 0.6 M thiourea and 0.1 M hydrochloric acid at 600 rpm and 35°C. The results showed that more than 99% of silver could be leached out and the impurities such as aluminium, calcium, iron, strontium, zinc were dissolved less than 17% in the leachate. After leaching, in order to recover the silver from the solution, cyclone type electrolytic cell was used to obtain the metallic form. As a result, more than 99% of silver was achieved in the powdery form at the flow rate of 12 L/min., current density of 0.75 A/dm2, and 35°C. The average particle size and the purity of the recovered silver powder was 20µm and 99.5% respectively.

**T-8: Simulation of the Solvent Extraction Process Applied to the Rare Earth Elements Separation**: *Keven Turgeon*[1]; [1]Université Laval
Achieving the separation of rare earth elements (REE) is a hydrometallurgical challenge. Most Canadian REE companies consider producing a concentrate bulk of all the REE to sell to a refinery which separates individually the REE due to the lack of knowledge of both, operation conditions and the cost of the separation. To answer this problem, we are currently developing our own counter-current solvent extraction simulator at Université Laval that can assay different configurations of solvent extraction circuits and operation conditions to achieve the desired separation of REE. This simulator is also being used for the estimation of the capital and operation costs. Such simulators are not widely available. The benefit of a simulator is the reduced cost and time of testing separation circuits.

**T-9: Thermal Plasma Extractive Metallurgy for E-waste Recycling**: *Jonathan Cramer*[1]; Daniel Morvan[2]; Frédéric Prima[2]; Frédéric Rousseau[2]; [1]Fondation Paristech; [2]Chimie ParisTech
Recycling processes are now widely recognized as one of the solutions against the primary mineral resources supply risk. The most developed countries are aware of this issue and aim to find innovative processes to recycle strategical metallic elements. Within the framework of alternative new recycling processes, we use the thermal plasma media to perform extractive metallurgy. The selective extraction and recovery of desired metal in binary/ternary samples alloys (FeCu, CuSn, CuSnIn…) has been carried out by a 15kW enhanced plasma process with the further objective to recycle strategic metals from more diverse and complex matrices. The enhancement lies in the modification (additives) and the control of the hot plasma chemical reactivity and temperature. The extracted elements are transported by the plasma flow and recovered by condensation on a capture plate. Multiple diagnosis tools (OES, LIBS, DRX, ICP…) are employed in-situ and ex-situ so that an extraction mechanism can be proposed.

**T-10: Use of Non-cyanide Lixiviants for the In-situ-leaching of Gold**: *Oscar Olvera*[1]; [1]AuTec Innovative Extractive Solutions Ltd.
To date, in-situ leaching (ISL) mining has been commercially applied for the recovery of copper and uranium only. In gold leaching, the most common leaching agent is cyanide. The application of ISL to gold mining has not been possible because of the threat that cyanide presents to the environment. Substitution of cyanide by other reagents could bridge the current gap that exists between ISL mining and the gold industry. Previous and current research has shown that gold dissolution is feasible using halides, aminoacids and calcium thiosulfate. In this work we compare different lixiviants for gold dissolution and assess the challenges and opportunities inherent to each technology from a thermodynamic and dissolution kinetics perspective.

**T-11: Selective Precipitation of Cerium from Acidic Rare Earth Solutions**: *James Mcneice*[1]; [1]Queen's Universuty
Separation of rare earth elements (REE) ores is usually achieved by acid leaching followed by solvent extraction (SX), to purify individual rare earth metals (REM). Cerium is commonly accounts for 50 % of the REE in ores. Demand for less prevalent REE, such as neodymium have caused an overproduction and devaluing of cerium relative to processing costs. To improve the economics of REE separation, cerium should be precipitated from solution prior to SX, via the oxidation of cerium (III) to cerium (IV). This poster contains an overview of selective oxidation of cerium in acidic solutions using the oxidants hydrogen peroxide, sodium hypochlorite, potassium permanganate, and Caro's Acid. Test conditions ranged from pH 1 - 4, 25 to 65 °C, cerium concentrations of 2 to 16 g/L, stoichiometry of 100 to 150 %, and with REE present in solution. Cerium recovery ranged from 14.2 to 99.99 %, depending on test conditions.

## Part A: Extractive Metallurgy Markets and Economics – Posters - Tuesday

*Program Organizers:* Luisa Moreno, Tahuti Global; Boyd Davis, Kingston Process Metallurgy Inc

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**T-12: Defying the Resource Curse: Why Transforming the Workplace Matters**: *Gracelin Baskaran*[1]; [1]University of Cambridge
Development literature often refers to rich endowments of oil and minerals as a 'natural resource curse.' According to Joseph Stiglitz, resource extraction can be a curse because it involves low job creation and as a result, unemployment increases. While technological advancements in the mining sector have introduced complex operating systems and machinery, there is still a severe shortfall in skilled labour to operate, maintain, and repair this technology. Mining firms have an unprecedented need to train and retain skilled labour to meet the demands of automation. This presentation will examine how firms can alter organizational practices to develop relational contracts - by creating a workplace with horizontal information flows, implementing skills development programs, and creating inter-firm mobility structures - thereby training and retaining workers, and ultimately increasing firm productivity and developing a more sustainable industry.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Posters - Tuesday

