WEDNESDAY, AUGUST 29, 2007, PM

COM 2007: International Symposium on **Light Metals** in Transport Applications
Session 61: Primary Product of Light Metals II
Sponsors: Light Metals Section of MetSoc, TMS
Chair(s): D. Gallienne, Alouette;
G. Dufour, Alcoa
Room Confederation 5—13:40

Paper #1152—13:40
GHG reduction at Baie-Comeau Søderberg plant
Y. Béliveau, Alcoa Canada

Emission of perfluorocarbon gases, CF_4 and C_2F_6, produced during anode effects from aluminum electrolytic cells are a significant part of the total equivalent CO_2 emitted by aluminum plants. With the current concerns about global warming, the reduction of these PFC gases is a key issue in reducing greenhouse gases for a smelter and achieving GHG emission agreement goals. This paper will present the approach taken by the Alcoa vertical-stud Søderberg plant in Baie-Comeau to reduce GHG emissions generated during anode effects and close emission gaps with other Alcoa Søderberg plants. The approach has been to adapt the existing technology in place at the Baie-Comeau Søderberg plant. PFC emissions were lowered by reducing both the anode effect duration and frequency through different methods. Examples of change include: implementing skimming practices and wider side crust break area for better alumina dissolution in bath, increasing the ratio between reacted and pure alumina, reducing the time to declare anode effects in the potrooms, implementing best work practices and finally educating the workforce on the importance of reducing PFC emissions.

Paper #1148—14:05
Isothermal thermal gravimetric analysis of magnesium chloride hexahydrate during rapid heating
S. Kashani-Nejad, Hatch Non-Ferrous Pyrometallurgy,
H. R. Harris, McGill University

Rates of weight loss of $MgCl_2.6H_2O$, Bischofite, were monitored during rapid heating to a range of temperatures. Small amounts of $MgCl_2.6H_2O$ were placed in the hot chamber of a homemade thermal gravimetric setup kept at the test temperatures. Weight loss was recorded as the function of time and the final products were identified and assayed. The mass loss measurements for rapid heating to 200 ^oC, 300 ^oC, 400 ^oC showed that the water removal was almost instantaneous and resulted in the formation of various magnesium chloride hydrates, $MgCl_2$ and MgOHCl. The mass loss for rapid heating to 500 ^oC and 600 ^oC showed that the initial mass loss was very rapid and products only contained $MgCl_2$, MgOHCl and MgO.

Paper #1168—14:30

Controlled precipitation of nesquehonite (MgCO3•3H2O) by the reaction of MgCl2 with (NH4)2CO3 at 303K

Y. Wang, Z. Li, Chinese Academy of Sciences,
G.P. Demopoulos, McGill University

In this study, homogeneous (unseeded) precipitation of nesquehonite ($MgCO_3 \cdot 3H_2O$) by the reaction of $MgCl_2$ with $(NH_4)_2CO_3$ in supersaturated solutions at 30 °C was investigated. Factors which influence the precipitation of $MgCO_3 \cdot 3H_2O$, such as initial concentration, temperature, stirring speed, titration speed, equilibration time, have been studied. SEM images show that the initial concentration and titration speed have significant effect on nesquehonite's crystal morphology and particle size. In addition, stirring speed and equilibration time also have some influence on its properties. With the optimization of operating conditions, the crystals can grow up to a length of about 40μm and a width of 5μm, indicating good filtration properties. High purity nesquehonite obtained in this study was calcined to produce highly pure MgO at 800 °C as shown by XRD results. The novel process may be used to separate Mg and Li from high Mg/Li ratio brines in Qinghai, China.

Paper #1141—14:55

Deoxidation of titanium dioxide compressed pellets by the FFC Cambridge process

N.K. Jabber, Induction Heating Technologies

Oxygen is removed from titanium dioxide by the novel new process: The FFC Cambridge Process developed by Derek Fray, George Chen and Tom Farthing at Cambridge's Department of Materials Science & Metallurgy. The process involves the electrolyses of the metal oxide in molten electrolyte. The final product is a relatively pure sponge titanium metal. In this work the FFC Cambridge process is performed on compressed TiO_2 discs in molten CaCl2 electrolyte at 950 degrees Celcuis after which the discs were tested for the presence of sponge titanium metal.

