2nd China-Canada Nonferrous Metallurgy Forum

588946: The Effect of Particle Size on the Corrosion Behavior of X100 Pipeline Steel beneath a Droplet and Sand Deposit Covered by Simulated Diluted Bitumen
Hongxing Liang, Rebecca Filardo Schaller, and Edouard Asselin, UBC

ABSTRACT The water phase containing chlorides in diluted bitumen (referred to as “dilbit”) pipelines exists as emulsified droplets [1]. These droplets coupled with associated solid deposits may accumulate on the inside surface of dilbit pipelines [2]. Our previous studies have investigated the corrosion mechanisms of chloride droplets without sand deposits under paraffin oil [3] and simulated dilbit [4]. However, to our knowledge, no attempt has yet been made to study the effect of sand particle size on the droplet corrosion behavior of steel covered by dilbit. It is reported that dilbit pipeline deposits contain varying sizes of solid particles (from less than 40 μm to more than 400 μm) [5].

In this study, the droplet corrosion behavior under 40 mesh (540 μm) and 200 mesh (43 μm) silica deposits on X100 pipeline steel covered by simulated dilbit for 24 and 240 h was studied in order to understand the effect of sand particle size. Scanning electron microscopy was used to monitor the corrosion development and profilometry was used to characterize the corrosion depth. After 24 h exposure, localized corrosion coupled with uniform corrosion occurred for both the 40 and 200 mesh silica deposits. After 240 h, the corrosion under both sizes of silica continued to develop. The maximum penetration rate of localized corrosion under the 40 mesh silica was faster than under the 200 mesh silica.

591350: Effect of Amino Acids in the Acid Leaching of Pure Gold in Ferric Chloride Media
Kresimir Ljubetic and Wenying Liu, University of British Columbia
Yeonuk Choi, YaKum Consulting Inc.

ABSTRACT The use of amino acids to enhance gold leaching has shown promising results in alkaline media. The present research focused on the effect of glycine, glutamic acid and cysteine on gold dissolution in a highly acidic environment. Using pure gold wire as an initial model system, the effect of amino acid concentration (0.13–0.52 mM), chloride concentration (1–3.5 M), and solution ORP (775–875 mV vs SHE) on gold extraction was studied by batch leaching tests at 40 ºC. Gold extraction was calculated by measuring the weight loss of the wire during leaching. The experimental results showed that the amino acids tested were unable to complex gold in the absence of chloride. In the presence of chloride, gold dissolution responded differently to the type of the amino acid used. Gold extraction increased by 5.6% at 0.52 mM of glycine, while the same concentration of glutamic acid led to a decrease in gold extraction by 33%. Gold extraction showed a remarkable increase in the presence of cysteine, reaching 99% within half of the leaching time. In the presence of cysteine, increasing chloride concentration and the solution potential had a positive impact on gold extraction. The results suggest that cysteine could be a potential catalyst on gold dissolution in acidic chloride media.

593033: A Novel Calculation Method of Carbonation Efficiency for Kinetic Analysis and the Application on CO2 Sequestration under Moderate Conditions
ABSTRACT Combination between CO2 mineral carbonation for global warming mitigation and minerals industries for metal recovery has been believed as a suitable way to balance the credits of CO2 sequestration and the high-cost investment. The detailed mechanism and kinetics of CO2 carbonation of olivine need to be illustrated clearly for its application. This work has developed a novel calculation method of carbonation efficiency during the continuous sampling of CO2 carbonation and its application into the investigation of kinetics analysis. The method can calculate the carbonation efficiency only based on the carbonation capacity of the raw materials and the carbon content of products after the carbonation. The difference between this method and the way based on the weight change before and after carbonation is less than 2%. Based on the calculation method, the carbonation mechanism and kinetics of olivine have been illustrated. The addition of sodium salts can help shift the mechanism from silica-rich layer diffusion control to chemical reaction control. With addition of sodium salts, the increase of CO2 partial pressure can also convert the mechanism controlled by diffusion through a dense carbonate layer to the chemical reaction control. Under the chemical reaction control, a quantified kinetic formula has also been developed, which can be applied to predict carbonation efficiency or the requirement of a specific factor. This calculation method can be theoretically suitable for the materials where the original carbon content is less than 0.1%.

594733: The Comparison Between Planetary Ball Milling and Heating Processes for Enhancement of Cerium Dissolution from Weathered Residual Rare Earth Ores
Tatsuya Kato, Waseda University
Yuki Tsunazawa, National Institute of Advanced Industrial Science and Technology
Chiharu Tokoro, Waseda University

ABSTRACT The objective of this study is to compare between planetary ball milling and heating processes for enhancement of cerium dissolution by sulfuric acid leaching from weathered residual rare earth ores from the point of view of power consumption. For this purpose, the weathered residual rare earth ores was ground by planetary ball mill and heated by microwave reactor. After these processes, the samples were leached by 1.0 mol/dm3 sulfuric acid for 24 hours. The effect on the crystal structure of the cerium minerals and phase composition of the ores by planetary ball milling and heating was investigated by x-ray absorption fine structure (XAFS) and extended x-ray absorption fine structure (EXAFS) analysis in cerium LIII and K-edge. From above experimental results, it was revealed that tetravalent cerium could be converted into trivalent cerium by planetary ball milling and heating. In addition, this reaction was beneficial to the cerium dissolution by sulfuric acid leaching from ores. Based on these results, we will compare between planetary ball milling and heating processes for enhancement of cerium dissolution by sulfuric acid leaching from weathered residual rare earth ores from the point of view of power consumption in this presentation.

594858: Alumina Solubility in NaF-KF-LiF-AlF3-Based Low Temperature Melts
Zheng Wei and Jianping Peng, Northeastern University
ABSTRACT NaF-KF-LiF-AlF3-based low temperature electrolytes are considered promising for aluminum production. In this work, the saturated solubility of Al2O3 in NaF-KF-LiF-AlF3-based melts with various contents of KF and LiF added were evaluated by measuring the weight loss of a rotating corundum disk at different temperatures, and the influences of KF content, LiF content and temperature on Al2O3 saturated solubility were discussed in detail. In contrast to LiF added, the introduce of KF has a positive effect on Al2O3 solubility improvement at the same temperature. For the electrolyte with a certain component, the saturated solubility of alumina increases with increasing the temperature of the melt. And at the temperature of 830-950 ºC, the solubility of alumina increases by about 0.22 wt. % for every 10 ºC increase in temperature. The following empirical equations were derived at various factors: With KF content (0-20 wt. %) and temperature (830-950 ºC): \[ S_{(C(KF,T))}/\text{wt.}\% = 132.52 - 0.32T + 16\text{[KF]} + 1.99 \times 10^{-2} T\text{[KF]} + 1.90 \times 10^{-4} T^2 + 14.0\text{[KF]}^2 \]

With LiF content (0-20 wt. %) and temperature (830-950 ºC): \[ S_{(C(LiF,T))}/\text{wt.}\% = 87.43 - 0.21T + 5\text{[LiF]} - 1.6 \times 10^{-2} T\text{[LiF]} + 1.31 \times 10^{-4} T^2 + 10.6\text{[LiF]}^2 \]

With KF content (0-20 wt. %) and LiF content (0-20 wt. %) at 830 ºC: \[ S_{(C(KF,LiF))}/\text{wt.}\% = 1.43 + 2\text{[KF]} - 9\text{[LiF]} - 10.4\text{[KF]}\text{[LiF]} - 4.39\text{[KF]}^2 + 17.2\text{[LiF]}^2 \]

Electrowinning & Electrorefining

594794: Influence of Entraining Solids on Nodular Growth in Copper Electrorefining
Shohei Mitsuno, Ken W. Adachi, Atsushi Kitada, Kazuhiro Fukami, and Kuniaki Murase, Kyoto University

ABSTRACT Although copper is a noble metal, the current efficiency in copper electrorefining process is 93% to 98%. The main cause of the loss of current efficiency is the short circuit between cathodes and anodes caused by protrusion-like deposits called “nodules” which develop on the cathode surface. To improve the current efficiency, it is important to reveal the formation mechanism of nodules. In the previous study we investigated the mechanism of nodule growth. We found that when the nodules are higher than 7 mm, the electric current concentrated on the tip of the nodule accelerates the growth and causes the rapid dendritic growth. On the other hand, when the nodules are lower than 7 mm, the influence of the electric current is limited and the non-faradic factors are thought to enhance the growth of nodules. Regarding the mechanism of nodule formation, it is reported that suspended particles such as anode slime adhered to the cathode form small protrusions of height of 2 mm or less, from which nodules will grow to contact the anodes. However, little has been known about the tendency to entrain impurities for each site of nodules and the kinds of impurities which cause nodulation other than anode slimes. In this study, we analyzed the nodules retrieved from the industrial process. We determined the quantity of the entrained solids, i.e., impurities floating in the electrolytic bath such as anode slimes and release agents for anode casting. We will discuss their influence on the growth of nodules.