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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**T-13: Thermodynamic Modeling of Oxygen Bottom-Blowing Continuous Converting Process**: *Songsong Wang*[1]; Xueyi Guo[1]; [1]School of Metallurgy and Environment, Central South University, Changsha 410083, Hunan, China
Recently, replacing Pierce-Smith converting process with the oxygen bottom-blowing continuous converting technology has become a new research focus. Based on the principle of Gibbs free energy minimization, the thermodynamic model of oxygen bottom-blowing continuous converting multi-phase equilibrium system has been established. The elements distribution behavior is calculated at the same burden composition and operation parameters as the industrial production. The results show that the absolute errors of the mass fraction(wt %) of Cu, Fe, S, Pb, Zn, As, Sb, Bi in crude copper are 0.06, 0.0030, 0.070, 0.38, 0.39, 0.020, 0.017, 0.034, 0.010, respectively, and the absolute errors of the mass fraction (wt %) of Cu, Fe, S, Pb, Zn, As, Sb, Bi in slag are 0.53, 0.81, 0.020, 0.23, 2.5, 0.0048, 0.0010, 0.0030, 1.49, respectively. The calculated results agree well with the actual industrial production data, indicating that the model can be well applied in the oxygen bottom-blowing continuous converting practice.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Posters - Tuesday

*Program Organizers:* Evgueni Jak, Pyrosearch, The University Of Queensland; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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**T-14: Application of Microwave Technology to the Production of Iron Nuggets from the Akpafu-Todzi Iron Ore using Mixed Plastics Waste as Reductants**: *James Dankwah*[1]; Bernard Agbenuvor[1]; Clement Owusu[1]; Pramod Koshy[2]; [1]University of Mines and Technology; [2]University of New South Wales

One challenge often encountered in waste plastics recycling is the need to sort out plastics waste into individual plastics. In this work the potential for producing iron nuggets from the Akpafu-Todzi iron ore in Ghana is investigated using mixed plastics waste (MPW) as reductants. Two variants of MPW (MPW1 and MPW2) were used along with the individual polymers as reductants. MPW1 was comprised of 40% PWS, 30% PP, 20% LDPE and 10% PS while MPW2 consisted of 40% PWS, 30% PP, 20% LDPE and 10% PET. Reduction studies were conducted on composite pellets of the ore containing MPW1, MPW2 and the individual plastics. Reaction products were characterised by SEM/EDS and XRD and the extent of reduction after 20 min was determined for MPW1, MPW2 and the individual polymers. It was observed that iron nuggets can be produced from the Akpafu-Todzi iron ore using MPW1, MPW2 and the individual waste polymers.

**T-15: Assessing the Techno-economic Feasibility of High-pressure Oxy-fired Flash Metallization of Iron Ore**: *Mohammad Asiri*[1]; Marc Duchesne[1]; Robin Hughes[1]; Bruce Clements[1]; [1]Natural Resources Canada

CanmetENERGY-Ottawa is developing a transformative technology for the iron and steel industry, in which, iron ore concentrate is directly reduced to liquid iron in a pressurized entrained flow reactor (PEFR). The direct reduction of the ore concentrate allows for the elimination of pelletization/sintering as well as the use of natural gas as a reductant, in place of coke. Process conditions require temperatures in excess of 1500 °C and elevated operating pressures beyond what would typically be seen in steel production processes. Various process arrangements were modelled using Aspen HYSYS to obtain material and energy balances. An economic analysis was then performed for the arrangements and compared to blast furnace and direct reduced iron (DRI) processes. The economic performance of the technologies was then compared under various market conditions to assess the feasibility of pressurized flash metallization as a next-generation technology.

## Part C-1: Hydrometallurgy 2018 – Posters - Tuesday

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinery; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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**T-20: Solvent Extraction of Rh(III), Pt(IV) and Pd(II) from HCl with Amide-containing Tertiary Amine Compounds**: *Hirokazu Narita*[1]; Mikiya Tanaka[1]; [1]National Institute of Advanced Industrial Science and Technology

We have found that amide-containing tertiary amine (ACTA) compounds exhibit high extraction efficiency for platinum group metal (PGM) complex anions in HCl solution. Among ACTA compounds, N-2-ethylhexyl-bis(N-di-2-ethylhexyl-ethylamide)amine (EHBAA) seems to be the most suitable for practical use, because EHBAA is superior in terms of solubility of extractants in practical diluents, formation of a third phase and so on. EHBAA extracted about 100% of Pd(II) and Pt(IV) in the studied HCl concentration range (0.5-10 M). The extraction efficiency of Rh(III) drastically decreased above 3 M HCl. In contrast, both Fe(III) and Cu(II) were quantitatively extracted above 3 M HCl. The extracted Fe(III) and Cu(II) were selectively scrubbed with distilled water over PGMs.

**T-17: Insights into the Surface Chemistry of Activated Carbon-catalyzed Arsenic Oxidation**: *Chengqian(Charles) Wu*[1]; Rebecca Radzinski[1]; Ahmad Ghahreman[1]; [1]Queen's University

Arsenic is a highly toxic element commonly associated with gold/copper-bearing ores. The arsenic immobilization is becoming increasingly crucial for mining and metallurgical operations. Activated carbon-catalysed arsenic oxidation is a promising process that employs oxygen as the sole oxidant. Surface chemistry is a significant and complex factor driving the catalyzed process which involves the oxidation and adsorption of arsenic species, occurring simultaneously. X-ray photoelectron spectroscopy was employed to examine the surface of activated carbon, treated with As(III) and/or As(V) solutions. Approximately 25% of the elements on the carbon surface was determined to correspond to O 1s spectra indicating large amounts of oxygen functional groups on the activated carbon surface which help the arsenic oxidation. Freundlich adsorption isotherm model was determined to best describe the characteristics of the activated carbon for As(III) and As(V) adsorption with an n parameter of 1.01 and a KF value of 0.01.