Cu2007: The John E. Dutrizac International Symposium on Copper
Hydrometallurgy, Incorporating the 37th Annual Hydrometallurgy Meeting
Session 62: Technology Development II
Sponsors: Hydrometallurgy Section of MetSoc, IIMCh, MMIJ, GDMB, EPD of TMS
Chair(s): P. Riveros, CANMET-MMSL;
R.S. Forgan, University of Edinburgh
Room Alberta—13:40

Paper #0974—13:40

Hydro-geochemistry of in-situ leaching – an integrated approach to management of solution mining

S. Orr, A. Getahun, Water Management Consultants

In situ leaching is a complex, multidisciplinary process, which requires both mastering and integration of the different disciplines involved. Particularly, in-situ leaching is the intersection between geology (geochemistry, mineralogy, structural geology), hydrology (hydrogeology, well hydraulics), metallurgy (hydrometallurgy, electrochemistry, aqueous chemistry), and economics (mineable ore, cost of operations, market). The management of such a complex system requires all relevant knowledge base, integration, and continual optimization. Our presentation starts with a description of the "expert system" – from data acquisition to information and knowledge, including determination of essential in-situ parameters, analyses, and modeling, which ultimately leads to an integrated, real-time, hierarchical management/control system.

Paper #0960—14:05

Correcting for scale-up phenomena in heterogenous material processing

M.L. Free, University of Utah

Laboratory scale extraction of metals from heterogeneous materials such as copper ores is often performed using fine material to increase kinetics and reduce sample size requirements and costs. In contrast, commercial extraction is usually accomplished using much larger material sizes than are used in laboratory settings. The large size difference between laboratory testing and commercial application materials makes it difficult to use laboratory test data to accurately predict performance for commercial material. One solution adopted widely in industry is the use of large test columns. Large test columns cost considerably more to set up and run and take much longer periods of time to evaluate than laboratory scale tests with small particles. Consequently, from a cost and data collection efficiency perspective, the development of accurate scale up methods offers significant potential for saving both time and money. This paper provides details for a new approach to correct for scale-up phenomena in heterogeneous material processing.

Paper #0986—14:30

Studies on the leaching of tennantite, tetrahedrite and enargite in acidic sulphate and chloride media

P.A. Riveros, J.E. Dutrizac, CANMET-MMSL

This paper describes the leaching of the common copper minerals tennantite ($Cu_{12}As_4S_{13}$), tetrahedrite ($Cu_{12}Sb_4S_{13}$) and enargite (Cu_3AsS_4) in acidic media using $Fe(SO_4)_{1.5}$, $FeCl_3$ or O_2 as oxidizing agents. At temperatures <100°C, tennantite dissolves slowly in $Fe(SO_4)_{1.5}$-H_2SO_4 media, and the rate is directly proportional to the area of the sized tennantite. The rate increases sharply with

increasing temperature and the apparent activation energy is 69 kJ/mol. Increasing $Fe(SO_4)_{1.5}$ concentrations slightly increase the tennantite leaching rate. The kinetics of dissolution of disks of synthetic iron-bearing tetrahedrite in $Fe(SO_4)_{1.5}$-H_2SO_4 media are linear; the leaching rates are slow but increase significantly with increasing temperature, with an apparent activation energy of 120 kJ/mol. The dissolution of sized particles of natural Ag-bearing tetrahedrite in $FeCl_3$-HCl solutions proceeds according to the shrinking core model, and both Cu and Ag dissolve at about the same rate, provided that the total chloride concentration of the solution is sufficiently high to solubilize the AgCl reaction product. The leaching rates are slow, and the apparent activation energy is 116 kJ/mol. The addition of sulphate ions to the $FeCl_3$-HCl system reduces the tetrahedrite leaching rate to values similar to those realized in the $Fe(SO_4)_{1.5}$-H_2SO_4 system. At <100°C, enargite dissolves slowly in either $Fe(SO_4)_{1.5}$ or $FeCl_3$ media, and the dissolution rate obeys the shrinking core model. The rate increases with increasing temperature and the apparent activation energies are 50-64 kJ/mol. The rate increases slightly with increasing $FeCl_3$ concentrations in 0.3 M HCl media. The leaching of enargite at elevated temperatures and pressures was also investigated. Potentially useful leaching rates are achieved above 170°C, at which temperature sulphate, rather than sulphur, is produced. Lower temperatures (130-160°C) lead to fast initial leaching rates, but the dissolution of the enargite is incomplete because of the coating of the enargite particles by elemental sulphur.