Hydrometallurgy

573933: A Review of the Treatment Copper Silver Gold Ores and Concentrates
Diego Medina and Corby Anderson, Colorado School of Mines
**ABSTRACT** Globally both copper and precious metal orebody grades have been dropping and the mineralogy has become more complex. As well, the cyanidation process for gold production has been dominant for over 130 years as consequence of its feasibility in the mining industry. For this reason, the industry is adjusting its methods for extracting precious metals with more efficient processes and technologies. Often gold may be found in conjunction with copper and silver in ores and concentrates. Hence, there may be difficulty in the application of cyanide to these types of ores because of the diversity of minerals found in these ores may cause that the application of cyanidation become more complicated. This paper will outline the practices, processes and reagents proposed for effective treatment of these.

590867: **Effect of Irrigation Rate and Particle Size on the Liquid Hysteresis inside Unsaturated Heap**

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Mohsen Hashemzadeh, Kresimir Ljubetic, and Wenying Liu, University of British Columbia

**ABSTRACT** The liquid holdup is closely affected by initial irrigation rate and particle size inside unsaturated heap, which directly influences the dissolution efficiency of valuable minerals. This poster studies the effect of the 6 constant superficial flow rate (interposed between 0.001 and 0.1 mm/s) and cyclical superficial flow rate (increase from 0.001 to 0.1 mm/s, and decrease from 0.1 to 0.001 mm/s) on the liquid hysteresis inside ore heaps dumped by 7 particle sizes (interposed between 16.02 and 2.83 mm). The results show that, regardless of the particle size and irrigation rate, preferential flow and liquid hysteresis effects are widely present. Under the higher superficial flow rate condition, the preferential flow forms earlier and attains a lower breakthrough time. The liquid holdup value tends to be higher under conditions of higher flow rate and smaller particle size. The hysteresis effect is more obvious with the smaller particle size. Based on cyclical irrigation tests, the liquid holdup of ore heap depends not only on the current input conditions, but also on the dripping history of the system. Liquid holdup of dry ore bed continues to increase even under the stimulation of decreased flow rate.

594622: **Effects of Halide Addition on the Ferric Sulfate Leaching of Chalcopyrite**

Yang Gao, Yu-ki Taninouchi, Akihiro Kishimoto, and Tetsuya Uda, Kyoto University

**ABSTRACT** The leaching behavior of chalcopyrite in ferric sulfate medium is significantly affected by the addition of halides, such as NaCl and KI, into the solution. However, its detail mechanism is not yet thoroughly understood. In this paper, we therefore carried out electrochemical and morphological study of the effects of the addition of potassium halides (KCl, KBr, and KI). For example, leaching tests with electrochemical measurements were performed using bulk specimens of chalcopyrite; it was confirmed that 1 mM KI addition notably changes the mixed potential of chalcopyrite and redox potential of leach solution.
595542: Adsorption Modeling of Catalyzed Heap Leaching
Prashanth Krishnamoorthy, University of British Columbia
David G. Dixon, UBC Material Engineering
Nelson Mora, Jetti Services Canada

ABSTRACT Heap bioleaching of primary sulfides such as chalcopyrite is challenging as passivation results in a low rate of dissolution. Jetti Resources has developed a catalyst which, when introduced into the heap as a solute, can help mitigate this problem by enhancing the leaching rate at ambient temperature. It has been observed that the solute interacts with minerals in the ore. In this work, a mathematical transport model accounting for adsorption of the solute was used in conjunction with the results of laboratory experiments to estimate corresponding adsorption rates. The model is 2D axisymmetric, incorporating transport of solute by advection, dispersion and adsorption in a column of crushed ore under a single point source representing a single drip emitter. The ore hydraulic parameters, describing water retention and permeability, are obtained from column water irrigation tests. Transport parameters affecting the distribution of water and solute in a porous medium are obtained from inert tracer tests. Consequently, the reactive solute was introduced into the column and the breakthrough curve fit with the model to evaluate the adsorption rate of the catalyst on the ore.

Mineral Processing
593643: Diethylenetriamine Mitigation in Pyrrhotite Tailings
Wendy Tian and Erin R. Bobicki, University of Toronto

ABSTRACT DETA, diethylenetriamine, is an effective pyrrhotite depressant used in the flotation of copper-nickel sulphide ores. Pyrrhotite is a low-value iron sulphide mineral that is rejected in flotation to increase concentrate grade and decrease smelter SO2 emissions. DETA is a chelating agent that forms stable complexes with nickel and copper at alkaline pH. Hence, the use of DETA in mineral processing can result in soluble nickel and copper complexes in effluent that cannot be removed by conventional wastewater treatment facilities. The objective of this project is to understand how DETA will behave in a tailings environment. Geochemical modelling was conducted using OLI systems software to determine the DETA species in solution under different conditions. DETA speciation is presented across the pH range with various ionic species and DETA concentrations. The interaction of DETA with the pyrrhotite surface was also explored via adsorption and desorption tests. DETA adsorption and desorption on pyrrhotite with time at pH 4 and pH 8, and 20°C and 4°C was investigated. Adsorption isotherms for DETA on pyrrhotite were also developed. The geochemical modelling and experiments results will be used to provide inputs for a model to predict DETA concentration in final effluents, and to develop a DETA mitigation plan.

594729: Investigation of Potential Mitigation Strategies for Diethylenetriamine-Metal Complexes in Pyrrhotite Tailings
Erin Furnell and Erin R. Bobicki, University of Toronto

ABSTRACT During the flotation of nickel/copper ores, pyrrhotite is depressed due to environmental concerns with its processing and to improve recover and concentrate grades.
Diethylenetriamine (DETA) is a very effective pyrrhotite depressant; however, it is challenging to manage in the tailings area. DETA forms stable chelates with Ni and Cu ions in solution which cannot be precipitated by traditional lime treatments. DETA-metal complexes occur both in the tailings supernatant and adsorbed to the surface of the tailings solids. Once in the tailings area the DETA-metal complexes can desorb from the solid upon dilution, dependant on pH and temperature. Once in the water cover of the pond these complexes can switch spontaneously between Ni-DETA and Cu-DETA complexes depending on the availability of ions. All these effects can result in final effluent that exceeds the allowable Ni$^{2+}$ and Cu$^{2+}$ concentrations by federal regulations. For DETA to be used in industry a mitigation strategy must be developed. The objective of the current project is to investigate potential mitigation techniques. Biodegradation of the DETA chelated to Ni$^{2+}$ or Cu$^{2+}$ is being investigated as a potential mitigation technique. Literature on the biodegradation of pure DETA is mixed and inconclusive and the literature on the biodegradation of DETA-metal complexes is non-existent. In order to isolate and identify a bacterium that can use DETA as an energy and a carbon and/or nitrogen source, native organisms were sampled from nickel mine sites and from locations that had been exposed to DETA previously. These organisms were then cultured in the presence of DETA and their ability to degrade DETA or destabilize the DETA-metal complexes was assessed by measuring the concentration of DETA in solution and the presence of degradation products.

598187: Computational Modeling of Foam Dynamics and Stability

Aashish Goyal, The University of British Columbia
Jan Cilliers, Imperial College London
Sanja Miskovic, The University of British Columbia

ABSTRACT The stability and dynamics of foam are crucial for the effective froth flotation process in mineral separation and various other industrial processes such as paper recycling and waste-water treatment. The recovery of fine particles in these processes immensely depends on the foam dynamics, which can be defined using foam flow and coarsening phenomena. Literature in the past has also mentioned the effect of film coarsening and foam motion on extraction efficiency. To elucidate the foam flow, Cole et al[1] and Brito-Parada et al[2] reported the foam flow patterns in a 2D and 3D system by solving Laplace’s equation numerically. Park et al[3] modeled the foam-particle interaction which explains the effects of particles on the foam stability. The premise of both these studies is drainage of liquid in the foam leading to foam coarsening and reduction of the film surface area available for particle extraction. Our research work captures both of these aspects by considering the coarsening at the film level and solving the dynamics of the 3D foam structure.

In our study, a modified discrete element methodology (DEM) is developed, which includes drainage of liquid and film coarsening to resolve foam dynamics. The numerical model solves a modified inter-bubble interaction force which satisfies Plateau’s law for the dry phase of foam. The physics involving the drainage of liquid in foam is integrated with the model to capture the film coarsening. The foam flow and coarsening predicted from the model are further validated by the experimental results. The experiments with a dual and triple combination of bubbles are carried out to justify the numerical behavior of bubble interaction forces. A foam development experiment in Hele-Shaw column is used to verify the overall flow of foam and film coarsening. The computational model developed in this study provides the insights on foam flow and film
coarsening for different properties of liquid which can be further extended to capture the effect of particles on liquid drainage, and eventually the prediction of extraction efficiency.

References:
[1] Cole et al., "Experimental studies and numerical model validation of overflowing 2D foam to test flotation cell crowder designs."