**T-16: Gold Leaching by Sodium Chloride and Calcium Hypochorite Solutions**: Felipe Avelino; Andreia Resende[1]; *Versiane Leão*[1]; [1]Universidade Federal de Ouro Preto

The search for environmentally friendly and cost-effective methods for gold extraction has been undertaken in order to provide alternatives to the use of cyanide leaching in the gold industry. Among such alternative reagents is the combination of chloride and hypochlorite ions due to their oxidation of metallic gold and its complexation. Therefore, the current work aims at investigating gold leaching from an oxidized material by means of a solution comprising calcium hypochlorite and sodium chlorite. The sample used in the current research contained 66.1% Fe2O3, 20.4% SiO2, and 35.7g/t of Au. In addition, XRD and SEM-EDS analysis revealed iron oxide, quartz and muscovite as the main crystalline phases in the sample. For comparison purposes, cyanidation of the oxidized material resulted in 90% gold extraction in 24 hours. The reference conditions for the leaching tests with the chlorite-hypochlorite system were: particle size -37µm, solid/liquid ratio of 10% (w/v), 10g/L NaCl, 10g/L Ca(OCl)2, pH 5-6, 3 hours of leaching. The effects of the: (i) Ca(OCl)2 concentration, (ii) NaCl concentration, (iii) pH range and (iv) the effect of pulp density in the extraction of gold were assessed. In addition, the stability of the hypochlorite solutions (OCl-) was investigated. The ideal concentrations of Ca(OCl)2 and NaCl were determined as 25g/L and 15g/L, respectively, whereas the optimal pH range was 4-6. Under these conditions, the final gold extraction reached approximately 84%. By varying the solids content of the pulp (10%, 20% and 30%), it was observed that the lower solids value resulted in greater gold extraction (84%). The degradation of the hypochlorite solution and the possible catalytic effect of the presence of the solid were evidenced. To sum up, in the experiment, high gold extractions were achieved in shorter periods of time (3 hours), as compared to the cyanidation of the same sample. On the other hand, it was necessary to use significant amounts of the reagent due to hypochlorite instability at the pH conditions recommended for high gold extractions.

**T-18: Selective Recovery of Manganese from Anode Sludge by Reductive Leaching**: *Toni Kauppinen*[1]; [1]Kokkola University Consortiu

Manganese oxide containing anode sludge is a common side product in zinc electrowinning. Anode sludge mainly consists of oxidized manganese (>40 %) and lead (>15 %). Selective recovery of manganese can be achieved by reductive sulphuric acid leaching. In this work reducing agents, temperature and solid to liquid ratio were investigated. Concentrated manganese sulphate solution can be obtained while concentrations of unwanted calcium and lead are limited. Pure manganese sulphate solution can be manufactured by adjusting reaction conditions. After refining planned uses could include chemical, fertiliser or battery industry.

**T-19: Separation and Extraction of Valuable Elements from Lead Matte**: *Gang Xie*[1]; Yuan NI[2]; Hongquan HUA[3]; Xiaohua YU[4]; [1]Technology Center of Yunnan Metallurgy Group Co.Ltd.; [2]Zinc Co., Ltd. of Yunnan Copper; [3]Yunnan Copper Company of science and technology; [4]Kunming University of Science and Technology

A full hydrometallurgy of retrieving copper, indium and zinc from lead matte is represented in this paper. Leaching solution which contains copper, indium and zinc is obtained by pressure leaching, various factors such as discussed sulfuric acid concentration, temperature, pressure, liquid-solid ratio, leaching time, grinding time are discussed. The leaching rate of copper, indium and zinc are 95%,88% and 97% under the optimum conditions respectively. Separating copper and indium by extraction under the situation of high-acid, concentration of extractant, mixing time, mixing ratio, extraction stage and multi-stage counter current extraction are investigated. The recovery rate of copper and indium are 94% and 98% if multi-stage counter current extraction under the optimum conditions is carried out.

## Part C-3: Processing of Critical Metals – Posters - Tuesday

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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**T-21: Rare-Earth Elements Recovery from Nd-Fe-B Hard Magnets by Hydrometallurgical Processes**: *Haydar Günes*[1]; Hüseyin Eren Obuz[1]; Furkan Çapraz[1]; Ezgi Ogur[1]; Murat Alkan[1]; [1]Dokuz Eylül University

In this study; the elements in the Nd-Fe-B hard magnetic structure have been recovered by hydrometallurgical processes. The rare-earth elements in the scrap (Nd, Dy and Pr) Nd-Fe-B hard magnet have been extracted by using hydrometallurgical process and then they have been recovered to compound form. Nowadays, the most used magnets are Nd-Fe-B hard magnets in electronical devices. This study also containing recovery or evaluate the other elements (Fe, B, coating materials) that in the magnet system. The chemicals that have been used during the study will be available again and avoid the poisonous gas emission. If the gas emission is cannot be avoided, these gases will be reused, stored or harmonized. The process will be designed for pilot scale industrialization. Nd-Fe-B hard magnets will be dissolve in solvent and the solution will be characterized. Precipitation agent and parameters will be determined and precipitation/extraction processes are proceed. The process efficiency will be calculated after the final characterization. The optimum experiment parameters will be determined.

## Part D: Sulfide Flotation – Posters - Tuesday

*Program Organizers:* Ronel Kappes, Newmont Mining Corporation; Tarun Bhambhani, Solvay

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*Session Chair:* Ahmet Deniz Bas, COREM

**T-22: Influence of Pulp Conditions on Oxidation, Grade and Recovery of Sulphide Minerals**: *Margreth Tadie*[1]; [1]Stellenbosch University

The semi-conducting properties of sulphide minerals have been exploited for their recovery in flotation since the discovery of xanthates collectors which are known to interact electrochemically with sulphide minerals. Interest in the effect of pulp potential on recovery is worth revisiting as mining depletes high grade ores leaving ores of increasingly complex mineralisation to be recovered. Whilst potential modifiers such as hydrogen peroxide have been applied in laboratory tests to control potential their possible application to operations still requires investigation. In this work, hydrogen peroxide is investigated as a potential modifier to two sulphide bearing ores from the Bushveld Complex in South Africa. It is found that low concentrations of hydrogen peroxide below 0.001 M can result in increased recovery and grade of sulphide minerals. Fundamental studies in the form of zeta potential measurements and voltammetry are used to provide further insight into the interaction of peroxide with sulphide minerals.