600711: Sustainable Extraction of Nickel from Canadian Pyrrhotite Tailings Using Chelation Technology
Nina F. Farac and Erin R. Bobicki, University of Toronto

ABSTRACT Decades of nickel sulphide flotation operations have led to a significant build-up of environmentally-hazardous pyrrhotite tailings. To prevent acid mine drainage, these reactive tailings are typically rejected into tailings ponds as waste material despite containing a profitable amount of nickel. Nickel is arguably the most utilitarian metal due to its vital role in many industrial applications such as stainless steel, catalysts, and new-generation electronic and automotive batteries. In recent years, global nickel consumption has drastically risen coupled with an ever-growing nickel demand. Moreover, high-grade nickel sulphide deposits are being depleted worldwide and with no new ones being discovered, this important metal is at risk for supply uncertainty. Therefore, it is imperative to explore secondary sources, such as low-grade pyrrhotite tailings, as a valuable nickel resource. To investigate the potential for pyrrhotite tailings valorization, a ligand-assisted extraction process for the sustainable recovery of nickel is being developed which involves chelation technology – use of various chelating agents for selective nickel extraction. The advantages of the proposed process include ambient operating conditions, non-corrosivity (i.e. neutral to slightly alkaline solutions), and low waste generation with the added benefit of consuming this environmentally risky waste material. This work aims to fully characterize the pyrrhotite tailings, utilize OLI mixed solvent electrolyte (OLI-MSE) software for chemical modeling, conduct ligand-assisted leaching experiments, and investigate kinetic and physiochemical mechanisms governing the extraction process. This work, in turn, will help mitigate the environmental liability of pyrrhotite tailings and help satisfy the global demand for nickel.

Process Control, Optimization, & Instrumentation

591012: Study on a Hybrid Approach and Optimum Predictive Model Development for Production of Copper Electrolyte from a Waste Copper Smelter Dust
Daniel Ogochukwu Okanigbe, Olawale Popoola, and Abimbola Popoola, Tshwane University of Technology
Michael Ayomoh, University of Pretoria

ABSTRACT This paper has presented a three level-two factors full factorial experimental design to study the process parameterization of combined pressure hydrometallurgy and process chemistry for the dissolution of copper and inhibited dissolution of iron from a waste copper smelter dust (CSD). This was followed by the development of an experiment specific predictive
model premised on the use of constrained interpolating functions at defined optimized intervals. The four significant experimental factors utilized in this investigation include: Temperature (146°C, 167°C, and 188°C), Pressure (3.8bar, 7.8bar and 12.8bar), a solution composition of H2SO4 and FeSO4.7H2O mixed in proportionate ratios of 120:5, 122:3, 124:1 at a fixed experimental time of 2hrs. It was observed that a maximum dissolution of 153 mg/l Copper was obtained with a corresponding minimum dissolution of 73mg/l iron under same test condition of 167°C, a pressure level of 7.8 bar after a duration of 2hrs and solution composition of H2SO4 and FeSO4.7H2O mixed in a proportionate ratio of 122:3 respectively. The experimental recovery effort occurred at a fixed ratio (1g: 5ml) i.e. 1g waste CSD for every 5ml of the concentrated solution (H2SO4 and FeSO4.7H2O). These outputs limits (maximum and minimum) and the associated experimental conditions depict the optimum operating conditions of the experiment. Furthermore, the predicted outputs from mathematical modeling premised on developed constraint interpolant models were well aligned with the experimental outputs. A maximum percentage error of 0.07% was recorded in the predictive outputs for both the copper and iron mineral fractions.

595601: Improved Diffuse Reflectance Spectroscopy for Characterization of Copper Ores
Jorge Yáñez, Claudio Sandoval, Rodrigo Fuentes, Jonnathan Alvarez, Pablo Cohelo, Marizu Velásquez, Ashwin Kumar Myakalwar, Danny Luarte, Daniel Sbarbaro, and Rosario Castillo, Universidad de Concepción, Chile

ABSTRACT Diffuse Reflectance Spectroscopy (DRS) is produced by the sample's rough surfaces reflection of the light in all directions and it is collected by using an ellipsoid or paraboloid mirror. Shape, compactness, refractive index, reflectivity, and absorption of the particles are all characteristic of the material being analyzed1. Radiation in the UV-Vis, NIR and MIR range can be used. The spectrometer splits different wavelengths through a CCD arrangement in 2D spatial and spectral dimensions, thus a hyperspectral cube of data is generated. This technique provides an alternative methodology for the characterization of minerals products in real time. In this work, multivariate methods were applied (PCA, PLS, SVM and NN) for the analysis of diffuse reflectance spectra and to explore the classification of mineral species in copper ores.

Reflectance spectra were obtained using Evolution 260 Bio UV-Visible spectrophotometer (Thermo Fisher, USA), Xeva hyperspectral NIR camera (Xenics, Belgium) and Hurricane 40 hyperspectral camera (Photonfocus, Germany), in 200-900, 900-1700 and 400-1000 nm range respectively. The reference spectra of the pure minerals used in the calibration models were obtained using a spectral metallurgical microscopic with BD objective (Optiphot Nikon, Japan) connected to a USB2000+ (Ocean Optic, USA) spectrometer 190-1100nm range. As a reference method for ore sample characterization, Qemscan® was used.

Preliminary results show that performing PCA analysis of the reflectance spectra ranging from 390 nm to 900 nm, clusters of the main minerals can be recognized (CuFeS2, FeS2, Cu2S, and CuS). Characteristic spectral bands for each mineral species explain the preliminary classification by PCA. The spatial recognition of the minerals in a sample can be achieved by standard classification models with a prediction acceptable accuracy >90% in the latter model. The use of this method shows a good correlation when contrasting with the conventional method, with less than 8% error. Further studies include the use of a high number of samples and mineral
species.

598049: Elemental Characterization of Copper Ores by Laser Induced Breakdown Spectroscopy (LIBS)
Jorge Yáñez, Marízu Velásquez, Jonnathan Alvarez, Rodrigo Fuentes, Ashwin Kumar Myakalwar, Claudio Sandoval, Martín Bravo, Danny Luarte, Daniel Sbarbaro, and Rosario Castillo, Universidad de Concepción, Chile

ABSTRACT
LIBS is based on the generation of an atomic emission spectrum by a sample, in which a micro-plasma is generated by a pulsed laser [1-2]. In this work, LIBS is applied to the quantification of the valuable elements (Cu, Mo, Ag) and penalized elements (As, Pb and Zn) in copper concentrates which control the commercial value of the copper concentrates.

The Details of instrumental and experimental arrangement: an Nd: YAG laser 266 nm (Quantel, France) of laser energy 25 mJ / pulse and 7 ns of duration is used. The detection was performed in a spectral range from 186-1049 nm using a CCD spectrometer (Aurora, Applied Spectra, CA, USA) with delay time ~ 0.01μs and exposure time 1.05 ms. The concentrations of Cu, Mo, As, Pb and Zn were determined by two standard analytical methods viz., atomic absorption spectroscopy (AAS) and ICP-OES.

The mineral concentrates are complex matrices affected majorly by multiple interferences. The univariate calibration for this type of samples delivers errors > 10%, on the contrary the use of multivariate calibration methods avoids interferences thereby decreasing errors down to 2%. It has been observed that there are no significant differences (p≤0.05) between the predictions of Cu, Mo, Ag, As, Pb and Zn concentrations using LIBS and those results obtained by conventional methods used in copper industry.

References

598082: Mineral Characterization in Copper Ores Based on Laser-induced Breakdown Spectroscopy (LIBS)
Jorge Yáñez, Jonnathan Alvarez, Rodrigo Fuentes, Marízu Velásquez, Danny Luarte, Daniel Sbarbaro, Rosario Castillo, Ashwin Kumar Myakalwar, Claudio Sandoval, and Eimmy Ramírez, Universidad de Concepción, Chile

ABSTRACT
Laser induced breakdown spectroscopy (LIBS) is an atomic emission technique where a pulsed laser beam is focused on a sample inducing thermal breakdown of the material and producing a hot plasma. The emission wavelengths are characteristic of atoms/ions present in the sample. LIBS offers attractive features compared to conventional methods used in mining industry. Samples in any form (solid, liquid or gas) can be used with less or without sample preparation, contrary to the intensive sample preparation of conventional ones. Almost all atoms in the periodic table can be explored. Online and distance based analysis capability is also possible thereby reducing experimental time.

This proposal is anticipated to address identification of mineralogical characterization and classification which has been attracted very less attention by researchers in the copper mining and not reported so far.
In this work, LIBS is used to obtain spectral information of some natural minerals such as pyrite (FeS2), chalcopyrite (CuFeS2), coveline (CuS), calcosine (Cu2S), bornite (Cu5FeS4), enargite (Cu3AsS4) and molybdenite (MoS2). The LIBS measurements were performed using a 266 nm Nd-YAG laser with energy 25mJ/pulse and duration of 7 nanoseconds (Quantel, France). The detection was performed in a spectral range from 186 to 1049 nm on a CCD spectrometer (Aurora, Applied Spectra, USA) with an average resolution of 0.12 nm. While analyzing each mineral good signal-to-noise ratio, the exposure time and delay time parameters were optimized. The spectral line identification processed through NIST database. Supervised classification like Principal component analysis (PCA) are considered for exploratory class analysis and supervised classification models such as Partial Least Square Discriminant Analysis (PLS-DA), Soft Independent Modeling of Class Analogy (SIMCA), Random Forest (RF) and Artificial Neural Network (ANN) are used to cope the mineral classification and identification. The results are promising and utilizing advanced machine learning can solve complex pattern distribution of minerals.


600712: Extrusion Process Optimization of a Novel Al-Mg-Si Alloy Intended for Crash Components of Modern Vehicles

Justin Plante, Université Laval

ABSTRACT The growing demand for fuel efficient vehicles made aluminum a top candidate for the automotive industry. In order to fulfill current need for mass reduction, Al is introduced into design of crash management system of modern vehicles. Critical safety components such as bumpers, crush boxes and sidewalls require high strength and toughness and are currently produced from 6xxx (Al-Mg-Si) and 7xxx (Al-Zn) series Al extrusions. However, poor recyclability of Al-Zn alloys complicates scrap management and opposes to life cycle optimization. In this work, two variants of an experimental Al-Mg-Si-Cu-Mn alloy either with or without Zr addition were studied as an alternative to 7xxx alloys. The effects of extrusion parameters and alloy composition were characterized in terms of mechanical properties and microstructure. Results are used to optimize the extrusion process in order to surpass strength of commercially available 7003, 6082 and 6008 Al alloys.

Sustainability & Waste Management

595802: Electrolytic Destruction of Cyanide on Bare and Manganese Dioxide Coated Stainless Steel

Jacob Schmidt and Eduard Guerra, Laurentian University

ABSTRACT Electrolytic destruction of cyanide was studied on bare AISI-304 stainless steel electrodes and manganese dioxide coated stainless steel electrodes. Manganese dioxide layers were deposited onto electrodes from manganese acetate and permanganate solutions using anodic and cathodic deposition, respectively. The electrochemical behaviour of the bare steel and coated electrodes was characterized in a 0.01M carbonate buffer solution at pH 10 with cyanide concentrations varying from 0-300ppm, using cyclic voltammetry and frequency response analysis. These results suggested that cyanide destruction was concomitant with oxygen
evolution. Further galvanostatic experiments explored cyanide destruction on bare and coated electrodes using the same carbonate solution bearing 250ppm cyanide and a stainless steel anode in a parallel plate cell arrangement. A current density of 0.1mA/cm² was applied for various times, up to 24 hours, and residual cyanide concentration was measured by titration with silver nitrate. A model correlating residual cyanide destruction with time is presented. The effect of the presence of copper, present as copper sulfate in varying concentrations up to 10ppm, on the rate and power requirements of cyanide destruction was studied.
Downstream Fabrication & Applications

586462: Numerical Simulation of Direct Continuous Casting Process of CuNiSi Copper Alloy
Guojie Huang, GRIMAT Engineering Institute Co., Ltd
Xin Pang, CanmetMATERIALS, Natural Resources Canada
Lijun Peng, Haofeng Xie, Xue Feng, Zhen Yang, Xiangqian Yin, Jiang Li, and Xujun Mi, GRIMAT Engineering Institute Co., Ltd

ABSTRACT Direct Continuous Casting (D.C.C) is an important method in casting CuNiSi lead frame copper alloy. In this paper, numerical simulation is adopted to investigate the casting process in order to optimize the D.C.C technical parameters, such as the casting temperature, casting speed. And different temperature field and stress field were analyzed. According to the numerical simulation, the suitable parameters were got. The results show numerical simulations provide the significant reference to the actual experiments.

594137: The Properties of Grapheme Reinforced Copper Matrix Composite Wire Prepared by Continuous Powder Extrusion and Draw
Xue Feng, Zhen Yang, Xujun Mi, Guojie Huang, Haofeng Xie, Lijun Peng, and Xiangqian Yin, GRIMAT Engineering Institute Co., Ltd

ABSTRACT Graphene, a two-dimensional structure of sp2 bonding carbon, has been intensively studied because of its extraordinary physical and mechanical properties. Its outstanding high strength and elasticity modulus, remarkable electron mobility (15,000 cm2/V·s) and super high thermal conductivity (5,000 W·m−1·K−1) make graphene an excellent candidate as reinforcement for different kinds of composites. Recently, copper matrix composites reinforced by nano carbon fillers, such as carbon nanotubes (CNTs), carbon nanoflakes, nano diamond and graphene, have attracted great attention since they can integrate mechanical properties (high strength and modulus) with high electrical conductivity, high thermal conductivity and low coefficient of thermal expansion. In this work, the copper matrix composite wires reinforced by grapnene were prepared by continuous powder extrusion and draw. The mechanical properties and electrical conductivity were also been tested. The results showed that an important increase of the Young’s modulus was observed because of the introduction of grapnene. The tensile strength also increased without sacrificing the electrical conductivity.

Electrowinning & Electrorefining

582968: From 2150 kWh Per EW Cu Ton to 1750 kWh Per EW Cu Ton
Robert P. Dufresne, Pultrusion technique Inc

ABSTRACT Electric efficiencies in electrowinning can be increased by 5.5 to 6% by installing a double electric contact point for each cathode and anode. Research in the design of insulating and contact system of the electrodes has reached optimum effectiveness of calculation and is user-friendly for the workers. Also, this new contact system is designed to reduce any type of Short Circuit by 70 to 80%. This reduction into the Short Circuits increased by another 3 to 6%
of the electric current effectiveness. The combination of these technologies gives a more uniform electric density inside each cathode and anode, and in each cell, and also for the whole electric circuit and tankhouse. The calculation method ensures a balanced electrical density at its maximum level inside the cell for maximum performance. The effectiveness has also reached a new maximum for the whole tankhouse. This system is applicable to any type of contact system. Research into chemical stoichiometry and into the behavior of different molecules has motivated us to create an outstanding chemical resistance to sulfuric acid and the whole process of hydrometallurgy to resist up to 19 years of continuous operation without maintenance. Good contact efficiencies have doubled the lifetime of the cathode and anode with this system. With the price of copper going down, it is more important to operate in a more ecological and efficient way.

**594963: The Research on the Process of Electroplating Copper Sludge Treated by Side Blowing Smelting Technology**

**Ling Wu, China ENFI Engineering and Technology Corporation**

**ABSTRACT** With the rapid development of Chinese economy, the center of global manufacturing and processing industry is moving to China, which also includes the production of electroplating products. In electroplating industry, the pollution of electroplating sludge is becoming more and more serious. There are many complex chemical components, such as chromium, iron, nickel, copper, zinc, lead and other heavy metal oxides, hydroxide and sulphate in electroplating sludge. Although the electroplating sludge contains many harmful substances, it can also be reused for human if the original harmful substances are converted into useful substances after proper treatment. In recent years, SSC(side blowing smelting ) technology developed by ENFI in China has been successfully applied in industrial application in the secondary resource treatment of heavy metals. The process of treating electroplating sludge by side blowing smelting process is as follows: electroplating sludge, flux and reducing agent are mixed and continuously added into SSC side blowing smelting furnace for smelting. The metal oxide in electroplating sludge is reduced to metal, other impurities in the sludge become to the slag with the flux quartz or limestone, the final output of black copper (containing copper, lead, zinc, nickel, iron and other impurities and some matte) and smelting slag. The black copper and smelting slag are treated in the next process respectively. This paper will introduce the research of SSC technology in the treatment of copper electroplating sludge, including the main reactions ,the slag type and the atmosphere in the furnace. It will convert the harmful substances in the electroplating sludge into benefit, turn waste into treasure, useful substances by utilizing this technology to treat copper electroplating sludge and achieve the green, energy saving and environmental protection goal in the industry.

**Hydrometallurgy**

**588613: Leaching of Cu from Cu Precipitate in Sulfuric Acid with Aeration and Cupric Ion**

**Kyoungkeun Yoo, Korea Maritime & Ocean University**

**ABSTRACT** Cupric ion (Cu2+) has been reported as an oxidant for Cu oxidation in chloride or ammonia solution. Cupric ion obtains an electron from the oxidation of Cu to cuprous ion (Cu+). However, since cuprous ions can’t exist in sulfuric acid, even though Cu is oxidized into cuprous
Ion under some conditions, cuprous ions oxidized into cupric ion or reduced into elemental Cu. Thus the oxidation of Cu by cupric ion was not proceed in sulfuric acid. In this study, it was investigated that the addition of cupric ion with aeration could accelerate the oxidation of Cu to Cu ion. Four conditions were prepared; the addition of cupric ions with aeration, the addition of cupric ions with the introduction of nitrogen gas, aeration without cupric ion addition, and the introduction of nitrogen gas without cupric ion. The results indicate that the addition of cupric ion with aeration enhanced the leaching efficiency of Cu from anode slime in sulfuric solution. Since the cupric ion generated from the process could be reused in the process as oxidants, economical and environment-benign process could be achieved. This process was applied to leach precipitate containing Cu, which was generated from a purification process of Zn leach solution by cementation, and the precipitate has been dissolved with sulfuric acid more than 8 hours. The leaching behavior of Cu was investigated using aerated sulfuric solution with Cu2+, and the results suggest that the leaching of Cu was enhanced with increasing initial Cu2+ concentration, oxygen flow rate and temperature.