## Last Call to Post Your Achievements: Extraction 2018 Poster Session – Posters - Wednesday

*Program Organizer:* Ahmet Deniz Bas, COREM

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| Wednesday AM | Room: Grand Foyer |
| August 29, 2018 | Location: Westin Ottawa |

*Session Chair:* Ahmet Deniz Bas, COREM

**W-1: A Fundamental Study of Hydrodynamic Cavitation Effect on Fine Particles Floc Generation and Flotation**: *Hao Huang*[1]; Nguyen Thuy Vu Truong[1]; Yuran Chen[1]; Mingda Li[1]; Qingxia Liu[1]; [1]University of Alberta

The hydrodynamic cavitation has been applied in the mineral flotation process to enhance the recovery, which was mainly explained by the generation of flocs in the cavitation process. This study aims to investigate the mechanism of flocs generation in hydrodynamic cavitation. The Venturi tube as a hydrodynamic cavitation device and fine molybdenite particles (<37µm) were investigated. The formations of flocs in different conditions were studied by measuring particle size distribution, microscopic imaging, turbidity, and zeta potential distribution. Experiment results demonstrated that fine particles are aggregated via the bubble bridge. The recovery of fine particles after cavitation has an increase of 10% in the micro-flotation test by using Hallimond tube, which could be explained by the formation of flocs through the cavitation enhanced the floatability of fine particles. The findings provide an important contribution to the fundamental understanding of the role of hydrodynamic cavitation on the enhancement of fine particles recovery.

**W-2: An Investigation of the Impact of L-Cysteine on Elemental Sulphur Formation and Retention in the Application of Atmospheric Pyrite Oxidation.**: *Denver Cowan*[1]; Ahmad Ghahreman[1]; [1]Queen's University

Two carbon-based catalysts (AF 5 and activated carbon) enhanced atmospheric oxidation of pyrite, and improved elemental sulphur formation. AF 5 promoted amorphous sulphur formation with nearly 100% sulphur retention, while activated carbon promoted the formation of crystalline sulphur globules with 60% found in the solid residue.XPS indicated the presence of a sulphur group on AF 5, likely that of L-cysteine. L-cysteine could promote the sulphur formation found during testing with AF 5, thus enhancing elemental sulphur retention. This study intends to determine if L-Cysteine does promote the generation and/or retention of elemental sulphur on the catalyst surfaces during pyrite oxidation. PET and HDPE beads were doped with L-Cysteine and included in bench scale oxidative pyrite leaches in ferric sulphate media for 48h at 55°C. Carbon-sulphur determination, TGA and XPS analysis were used to analyze solid samples. The findings indicate that L-Cysteine does aid in elemental sulphur generation and retention.

**W-3: Energy Efficient and Environmental Friendly Production of Electrolytic Manganese Dioxide (EMD)**: *Mbuyu Ntunka*[1]; Brian Loveday[1]; [1]University of KwaZulu-Natal

The conventional process of production of electrolytic manganese dioxide (EMD) requires the ore to be reduced by contact with coal at high temperature, to facilitate leaching in sulphuric acid. However, it was noted that the ore can be leached directly, using ferrous ions and acid and that the conventional electrolytic stage generates hydrogen, which is hazardous. A significant reduction in the voltage for electrolysis was achieved and the environmental unfriendly and costly ore reduction process was eliminated. Laboratory tests included leaching size fractions of ore, to determine the effects of particle size, acid concentration and leaching temperature. The conditions required for conventional plating of MnO2 were compared to plating with a membrane, and ferrous/ferric ions in the body of the cell. It was concluded that the process was technically feasible and that it offered significant potential to reduce the basic costs.

**W-4: Extraction and Separation of Vanadium and Molybdenum from Estonian Phosphorite Using Ionic Liquids**: *Liis Siinor*[1]; Carolin Siimenson[1]; Silvester Jürjo[1]; Päärn Paiste[1]; Enn Lust[1]; [1]University of Tartu

Rare-earth elements (REEs) as well as Vanadium and Molybdenum are becoming increasingly important in the transition from traditional economy to novel more efficient, green and low carbon economy as REEs are applied in innovative technologies, such as strong permanent magnets, Li-ion, and Na-ion batteries, fuel cells, solid oxide electrolyzers etc. In the report "Critical raw materials" (2014) made for the EU, REEs are associated with the highest long-term supply risks and the highest predicted demand growth. Separation of individual REE is challenging due to the similar physical and chemical properties of REEs. The most promising method is the homogeneous liquid–liquid extraction. Ionic nature of IL makes them thermodynamically favourable solvents for extractions of various ionic species from acidic or basic aqueous media. In current work we determine the content of Estonian phosphorite and separate V and Mo of it using ionic liquids such as OMImPF6, HMImPF6 and Aliquat 336.

**W-5: Flash Furnace Burner Sensor for Monitoring Combustion**: *Arthur Stokreef*[1]; Hans-Peter Loock[1]; Jack Barnes[1]; Boyd Davis[2]; Trevor Lebel[2]; Roberto Parra[3]; [1]Queen's University; [2]Kingston Process Metallurgy Inc.,; [3]University of Concepcion

A new, patented sensor for burner monitoring in copper flash smelting is being developed. The sensor uses fiber optics and optical emission spectroscopy to measure flame temperature and stability in real-time based on the black-body emission collected from flash combustion reactions. Proof of concept testing in the lab was done using a continuously fed, drop tube reactor with oxygen:sulfur ratios between 0-4. The testing was done on four different feeds to compare the emission spectra, flame temperatures and reaction mechanisms. Emission lines from Na (589.43 nm) and K (766.5 and 769.9 nm) were observed in the signal from all feeds, however the temperature of the flame in the lab was not high enough to produce copper or iron emissions which would be useful for diagnosing the flame quality. The temperature attained by the flame was found to be dependent on the feed material and the oxygen:sulfur ratio.

**W-6: Methodology to Optimize the Pressure Oxidation Step for Refractory Ores by Multiple Regression**: *Marcus Magalhaes*[1]; Márcio Pereira[1]; Vinicius Assis[1]; Guilherme Peixoto[1]; Sônia Denise Rocha[2]; [1]Anglogold Ashanti; [2]Universidade Federal de Minas Gerais

Gold extraction at the Córrego do Sítio mine, Anglogold Ashanti, Brazil, involves the concentration of sulphides in its processing stages, with 98% of the gold associated with arsenopyrite, a concentrate characterized by a high degree of refractoriness. Such concentrates are decomposed by a reaction involving the oxidation of sulfide by oxygen. The oxidation step is conducted in an autoclave at 225 ° C and 3,200 kPa of oxygen gas pressure with continuous feed. Continuous efforts are employed to optimize the oxidation step, results obtained from the database of the operation of the previous and subsequent stages, the oxidations of the concentrate were used to build a short-term production optimization model. The model allowed to determine the relationship between recovery of the flotation stages, sulfur content in the concentrate, CIL recovery and oxidation degree generating an increase in the global recovery of the metallurgical plant.

**W-7: Recoveries of Elements from Coal Fly Ash Using Sulphuric Acid**: *Momboyo Clotilde Apua*[1]; Geoffrey S. Simate[1]; [1]University of the Witwatersrand

Coal fly ash (CFA) sample produced in coal fired power plants contains substantial amounts of oxides of iron, aluminium, and other strategic elements like silicon, magnesium, and calcium for the synthesis of wastewater treatment coagulant. In order to produce a coagulant, the dissolutions of these elements from CFA were investigated in sulphuric acid (H2SO4) media. The effects of contact time, H2SO4 concentration, temperature, and solid to liquid ratio were explored for the dissolution process. Leach residues were characterized using particle size distribution (PSD), X–ray diffraction (XRD), X–ray fluorescence (XRF), Fourier transform infrared (FTIR), and scanning electron microscope (SEM). Thermodynamic feasibility was explored using Hydra/Medusa software. The leaching efficiency of iron, aluminium, silicon, magnesium, and calcium were 57.90%, 33.86%, 11.12%, 73.21%, and 25.43% respectively, in 1.5 M H2SO4, pH ranges from 0.5 to 3.9, at 300 rpm, 150 °C, 0.20 solid to liquid ratio and leaching period of 6 h.

**W-8: Selective Flotation Separation of Copper-molybdenum Sulfides by a Nontoxic and Cost-effective Derivative of Chitosan**: *Duowei Yuan*[1]; Ken Cadien[1]; Qi Liu[1]; Hongbo Zeng[1]; [1]University of Alberta

The flotation separation of Cu-Mo sulfides generally relies on the toxic and hazardous depressants such as sodium sulfide. In this work, a nontoxic, biodegradable and cost-effective derivative of chitosan, O-Carboxymethyl chitosan (O-CMC), has been explored as a selective depressant for molybdenite during the Cu-Mo flotation separation. Single mineral flotation tests revealed that O-CMC strongly depresses molybdenite flotation from pH 3 to 11, while chalcopyrite flotation was not affected by O-CMC in most pH range. Mixed minerals flotation confirmed O-CMC depresses the molybdenite well without significantly affecting chalcopyrite recovery and selective separation was achieved from pH 3 to 11. The adsorption characteristics of O-CMC on both minerals and the interaction mechanisms were investigated by electrokinetic study, AFM imaging and ToF-SIMS analysis, which revealed that the interactions between chalcopyrite and O-CMC are relatively weak physical interactions such as electrostatic interaction, while the interactions between O-CMC and molybdenite are dominated by hydrophobic interaction.

**W-9: The Development of an Integrated Testing Methodology for In-situ Leaching**: *Benjamin Kresnyak*[1]; Benoit Bissonnette[2]; [1]AuTec; [2]Barrick Gold Corporation

In-Situ-Leaching (ISL) is becoming an area of focus due to the ever increasing difficulties in mining ores that are either too deep for open pit, or too low grade for conventional underground mining. AuTec and Naturafrac have developed an integrated testing methodology that includes material properties testing, ore stimulation using Naturafrac's patented Multi-Pulsed Dynamic High Pressure Combustion Technology and AuTec's pipe and large vessel leaching techniques on alternative leachants like glycine and iodine. This poster presents the various processes and techniques used to assess the potential for ISL of an ore.

## Part A: Extractive Metallurgy Markets and Economics – Posters - Wednesday

*Program Organizers:* Luisa Moreno, Tahuti Global; Boyd Davis, Kingston Process Metallurgy Inc

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**W-10: Economics of Metal Production in Mars**: *Pedro Pino Veliz*[1]; Elpidio Reis[2]; [1]PEK TEKNEP OVERSEAS ENGENHARIA S. A. ; [2]PEK TEKNEP OVERSEAS ENGENHARIA S. A.