594919: Depassivation of Chalcopyrite with Jetti Catalyst
Zihe Ren, Jetti Services Canada Inc
Edouard Asselin, UBC
David G. Dixon, UBC Material Engineering
Nelson Mora, Jetti Services Canada

ABSTRACT Chalcopyrite (CuFeS2) is the world’s primary mineralization of copper. However, it is widely known that Cu cannot be extracted efficiently from CuFeS2 by hydrometallurgical methods due to the mineral’s tendency to passivate. The Jetti Resources catalyst is introduced to provide a viable approach for the extraction of copper from chalcopyrite in heaps and dumps. Electrochemical studies (Electrochemical Impedance Spectroscopy, Linear Polarization Resistance, Potentiodynamic Polarization and Mott-Schottky) using mineral electrodes showed that the nature of the catalytic mechanism is through depassivation of the chalcopyrite and covellite surfaces. The catalytic effect is further confirmed through reactor leaching (abiotic) and column bioleaching tests on various kinds of minerals. Various characterization techniques such as XRD, SEM, EDX and TOF-SIMS have also been used to demonstrate the effect of catalyst on mineral surfaces.

600713: Selective Precipitation of Copper Ions from Acid Leaching Solution Using Monoclinal Pyrrhotite
Haisheng Han

ABSTRACT Pyrrhotite is a potential source of S2- for sulfide precipitation of nonferrous metal ions in hydrometallurgy. In this study, different pyrrhotite crystals were prepared using zero-valent iron and sulfur to study the effect of pyrrhotite structure on the sulfide precipitation of copper ion. The results indicate that sulfide precipitation of copper ion highly depends on the crystal form and crystallinity of pyrrhotite. Monoclinal pyrrhotite was found to be the most effective structure for copper precipitation, but more amorphous structure will also make some contributions to the sulfide precipitation. Monoclinal pyrrhotite is easy to decompose into Fe2+ and S2- in strong acid, and S2- will react with Cu2+ to form CuS precipitates. What’s more, XRD analysis shows (CuxFe1-x)S exists, indicating some copper ions enter into the FeS lattice.
by a lattice substitution reaction. Monoclinal pyrrhotite can be used for selective precipitation of copper ion from waste acid, Zinc leaching solution, Nickel leaching solution, and water treatment.

**Mineral Processing**

566374: Copper Nickel Separation Challenges & Flowsheet Development  
*Damian Connelly, METS Engineering Pty Ltd*

**ABSTRACT** The feasibility of selling a bulk concentrate is not considered economical on the basis that the value of either copper or nickel is not reimbursable when selling to a nickel or copper smelter. When considering that the economics of selling separate concentrates is poor, it is clear that this option would not be economical. There are limited smelters or facilities who could process this concentrate. This paper describes the testwork undertaken to produce separate copper and nickel concentrates and flowsheet options including downstream processing.

594812: Effect of Hydrogen Peroxide on Floatability of Chalcopyrite, Bornite, Tennantite, and Enargite  
*Gde Pandhe Wisnu Suyantara, Kyushu University  
Tsuyoshi Hirajima, Kyushu University & Sumitomo Metal Mining Co., Ltd.  
Hajime Miki, and Keiko Sasaki, Kyushu University  
Makoto Umedera, Takeshi Nakamura, and Shigeto Kuroiwa, Sumitomo Metal Mining Co., Ltd.*

**ABSTRACT** In this study, the effects of oxidation treatment using hydrogen peroxide (H2O2) on floatability of copper sulfide minerals (i.e., chalcopyrite and bornite) and arsenic-bearing minerals (i.e., tennantite and enargite) were investigated. Flotation tests using single mineral indicate that H2O2 exhibited a strong depressing effect on all minerals, following the order of tennantite > enargite > chalcopyrite > bornite. Interestingly, flotation tests using mixed mineral of chalcopyrite and tennantite and chalcopyrite and enargite show that H2O2 treatment followed by the addition of potassium amyl xanthate (PAX) had an adverse effect on chalcopyrite floatability. Meanwhile, tennantite and enargite had a higher floatability compared to that of chalcopyrite, indicating a possibility of selective flotation of chalcopyrite and both arsenic-bearing minerals. Furthermore, bench-scale flotation tests demonstrated that the oxidation treatment could deliver a satisfied separation of arsenic bearing minerals and copper sulfide minerals. Contact angle measurements, atomic force microscopy, FTIR analysis, adsorption tests, and X-ray photo electron spectroscopy were performed to characterize the mineral surface. A possible mechanism is proposed in this study to understand the phenomenon.

594818: Effect of Heating Treatment on Magnetic Properties of Chalcopyrite and Molybdenite  
*Hajime Miki, Kyushu University  
Tsuyoshi Hirajima, Kyushu University & Sumitomo Metal Mining Co., Ltd.  
Gde Pandhe Wisnu Suyantara and Keiko Sasaki, Kyushu University*

**ABSTRACT** The influence of heating treatment on magnetic properties of chalcopyrite and molybdenite was investigated in this study. The heating treatment was conducted using a tunnel
furnace at temperature range from 250°C to 750°C at various treatment time. Magnetic susceptibility and a lab scale magnetic separation was used to study the effect of heating treatment on magnetic properties of both minerals. The magnetic susceptibility measurements show that magnetic susceptibility of chalcopyrite increased with increasing temperature and treatment time. Moreover, the magnetic fraction of chalcopyrite followed the similar trend as found from magnetic susceptibility results. Meanwhile, magnetic susceptibility of molybdenite relatively unaffected by the heating treatment, resulting in a low magnetic fraction of molybdenite. X-ray diffraction (XRD) spectra show that various magnetic minerals such as hematite, maghemite, and magnetite formed on chalcopyrite after the heating treatment. On the other hand, the molybdenite surface was oxidized forming non-magnetic molybdenum oxides. This results indicate that the heating treatment might be applied for separation of chalcopyrite and molybdenite using magnetic separation.

Process Control, Optimization, & Instrumentation

590449: I4.0 Ready Pneumatic Handling Systems and Other Visualisation Systems
Mark Coleman, Schenck Process UK Ltd

ABSTRACT Schenck Process is an established customer-driven solutions provider, utilising its knowledge, expertise and technologies to transform production processes. The current trend of ‘Big Data’ and I4.0 is pushing our Clients to collect more and more data, look for patterns and have visibility at internet level. Schenck Process have developed a number of solutions to deliver the requirements. We have been fitting sensors to our vibrating screens for a number of years under the banner of CONiQ®, now able to link these together either site DCS to give predictive maintenance, just in time spares supply, and off site ‘expert’ feedback. Now we can fit independent sensors and supply overview of the equipment condition via an internet viewer giving high level equipment condition and operation for management purposes. Ever wanted to check everything is OK before a meeting with a client or the board!

This equipment has now been introduced to pneumatic handling equipment allowing the systems to deliver IoT information and support via the internet. Systems can deliver data for analysis or access for maintenance via the web, including via mobile 3G or 4G communications. New products PHASiQTM for transport systems and STREAMiQTM for injection systems provide state of the art integrated controls, with IP68 HMI, integrated PC, PLC and Valve Interface mounted locally and communicating over Ethernet to the DCS and via router to remote server. These units replace the usual PLC panels and supply much greater flexibility of control and high level data collection and at a fraction of the old solutions.

We are now providing support to a number of clients via secure third party server from the Centre of Competence in the UK. A yearly support fee gives highly competent software and equipment support in real time. It is possible from recorded cycle data to reprogram the cycle to suit changing material which are causing problems without the need visit site. Data can also be viewed via our Schenck family E-Nizing® software. This allows monitoring from anywhere by any registered device. allows access to check equipment you have registered. E’Nizing® can collect data, visualize, analyse, predict and provide first level action calling a responsible person. This is available on a subscription basis. The paper will show how these systems can deliver data
Tuesday, August 20, Atrium Foyer

acquisition, remote support improving your return on investment.

Schenck believes this shows our commitment to 'make processes work'.

593423: An Outlook for Domestic Investors in Aynak Copper Mine in Afghanistan
Mohammad Omar Andar, Kabul University
Najibrahman Saboory, Destiny Consulting Services (DCS)

ABSTRACT Most mineral resources including the Aynak copper mine have been studied during 1950 and 1985 in Afghanistan under leadership of Russian experts. United States Geological Survey (USGS) revisited the mine and its subareas between 2007 and 2011. The data gathered from these studies discuss quality, type and volume of the mine. The contribution to the national economy has been conceived as mere returns on selling of raw materials to offshore clients. Involving domestic firms/investors, transferring mining knowledge to locals and subsequently improving the very traditional copper processing skills of local copper workers have not been discussed in any study yet.