The paper analyze and discuss market fundamentals to support Martian mining and metallurgy and to compare the probably Martian price and supply of some metals. The authors assumed that in Mars will possible to find and exploit some of the most common metals available in Earth like nickel, copper, titanium, iron, platinum, palladium and chromium. The vast volcanoes identified on Mars are indicative that large igneous provinces probably should be found.The paper will discuss the economic fundamentals of exploration, mining and metallurgy of minerals products in Mars to supply raw material for development of a fully robotized mining and metallurgical industry aiming the production of equipment and installations to produce "Made in Mars" system for future generations. The main source to support the paper are detailed studies and public data available from NASA, European Space Agency and other international academic and public entities.

## Part B-1: 7th International Symposium on Advances in Sulfide Smelting – Posters - Wednesday

*Program Organizers:* Dean Gregurek, RHI Magnesita; Joel Kapusta, BBA Inc; Thomas Battle, Extractive Metallurgy Consultant; Mark Schlesinger, Missouri University of Science & Technology; Gerardo Alvear Flores, Aurubis

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**W-11: Thermodynamic Considerations of Copper Complex Resources Smelting Process**: Miao Tian[1]; Xue-Yi Guo[1]; [1]School of Metallurgy and Environment, Central South University, Changsha, 410083, Hunan, China

Large quantities of copper complex resources are produced globally and urgent to be cleaner processed. This article presents a thermodynamic calculation and performance analysis of mix smelting process with low-grade polymetallic copper sulfide concentrates, high copper content sulfide concentrates, metallurgical by-products (copper removal slag from lead metallurgy), and copper powder from electronic waste. A top blown smelting reactor to simulate mix smelting process is developed using a metallurgical process simulator, METSIM. Reactor parameters, heat loss and phase distributions are estimated from actual plant data. The proper proportion between complicated primary and secondary copper resources is proposed by analyzing the influence of the feed rates of various resources, oxygen, silica flux and revert on the smelting performance. Autogenous smelting processs is built by optimized matching materials of copper complex resources, in terms of the reactor temperature, copper content in matte and slag, and the percentage of magnetite in slag.

## Part B-2: Peter Hayes Symposium on Pyrometallurgical Processing – Posters - Wednesday

*Program Organizers:* Evgueni Jak, Pyrosearch, The University Of Queensland; Graeme Goodall, XPS- Glencore; Gerardo Alvear Flores, Aurubis

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**W-12: Calcination Behaviour of a Naturally Occurring Siderite Ore and its Amenability to Reduction by Waste Polymers**: *James Dankwah*[1]; Pramod Koshy[2]; James Dankwah[1]; Jessica Dankwah[3]; [1]University of Mines and Technology; [2]University of New South Wales; [3]Goldfields Ghana Limited (Damang Mine)

Siderite (FeCO3) ore from Guizhou, China was heated for 40 mins in air in the absence and presence of high density polyethylene, HDPE, (sourced from waste pure water sachets) in a horizontal tube furnace and gas fired furnace. Solid reaction products were characterised using XRF, XRD and SEM/EDS analyses whilst gaseous products were analysed by a continuous infrared gas analyser. Composite pellets of the calcined product with HDPE were then heated in a gas fired furnace for 180 mins and the product was analysed by XRD and SEM/EDS analyses. The solid products after calcination were found to be highly magnetic with Fe2O3 composition of 95.82% compared with an original Fe2O3 composition of 51.43% Composite pellets of the calcined product with HDPE were easily transformed to premium grade metallic iron after heating for 20 mins in the microwave oven.

**W-13: Pyrophos: the smelting of phosphorus from phosphorite concentrates and ore**: *Steven Wright*[1]; Brian Campbell[2]; Ewan Wingate[3]; [1]CSIRO Mineral Resources; [2]Pyrophos Pty Ltd.; [3]ProcessCapital Pty Ltd.

The Pyrophos process is an opportunity to recover phosphorus from phosphorite ores using a top submerged lance (TSL)/bath furnace. Smelting provides a real alternative to wet acid processing. Pyrophos's reductive smelting produces a phosphorus rich gas, where P2 is recovered, oxidised to P2O5 and converted to phosphoric acid. Financial, process and thermodynamic modelling showed that Pyrophos was economic, especially when combined with post combustion heat recovery. The key is to maximise value from product streams, acid, heat and slag. The majority of the phosphorus should be recovered as gaseous P2 and converted to high grade acid. Heat is recovered from complete post combustion. The slag has qualities for cement making or is suitable as road base. Laboratory evaluation of ore/concentrate from an Australian deposit confirmed low levels of phosphorus in the slag and high phosphorus recoveries were achievable. Preliminary financial evaluation strongly suggests that Pyrophos is viable.

## Part C-1: Hydrometallurgy 2018 – Posters - Wednesday

*Program Organizers:* Michael Free, Univ of Utah; Edouard Asselin, Univ of British Columbia; Alexandre Chagnes, University of Lorraine; David Dreisinger, University of British Columbia; Matthew Jeffrey, Newmont; Jaeheon Lee, University of Arizona; Graeme Miller, Miller Metallurgical Services Pty Ltd; Michael Moats, Missouri S&T; Ronald Molnar, MetNetH2O Inc.; Jochen Petersen, University of Cape Town; Niels Verbaan, SGS Canada Inc; Shijie Wang, Rio Tinto, Kennecott Utah Copper Refinergy; Virginia Ciminelli, Univ Federal of Minas Gerais-UFMG; Qian Xu, Shanghai University,China

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**W-14: Selection of Microorganism for the Bio-oxidation of a Refractory Gold-concentrate with Focus on the Behaviour of Antimony Sulphides**: Liliane Carvalho[1]; Suzimara Silva[1]; Romeu Giardini[1]; Lucas Magalhaes[1]; Michael Rodrigues[1]; *Versiane Leão*[1]; [1]Universidade Federal de Ouro Preto

In the current study, bio-oxidation tests were carried out in shaking flasks with a flotation concentrate containing the sulphides pyrite, arsenopyrite and gudmidite. The tests were performed with mesophilic microorganisms (At. ferrooxidans) at 30°C and also with the moderate thermophile S. thermosulfidooxidans, at 50°C. The effects of (i) previous adaptation of the microorganisms to the concentrate, (ii) ferrous iron concentration and (iii) pulp density (2%, 4% and 6% (w/v)) on the dissolution of the sulphide were studied through arsenic extractions. S. thermosulfidooxidans was more sensitive to the pulp density in comparison to At. ferrooxidans as a reduction in sulphide oxidation was observed with the increase in the solid content to 6%. Therefore, the mesophilic strain was selected for further work, which comprised a rolling bottle experiment at 10% solids. After 40 days of bio-oxidation, the solid material was subjected to cyanidation, which revealed 85% gold extraction as compared to 21% from the original concentrate. The antimony sulphide grains in the bio-oxidized product showed similarity to what was observed in the original sample, suggesting such particles were not susceptible to the bio-oxidation process.

**W-15: Adsorbent for Selective Recovery of Antimony**: *Takeshi Ogata*[1]; Hirokazu Narita[1]; Mikiya Tanaka[1]; [1]National Institute of Advanced Industrial Science and Technology

We have synthesized an adsorbent for selective recovery of antimony from copper electrolyte, which contains antimony, arsenic, and bismuth as impurities. The adsorbent is made from tannin which is one of the biomass materials that are inexpensive and ubiquitous natural polymers extracted from leaves or barks of plants and has many hydroxyl groups. It was found that the tannin adsorbent adsorbed antimony from 200 g/L sulfuric acid solution. Arsenic and bismuth, on the other hand, were little adsorbed onto the adsorbent in the experimental conditions. As the result, the tannin adsorbent has the possibility for selective separation of antimony from copper electrolyte. We conducted the recovery test of antimony from simulated copper electrolyte using the tannin adsorbent-packed column. Antimony in the simulated solution was adsorbed, and the other elements were not adsorbed. The adsorbed antimony could be easily desorbed by hydrochloric acid and recovered with high concentration and purity.

**W-16: The Potential of Deep Eutectic Solvent Ionic Liquids for Processing Chalcophile Critical Elements**: *Gawen Jenkin*[1]; Hugh Graham[1]; Daniel Smith[1]; Andrew Abbott[1]; David Holwell[1]; Evangelia Zygouri[1]; Robert Harris[1]; [1]University of Leicester

Gold and copper concentrates often contain high enrichments of scarce or critical elements such as Te, Bi and Sb, but there are few financial incentives for recovery these elements as by-products. Deep eutectic solvents (DES) may provide novel processing opportunities – these are a form of ionic liquid that are mixtures of salts such as choline chloride with hydrogen-bond donors such as urea. DESs are environmentally benign, yet chemically stable and, furthermore, the components are already produced in large quantities at low cost.We have demonstrated that gold is rapidly dissolved in DES by iodine oxidation, whereas many base metal sulfides are unreactive or react only slowly. However, many trace minerals that host the majority of Te, Bi and Sb in a concentrate, such as tellurides, or Bi- or Sb-bearing sulfosalts, are rapidly dissolved at similar rates to gold, suggesting routes to recovering gold and critical elements.

**W-17: Purification of Titanium Based Cemert from Reduced Ilmenite**: *Basil Baloyi*[1]; Munyadziwa Ramakokovhu[1]; Mxolisi Shongwe[1]; Peter Olubambi[2]; [1]Tshwane University of Technology; [2]University of Johannesburg

Titanium based cermets, in particular titanium carbide-based cermets (TiC-based cermets), are among the most important hard materials. In this study, an attempt will be made to purify TiC from the carbothermic reduction of ilmenite concentrates (FeTiO3) from KwaZulu-Natal. The use of ilmenite concentrates eliminates the necessity for purification into TiO2 and reduction to metallic titanium. The aim of the project is to purify the Fe-TiC product from the carbothermic reduction of ilmenite into high grade TiC. Material characterisation will be conducted using scanning electron microscopy (SEM), X-Ray diffraction (XRD), and transmission electron microscopy (TEM). It is expected that this work will serve as a guideline for subsequent work on production of high purity titanium based cermets using ilmenite.

**W-18: Effect of Temperature on Hydrothermal Precipitation of Scorodite from Arsenic-bearing Waste Water**: *Zhonglin Ye*[1]; Cunxiong Li[1]; [1]Kunming University of Science and Technology

The removal of arsenic from arsenic-bearing waste water is the urgent problem in hydrometallurgical processing of nonferrous metals. Precipitation of arsenic as its environmtal friendly precipitate, scorodite from ferrous sulphate solutions is of great interesting. The influence of temperature on crystalline, specific surface area, particle size and purity of arsenic precipitates were researched in hydrothermal precipitation process.The results showed that when temperature lower than 160°C,there are no scorodite formed but other ferric arsenate. An increase in temperature and initial pH produced precipitates with smaller particles, larger specific surface area, better crystalline and high purity.

## Part C-2: Gordon Ritcey Symposium: Advances in Hydrometallurgical Solution Purification Separations – Posters - Wednesday

*Program Organizers:* Ronald Molnar, MetNetH2O Inc.; Jeff Adams, Hatch Ltd.; Wenying Liu, Univ of British Columbia

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**W-19: Crowding Effect on Dysprosium Extraction and Separation from Post-consumer Waste of Permanents Magnets**: *Rajesh Kumar Jyothi*[1]; Jin-Young Lee[1]; Kyeong Woo Chung[1]; [1]Korea Institute of Geoscience and Mineral Resourses (KIGAM)

Rare earths (REs) playing key role in new modern lives; REs were having numerous applications in the areas of electrical, electronic fields. Hydrometallurgy is the cheapest and convenient for REs recovery from primary resources/secondary resources. The present experimental approach towards recovery of rare earths such as dysprosium and terbium from post-consumer waste of permanent magnets (PCWPMs) was designed and developed by hydrometallurgical approaches. Numerous phosphorous based extractants such as Cyanex 272, D2EHPA, PC 88A and TBP tested for suitable for REs separation and recovery. Kinetics of the extraction equilibria was studied. And as well as various pH conditions were tested and optimum condition was fixed for possible separation of each other REs. Scrubbing studies (crowding effect) was tested with dysprosium rich solution as scrub solution at different feed pH conditions. Finally, proper flowsheet for dysprosium separation from other REs was developed.