This study exemplifies copper mining development pathways, motives for domestic investors in copper industry and summarizes lessons learnt in certain economies where copper mining has significantly contributed for national economy (J. Sikamo et. all. 2016). Moreover, potentials for domestic investors have been sought in a challenging environment where extreme focus is merely on selling out raw extracts. Certain countries’ economic mining models and histories of mining development have been reviewed and lessons learnt from their setups are discussed in an effort to give perspectives to future mining strategy developers/implementers in establishing a suitable copper mining investment structure.

Pyrometallurgy (The Phillip Mackey Symposium)

586326: Effect of Addition of CaO, Al2O3 and Cu2O on the Viscosity of Copper Slag
Li Bo, Yonggang Wei, Hua Wang, and He Zheng, Kunming University of Science and Technology

ABSTRACT In order to improve the efficiency of copper smelting and realize the separation of slag and copper, it is very important to obtain the viscous behavior of copper slag. The viscosity of copper smelting slag was determined by rotating spindle method. The effect of three components of CaO, Al2O3, Cu2O on the viscosity of copper slag system was studied. The research results showed: when the content of CaO increased to 7%, a complex compound was formed, resulting in increase of slag viscosity; high temperature pyroxene phase was formed in the adding process of Al2O3, which increased the viscosity of copper slag; Cu2O reacted with Fe2+ in slag to form Fe3O4, resulting in increase of viscosity of copper slag. The effect of additive content on viscosity was explained by apparent activation energy of viscosity.

587518: Opportunities with High Density Solids (HDS) Precipitation
Daryl J. Purdie and Tony Warner, Advisian, WorleyParsons Group
**ABSTRACT** High Density Solids (HDS) Precipitation was first patented over 45 years ago, and since then has been widely used in the mining industry for Acid Rock Drainage (ARD) and tailings pond overflow treatment. This paper aims to review for designers, operators and managers the benefits of applying an HDS process to any precipitation circuit in their smelting, refining and bleed treatment operations, whether it is sulfide, carbonate or hydroxide precipitation. This paper discusses the development and subsequent application of the HDS process at two copper smelters, which resulted in significant improvements in settling and filtration rates, operability as well as reduced capital, maintenance and reagent costs.

**595464: Experimental Study on the Effect of “CaO” and “Al2O3” for refractories of Converter Furnaces Using High Matte Grade**

Hector Mario Henao and Danitza A. Lizana, Technical University Federico Santa Maria
Claudio Pizarro, Codelcotech

**ABSTRACT** In the piro-metallurgical production of copper in Chile, the slag generated in the Peirce Smith converter has high concentration of copper (>40 wt%) and a large proportion of solid (spinel and tridymite). This situation generate a number of operation difficulties, including safety issues. Studies report in the literature indicate the possibility of reducing the proportion of solid with the addition of CaO and Al2O3 to the process. However, the adding of those oxides may impact the performance of the refractory. This work contribute to understand the effect of the addition of those compounds in the formation of new phases or the incorporation of elements in the phases as solid solutions. The experiments were carried out on the interaction of slag with a refractory of MgO/Cr2O3. The obtained samples were analyzed with a Scanning Electron Microscope (SEM) coupled with an Energy-dispersive X-ray spectroscopy (EDS). The experimental results, complemented with computer simulation (using FactSage), indicated the formación of forsterite, Spinel and perovskite. All the observed crystals (including the original crystals of chromite and periclase) present variable concentration of ions as Cu, Al, Si, Fe as solid solutions. The formation of the new phases and the reaction of the slag with the matrix of the refractory indicated the key factors to understand the performance of the bricks with the addition of CaO and Al2O3.

**600714: Analysis and Development of Improved Concentrate Burners**

Thomas Gonzales, Hatch Associates
Matthew White and W. Taylor, Hatch

**ABSTRACT** Utilising a fundamental understanding of particulate combustion, Hatch has innovated solutions to improve concentrate burners in the copper smelting industry. Advanced numerical methods, such as computational fluid dynamics (CFD) and discrete element modelling (DEM), have been used to address known inefficiencies within the flash smelting system. Mixing conditions between concentrate and oxygen enriched blast have been investigated to improve operational problems. An example of this improvement is the Hatch Disperser technology, which has been engineered to improve the spatial mixing between solid concentrate and oxygen enriched blast within the reaction shaft. The current paper provides a historical review of concentrate burners and a summary of recent work carried out by the authors including analysis, design, and operational improvement.
**Sustainability & Waste Management**

**592944: Energy Efficiency Programs and Decreasing Our Carbon Footprint - Is It Feasible**

*Michael E. Reed, Front End Solutions, Worley Pty Ltd*

*Patience Showa, Phil O'Neil, Ahmed Vahed, and Tony Warner, Advisian, Worley Parsons Group*

**ABSTRACT** The Advisian group have assisted several operations complete energy management surveys with the aim of improving business performance. The approach has involved reviewing the operations to determine where opportunities for significant energy saving and integration with renewable energy supply exist. Alternative energy sources that have been reviewed include:

- Solar/battery support to remote operations
- Organic Rankine heat recovery
- Wind power
- Battery storage solutions

The other significant operational challenge that faces all operations globally is decreasing our carbon footprint. This paper looks at a conventional furnace heat balance and considers alternative energy sources to minimize our carbon footprint.


*Kevin Heppner, SysCAD*

**ABSTRACT** A rigorous thermodynamic model of a water treatment circuit for hydrometallurgical waste water is presented. The chemical process simulator, SysCAD, is seamlessly linked to an external thermodynamic engine to enable first principles modelling of a ferric lime water treatment plant of solvent extraction raffinate. This plant model incorporates simultaneous precipitation and sorption calculations using free energy minimization to predict the removal efficiency of trace metals. The effect of feed water characteristics, operational parameters, and clarifier performance on overall plant performance is simulated.
2nd China-Canada Nonferrous Metallurgy Forum

592627: Copper Slag Cleaning in Electric Furnace Using Spent Cooking Oil as a Green Reductant
Yu Shi, Guangping Dai, Shiwei Zhou, Li Bo, Prof. Yonggang Wei, Kunming University of Science and Technology

ABSTRACT Copper slag cleaning in electric furnace is an effective means to reduce the copper losses in slag. Various agents have been used in the past for this purpose such as coal, coke, ferrosilicon, etc, all with different degrees of success. This research looks into using spent cooking oil, as a green reductant, to reduce magnetite of the slag which results in reduced viscosity and improved settling of copper containing phases. During the experiment, the calcium borate was firstly adopted as flux to adjust the rationality of molten slag for copper separation from slag, subsequently, based on the adjusted slag, the reduction and cleaning of copper slag in electric furnace were carried out using spent cooking oil. The effects of oil on slag reduction was analyzed using thermodynamic knowledge and experiments. The results show that the proper amount of calcium borate can decrease the liquidus temperature and viscosity, the increase of spent cooking oil dosage can promote the reduction of Fe3O4 in slag, and significantly improve the settling of copper containing phases.

594793: Assessment of Critical Elements in Some Pegmatite Ore Bodies to Determine Their Amenability for Concentrating and Processing
Mark Aylmore, Curtin University

ABSTRACT Granitic pegmatites are well known important source of rare metals including lithium, tin, tantalum, niobium, beryllium, cesium, rubidium, scandium, thorium, uranium and rare earths. To facilitate further process development, a comprehensive understanding of the deportment of these various elements and associated minerals in ore bodies is essential to allow the industry to predict the response of ore reserves to metallurgical treatment options. This poster 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 ore bodies and determine their amenability to potential processing options for the extraction of Li, Sn, W, Rb, Zn, Ta, Cs, Ce, Ga, Nb and Sc. The mineralogy, mineral associations, and liberation characteristics of ore-bearing and gangue minerals were characterised using a combination of the TIMA and XRPD studies. The elemental content and distribution within minerals were defined using LA-ICPMS and field emission scanning electron microscopy techniques (EBSD, ToF-SIMS) and atomic probe microscopy.

595789: Leaching of Manganese Nodules with Steel Scrap and Sulfuric Acid at Room Temperature
Norman Toro, Universidad Católica del Norte
Alessandro Navarra, McGill University
Jonathan A. Castillo, Universidad de Atacama
Julio Valenzuela, Universidad Católica del Norte
Roxana Acosta, Universidad de Antofagasta
ABSTRACT In this study, surface optimization methodology was used to assess the effect of three independent variables namely time, particle size and sulfuric acid concentration, in three levels (low, medium, high) to Mn extraction from marine nodules during leaching with H2SO4 in the presence of steel scrap. In addition, the effect of the MnO2 / Fe ratio was evaluated for the optimal results found in the statistical model, where the maximum extraction of Mn was obtained (79%) when an MnO2 / Fe ratio of 1/2, 1 M of H2SO4 and a particle size of -320 + 400 Tyler mesh in a leaching time of 30 min.