## Part C-3: Processing of Critical Metals – Posters - Wednesday

*Program Organizers:* Niels Verbaan, SGS Canada Inc; John Goode, J.R. Goode and Associates Metallurgical Consulting; Ian London, Avalon Rare Metals Inc; Gisele Azimi, University of Toronto; Alex Forstner, SGS Minerals

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**W-20: Efficient Recovery of Rare Earth Elements From Coal Based Resources**: *Prashant Sarswat*[1]; Michael Free[1]; Aaron Noble[2]; Gerald Luttrell[2]; [1]University of Utah; [2]Virginia Tech

Rare earth elements (REE) are generally extracted from monazite or bastnasite concentrates in either acidic or alkaline media. Many of the processing routes that are generally applicable for rock or mineral deposits are not applicable for all coal-based REE deposits; although, they may find some suitability in specific circumstances. In many scenarios, REE-bearing minerals in coal material are very fine, with individual mineral grains often less than 10 microns. While grinding and separation are challenging at this size, innovations in mineral processing, combined with low cost chemical extraction and separation technologies, are likely to enable even low grade coal-based resources with 200-400 ppm REEs to be economically recovered using environmentally friendly methods. This paper will discuss associated research and development to enable economically viable, efficient recovery of REEs from coal-based resources.

**W-21: Recovery of Rare Earth Elements from Coal Fly Ash and Recovery from PLS with IX**: *Rory Cameron*[1]; Yves Thibault[1]; Rolando Lastra[1]; John Chaulk[1]; Jean-Michel Bondy[1]; [1]CanmetMining

Rare earth elements (REEs) may be produced from secondary waste sources such as: uranium tailings, red mud, coal by-products, wastes from phosphate fertilizer production, and mineral by-products. Total REE concentrations within these secondary sources range from 100s to 1000s of ppm. This study examines the technical feasibility of recovering REEs from several Canadian coal fly ash samples. During the screening phase a number of different lixivants were screened for their ability to selectively leach REEs from the coal ash samples. A number of ion exchange (IX) resins were screened for REE recovery from the pregnant leaching solutions; several of which were selective for recovering REEs. The results of the leaching and metal recovery experiments will be summarized.

**W-22: Selective Adsorption of Rare Earth Elements Using Polymeric Adsorbents with Diglycolamic Acid Ligands**: *Tomohiro Shinozaki*[1]; Takeshi Ogata[2]; Hirokazu Narita[2]; Chiharu Tokoro[3]; Mikiya Tanaka[2]; [1]National Institute of Advanced Industrial Science and Technology (AIST), Waseda University; [2]National Institute of Advanced Industrial Science and Technology (AIST); [3]Waseda University

Rare earth elements (REEs) have supply challenges such as lack of supply diversity. The non-traditional resources which contain relatively dilute concentrations of REEs have gathered attention to secure the reliable supply of REEs. However, high concentrations of base metals coexist in most of the resources and prevent the effective recovery of REEs. Therefore, we have developed a novel polymeric adsorbent modified with diglycolamic acid ligands for the selective recovery of REEs. Polymeric particles were prepared by suspension polymerization of styrene, divinylbenzene, and glycidyl methacrylate in the presence of diluents. The obtained particles were functionalized with amino groups, and then diglycolamic acid ligands. It was found that the synthesized polymeric adsorbents adsorbed REEs selectively from a solution where the high concentrations of base metals coexist. The adsorption behavior was affected by the pore characteristics of the polymeric adsorbents which depended on the diluents composition during the suspension polymerization.

## Part D: Sulfide Flotation – Posters - Wednesday

*Program Organizers:* Ronel Kappes, Newmont Mining Corporation; Tarun Bhambhani, Solvay

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**W-23: A Fundamental Study of Di-Sodium Carboxymethyl Trithiocarbonate (Orfom® D8) Depressant in Flotation Separation of Copper-Molybdenum Sulfides**: *Simon Timbillah*[1]; Courtney Young[2]; Avimanyu Das[2]; [1]Montana Tech ; [2]Montana Tech

The Cu-Mo sulfide flotation industry is increasingly turning to organic depressants as suitable replacements for inorganic reagents, such as NaHS, due to environmental and safety concerns as well as high consumption rate of the inorganic reagents. This presents an opportunity for improvements or design and synthesis of alternative reagents. Di-sodium carboxymethyl trithiocarbonate (Orfom® D8) depressant is an organic depressant with a carboxylate group on one end and a trithiocarbonate group at the other end. Fundamental results are shown regarding the interaction of the Orfom® D8 depressant in the bulk flotation of a chalcopyrite-molybdenite concentrate from an operating North American mine. Cyclic Voltammetry on pure copper and Fourier Transform Infrared Spectroscopy (FT-IR) and X-ray Photoelectron Spectroscopy (XPS) measurements on pure chalcopyrite with Orfom® D8 depressant treatment are also reported. Through such characterization techniques, a potential adsorption mechanism of Orfom® D8 on the mineral surface was identified and its depressant characteristics in the Cu-Mo flotation systems explained.

EXTRACTION 2018