596857: Efficient Photochemical Recovery of Rhenium from Aqueous Mixed Metal Solutions
Hisao Hori and Takafumi Otsu, Kanagawa University

ABSTRACT Rhenium, a minor metal with a high melting point, has recently been recognized as a strategic material, owing to its high heat resistance, high corrosion resistance, high hardness, and other characteristics. Rhenium is present in molybdenum and copper ores, and is produced commercially as a by-product of the metallurgical processing of these ores: specifically, the rhenium component in the ores is oxidized to Re2O7 in flue dust and is subsequently dissolved in aqueous solution as perrhenate ion (ReO4-). The resulting solution contains molybdenum and other metal components originating from the ores, and separating rhenium from molybdenum is difficult because the two elements have similar chemical properties. Aqueous solutions containing ReO4- along with other metals (e.g., molybdenum and tungsten) are also generated during the processing of secondary raw materials such as alloy scraps and spent catalysts. Therefore, the separation of rhenium from other metals in aqueous solution is an important task in the production of rhenium from ores and secondary raw materials.

In the present work, we investigated selective precipitation recovery of rhenium from aqueous solutions containing a coexisting metal (molybdenum or tungsten) by means of UV-visible light irradiation in the presence of 2-propanol and acetone. When the pH of the rhenium-molybdenum solutions (initial concentration 10.4 mM for each metal) was in the range from 6.3 to 12.5 and the irradiation time was 6 h, the rhenium in the initial solutions was efficiently recovered in the precipitates (92-99%), and the rhenium selectivity was high (the rhenium recovery ratio was 9.2-21 times that of molybdenum). The high selectivity for rhenium was also observed at different molybdenum concentrations (4.8-15.7 mM) and at a higher rhenium concentration (17.5 mM). Rhenium was also recovered efficiently and selectively from rhenium-tungsten solutions (initial concentration 10.4 mM for each metal): when the pH ranged from 7.0 to 12.0 and the irradiation time was 6 h, the rhenium recovery was 90-95% and the rhenium recovery ratio was 7.3-45 times that of tungsten. At the presentation, characterization of the precipitate and extension of this method to industrial scale are also described.

600715: Electrochemical Impedance Spectroscopy of Chalcopyrite with the Addition of Cu and Fe Ions in Acid Medium
Denise Bevilaqua, São Paulo State University - UNESP

ABSTRACT Electrochemical techniques are important tools to study the leaching conditions and to provide relevant parameters related to the copper extraction from chalcopyrite. Among these techniques, electrochemical impedance spectroscopy (EIS) is the most promising one for
investigating the formation of passive layer, leaching kinetics and reaction mechanisms, but there are few works using EIS. It is well known that the addition of Fe(II) and Cu(II) ions maintain lower redox potentials (about 380-480 mV/Ag|AgCl) enabling more effective mineral dissolution. These ions act in the leaching process in two stages: (1) reduction of chalcopyrite to chalcocite (Cu2S) and oxidation of chalcocite to Cu(II) ions to the solution. The aim of this work was to study the carbon paste electrode modified with chalcopyrite (CPE-chalcopyrite) in salt solution (pH ≈ 1.8) containing 0.5 g L⁻¹ of each of the salts: MgSO₄ 7H₂O, (NH₄)₂SO₄ and KH₂PO₄, using EIS. EIS experiments were also performed with the addition of 20 or 100 mmol L⁻¹ of cupric and 200 mmol L⁻¹ ferrous ions to the salt solution. EIS diagrams were obtained at different times up to 100 h, at 25°C and the open circuit potential (EOCP) of the electrode was monitored between EIS measurements. When 200 mmol L⁻¹ Fe(II) were added, a gradual decrease of Zreal values with the immersion time was observed. In the presence of Cu(II) ions, the Zreal values were similar to those obtained with the iron addition, however the real impedance slightly increased with the immersion time. The addition of both Cu(II) and Fe(II) ions resulted in almost unchanged EIS diagrams with lower impedance, suggesting different mechanisms. The lowest impedance values were obtained for the solution with 200 mmol L⁻¹ of Fe(II) + 100 mmol L⁻¹ of Cu(II) indicating a greater leaching of chalcopyrite.

Electrowinning & Electrorefining

595059: Some Challenges of Copper Recycling from E-waste with Focus on the Electrolytic Processes

Daniel Majuste, Poliana M. Ferreira, Saulo L.S.P. de Rezende, Nelson H. J. Freire, Tamiris R. da Silva, Universidade Federal de Minas Gerais
Sérgio A. Penciel Jr. and Adelson D. Souza, Nexa Resources S/A
Virginia S.T. Ciminelli, Universidade Federal de Minas Gerais

ABSTRACT This paper discusses some challenges in the production of copper from waste electrical and electronic equipments (WEEE) with focus on technologies that includes electrowinning and electrorefining processes. The global amount of WEEE generated worldwide is expected to grow in the next years by 4 to 5% annually. It is well-established that copper represents the main metallic element in many types of WEEE, mainly in printed circuit boards (PCB) from appliances such as TVs, computers and mobile phones. Pyrometallurgy is the traditional technology used to recover nonferrous and precious metals from these wastes, typically through co-processing of mineral concentrates and electronic scraps. The processing of scraps by pyrometallurgy has been employed commercially and also tested in lab- and pilot-scale. The production of blister with copper content lower than 95% (w/w), which means high levels of some impurities, for instance, tin, nickel and iron, may be produced. In this context, the electrorefining of a material with such features is an attractive challenge. The possible effect of such impurities on anode passivation and cathode quality may require different operating conditions than those employed in the conventional electrorefining processes. In turn, many options for the hydrometallurgical processing of WEEE have been tested worldwide. Most publications have focused mainly on copper and gold leaching with lesser emphasis on metal recovery. Therefore, the effect of the electrolyte features (i.e. type of aqueous medium and type/level of impurities) on current efficiency and energy consumption of the electrowinning processes, as well as on cathode quality remains to be investigated. In summary, the present
work will discuss case studies about the effect of anode features and electrolyte quality on the performance of electrorefining and electrowinning processes, respectively, both anode and electrolyte obtained from WEEE processing.

Hydrometallurgy

**594132: Experimentation and Mathematical Model Development for Predicting Tenorite Nanoparticles Production from Purified Leach Solution Af a Waste Copper Smelter Dust**

*Abraham Adeleke, Obafemi Awolowo University*

*Daniel Okanigbe, Abimbola Popoola, and Olawale Popoola, Tshwane University of Technology*

*Michael Ayomoh, University of Pretoria*

**ABSTRACT** The aim of this study was to produce tenorite nanoparticles from purified pregnant leach solution of a waste copper smelter dust (CSD). This paper presents a two factors three levels full factorial experimental design to investigate the process parameterization of two linked unit operations to produce the langite precursor and tenorite nanoparticles from thermally decomposed langite. Sequel to this was the development of an experiment specific predictive model premised on the use of constrained interpolating functions at defined optimized intervals. The five significant experimental factors utilized in investigating the first unit operation were dropwise rate of Na2CO3 (drops/min), concentration of purified pregnant leach solution (PLS) (M), concentration of Na2CO3 (M), stirring speed (rpm) and temperature (˚C). Four factors were considered in the second unit operation and these are temperature (˚C), time (hrs), oxygen (O2) flowrate (L/min) and furnace door opening (mm). The results for the first experiment showed a maximum percent langite content to be 24, while the second experiment showed the maximum tenorite nanoparticle content to be 27%. These productions of 24% and 27%, langite and tenorite nanoparticles, respectively were obtained under test conditions for unit operation of one dropwise rate of Na2CO3 (4 drops/min), concentration of purified PLS at 0.2M, concentration of Na2CO3 of 2.0M, stirring speed of 750 rpm and temperature of 55˚C), while unit operation two was carried out at a temperature of 750˚C, contact time of 2 hrs and furnace door opening of 25 mm. However, the flow rate of oxygen was not determined. These outputs limit (maximum) and the associated experimental conditions depict the optimum operating conditions of the experiment. Furthermore, the predicted outputs from mathematical modeling premised on developed constraint interpolant models were well aligned with the experimental outputs. A maximum percentage error of 0.10% was recorded in the predictive outputs for both the langite and tenorite nanoparticles fractions.

**595486: Geometallurgical Study of Copper Whole Ore from an Open Pit Mine with Various Leaching System**

*Betty Rathbone and Jaeheon Lee, University of Arizona*

*Jaewoo Ahn, Daejin University*

**ABSTRACT** Nine metallurgical composite samples were selected based on the chemical assays, rock types, and mineralization out of 20 composites collected from two separate pits located in Southern Arizona. All materials are subject to be ROM dump leaching followed by solvent extraction and electrowinning. The copper grades were varying from 0.1% to 1.0% and QEMSCAN (Quantitative Evaluation of Minerals by Scanning electron microscopy) was used to
identify copper minerals from the samples. Main minerals are chalcopyrite, chalcocite, covellite, malachite, chlorite and Cu-Mn-Fe oxides. 

A depleted copper sulfide deposit is now subject to heap leach, solvent extraction and electro-winning. Ore samples with grades ranging from 0.1% to 1% copper by weight were analyzed using QEMSCAN and mineral grain designations, quantifications were identified for copper concentrations at and below 0.01%. Copper bearing minerals present include chalcopyrite, chalcocite, covellite, malachite, chlorite, and Cu-Mn-Fe oxides. Over 80% of gangues are quartz, plagioclase and K-feldspar by XRD analysis. There are several clay minerals such as muscovite and kaolinite.

Bottle roll leaching tests were performed under various acid concentrations of sulfuric, sulfurous, and methanesulfonic acid (MSA) with different oxidants. Glycine was also used as a lixiviant in alkaline condition. General copper extractions with reagent consumptions will be discussed and the geometallurgical models with mineralogical data will be presented.

Mineral Processing

594664: Future of Advanced Analytical Techniques and Data Modelling in Process Mineralogy Applied to Copper Deposits
Sarah J. Prout, SGS Canada Inc.
Tomas Hrstka, SGS Minerals
Tassos Grammatikopoulos, SGS Canada Inc
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ABSTRACT New technological advancements in automated mineralogy can be used to better understand complex mineral deposits and the metallurgical response of ores in mineral processing. The use of TIMA (Tescan Integrated Mineral Analyser) in automated mineralogy, has offset some of the limitations related to detection limits and fine texture data collection and interpretation. We will demonstrate the benefits of using the newly developed DOTmap approach for a study of complex mineralogical samples on a variety of ores from around the globe. This approach uses high resolution BSE imaging in combination with lower resolution EDS mapping to understand the recovery and co-recovery of minerals and metals of interest. It will be demonstrated that the emerging technologies like TIMA, which now have become available along with the well establish QEMSCAN solutions, are more appropriate for the mineralogical analysis of certain ores. We will also demonstrate ways to link the process mineralogy data with geometallurgical testwork and process optimization. It will also be shown that the process of full integration of mineralogical data can be significantly improved with the use of machine learning.

595529: Novel Frothers for Improved Copper Flotation
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ABSTRACT Frothers are very important flotation reagents that play multiple roles in the flotation process, including the stabilization of the froth phase. Having a froth phase that is too stable would increase the amount of entrainment of gangue minerals, while a froth phase that is too brittle or weak would not provide the optimum conditions to float the coarser particles. This means that the froth stability would need to ensure there is a delicate balance, so that minimal
gangue minerals are recovered with the maximum possible recovery of the valuable minerals. Frothers and collectors may also show synergistic effects through interactions between the different chemicals, such as hydrophobic interactions, that may provide an overall improvement in the froth flotation process. The proper selection of frother reagents is a crucial aspect to obtaining the highest recoveries possible with the given reagents and operating conditions at a mine. Generally speaking, frother reagents consist of similar chemistries across the different available products on the market. The main frother chemistries include alcohols, alkoxy type, polyglycols, or mixtures of these different reagents. Newly developed novel frother reagents can increase copper recoveries at the mine, depending on the operating conditions. These innovative frother reagents contain specialized additives that were selected to provide more favorable flotation conditions that will increase the recovery of copper and thus increase the overall flotation performance of a mining operation.

Process Control, Optimization, & Instrumentation

594806: Latest Improvements in Fully Automatic Flash Smelter Control Using the Process Advisor
Peter Björklund and Mikko Korpi, Outotec (Finland) Oy
Jouni Pihlasalo, Outotec Research Center
David Grimsey, BHP

ABSTRACT The Outotec® Process Advisor has successfully been used for automatic control of flash smelting furnace setpoints continuously for 4 years. This is one contribution that has enabled record long furnace campaign life due to the improved matte temperature control, which has prevented matte infiltration into the hearth. Building on this success, the Process Advisor has been enhanced to further utilize the online dynamic heat and material balance model also for other purposes than direct process control. This paper covers some of the latest improvements taken into use after the initial startup. These include, for example, an online maximum feed rate estimator, which continuously updates the maximum feed rate possible for the operator and an online matte level estimator to get a better matte level estimate also between sounding.

Pyrometallurgy (The Phillip Mackey Symposium)

594654: Numerical Simulation of the Stirring Effect of the Fluid Oscillations in Bottom-blown Bath
Peng Li, Xin Yao, Tianyu Guo, Zeshang Dong, and Dongbo Li, China ENFI Engineering Corporation

ABSTRACT In order to clarify the stirring mechanism of the bottom blow pool oscillation, VOF multiphase flow model was adopted to simulate the gas-liquid two-phase flow process. The influence of gas jet oscillation on melt flow process was analyzed on the basis of the reasonable simulation results. The results show that a stable vertical jet can be formed within 1s, while the jet starts to sway after 20s, and the gas distribution in the furnace chamber is not uniform. The maximum volume fraction of oxygen in molten pool is 5.2%, which is kept at about 4% after stable operation. As the jet blowing, the swing amplitude of the jet along the axis of the furnace is larger, and the frequency is more faster, while the swing amplitude of the radial jet along the
furnace increases and the frequency decreases.

592968: Upgrading Practice of Electrostatic Precipitator for Copper Smelting
Jianhua Tu, Wei Wang, Jun Hu, Wei Li, Liangliang Zhou, China Nerin Engineering Co., Ltd.

ABSTRACT The paper reviews the successful experience of electrostatic precipitator upgrading in a copper smelter in Southeast Asia, including engineering, implementation and operation. Based on the in-depth study of the installation position and foundation of the original electrostatic precipitator, the solution of reconstructing and expanding a new horizontal double-chamber three-field electrostatic precipitator for flash smelting furnace and a new horizontal double-chamber four-field electrostatic precipitator for converter furnace are determined. Under the overall upgrading program of "Parameters and structure determination - Three-dimensional design - Modular pre-assembly and Foundation pre-construction - Modular hoisting", the demolition of the original electrostatic precipitator and the installation and commissioning of the new electrostatic precipitator were successfully completed within the planned date. The operation data show that the new flash smelting furnace electrostatic precipitator and converter furnace electrostatic precipitator fully meets the production requirements after expansion, and the outlet dust concentration is better than the design value.

595480: Treatment of Copper Smelting Dust in a Fluidized Bed Reactor Using a Novel Pyrometallurgical Process
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Rodrigo Antonio. Diaz and Javier Ortiz, Ministro Hales División, Codelco Chile
Osvaldo Francisco Saavedra, CodelcoTech SpA
Diego Jaques, Universidad Técnica Federico Santa Maria

ABSTRACT The dusts generated by electrostatic precipitators of the smelters of copper show high concentrations of arsenic, this situation prevents its circulation in the process of fusion. These dusts, in many case, despite its high values of precious metals, copper and others are considered industrial waste. The present work shows the results of experimental works which indicated that it is possible to remove a 90 wt% of content of arsenic in these dusts. The experimental result led to the development of a new process which was validated in an industrial test.

Sustainability & Waste Management

580121: The Feasibility of Separation of Lanthanium and Europium by Use of Electrodialysis
Sanaz Mosadeghsedghi, Saviz Mortazavi, and Maziar Sauber, CanmetMINING-NRCan

ABSTRACT The dominant Rare Earth Elements (REE) separation method, currently applied by the industry, is multi-stage solvent extraction, which involves a significant degree of downstream processing and produces significant amounts of secondary hazardous waste streams. Due to the increasing demand for a wide range of REE applications as well as regulatory pressures, there is an increasing need for the development of alternative solvent-free processes. Electrodialysis (ED), a proven membrane-based technology, which is currently used at industrial scale in water
treatment and drinking water production applications. ED could be a promising technology alternative for REE separation. ED has clear advantages over conventional solvent extraction, including: lower energy consumption, no downstream post-treatment requirements, no hazardous waste production, operational simplicity and modularity. This paper presents the results of study on the feasibility of the separation of different REE using ED with the use of different complexing agents. Lanthanum, as a light and europium, as a mid REE were effectively separated in a bench-scale ED system in the presence of different chelating agents such as EDTA and DTPA. The effect of operating parameters on ED were studied and optimized for effective use of ED for separation of La/Eu and other REE pairs.

594699: Application and Development of Side Blown Smelting Technologies In China’s Hazardous Waste Treatment Industry

Bin Tang, Chuanyu Jiang, Weiyan Yang, Xiaoming Zhang, Yang Liu, and Longyi Duan, China NERIN Engineering Co., Ltd

ABSTRACT In recent years, the amount of plants with copper-laden hazardous waste treatment in China has grown rapidly and the scale has become larger. However, most of copper-laden hazardous waste plants are still treated by traditional technologies at current stage, such as blast furnaces. In recent years, side blown smelting technologies have been applied to copper-laden hazardous waste treatment. This paper analyzes the constructional and operational situations, and major technical parameters & economic benefits of several large-scale copper-laden hazardous waste treatment plants applying side blown smelting technology, which reflects the technical strongpoints of side blown smelting technologies in the said industry, especially in collaborative treatment of hazardous waste and harmless waste materials, providing a new way for hazardous waste recycling. This paper also discusses the further efforts of the side blown smelting technologies to treat copper-laden hazardous waste in adapting to increasingly strict emission standard and improving the economic benefits of the plants.