Paper #0954 —14:55

The behaviour of copper during the dissolution of metallic nickel in $CuSO_4$ solutions

L.V. Volkov, M.I. Kalashnikova, Y.M. Shneerson, Gipronickel Institute

The equilibrium of the Cu^o-Cu_2O-Cu^+-Cu^{2+} system with various chloride ion concentrations in solution in the presence or absence of an oxidant was investigated. It is shown, that, regardless of the presence or absence of chloride ions or oxidant (oxygen) in the system, the process can be divided into three stages, which are characterized by differing rates and mechanisms of metallic copper cementation and cuprite precipitation and, hence, lead to differing rates of the dissolution of nickel into solution. The effect of the concentrations of chloride ion and oxidant on the phases in the process residues is also discussed. The addition of an oxidant increases the amount of cuprite (Cu_2O) in the leach residue. With increasing chloride ion concentrations, the rate of copper cementation increases, even without an oxidant in solution. The results of these laboratory experiments and the mechanisms developed are consistent with analysis of samples of industrial cement copper obtained from the Severonickel Combine. Cu2007: Concurrently designing both the solvent extraction and the electrowinning processes of a copper SX EW project, in an integrated and consecutive approach, with one technology partner, will ensure continuity in the process flow and smooth execution of the engineering function with minimum duplication, time loss and errors, maximizing time efficiency resulting in excellent

quality and quick and effective start-up of the plant. Projects will benefit significantly from the common technology partner approach as not only will the SX and EW processes be optimally efficient individually, but the overall process efficiency will be optimized eliminating the common problem of efficiency losses and integration difficulties when combining two consecutive processes which also require to circulate flows between them. Plant operation will also benefit from the fact that impurity control will be on a global basis, rather than concentrated on certain parts of the process, hence, better results and more efficient control. The operation of equipment will be more effective and efficient. Further, proprietary technological equipment that focuses on maximizing plant performance, such as Dispersion Depletor Gate (DDG) Fences and Outokumpu Cathodes, will be applied throughout the plant as the design philosophy will be to utilize technology to maximize production.

Cu2007: International Symposium on **Electrowinning and Electrorefining**, Incorporating the 37th Annual Hydrometallurgy Meeting
Session 63: Emerging Technologies
Sponsors: Hydrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): M. Palacios, Altlantic Copper S.A.;
T.G. Robinson, Freeport-McMoran Copper and Gold Inc.
Room British Columbia—13:40

Paper#0748—13:40
Utilization of cell voltage and temperature data of wireless cell sensors in copper refinery monitoring, control and maintenance
A. Rantala, Outotec,
E. You, D. Kim, Kennecott Utah Copper,
K.Pienimäki, Boliden

Over the years, efficient on-line monitoring of performance and status of an electrolytic copper refining process has been challenging due to the need for complex electrical measurement systems and the management of the enormous volume of data. Recent innovative developments by Kennecott Utah Copper Corporation and Outokumpu Technology in wireless cell voltage and individual cell temperature sensing opens new possibilities to improve and modernize tank house management. This paper describes the powerful Outokumpu CellSense™ refinery monitoring system for efficient interpretation of data produced by wireless CellSensor™ system with traditional refinery measurements. Examples from commercial tank house installations demonstrate the benefits of the system to improved process control and operation. The Outokumpu CellSense™ monitoring system is simple to operate and accessible to all the plant operation teams.

Paper #0755—14:05

An update of recent applications of molecular recognition technology (MRT) in the copper industry

S.R. Izatt, J.B. Dale, N.E. Izatt, R.L. Bruening, IBC Advanced Technologies, Inc.

The use of MRT, a highly selective separations technology, has long been demonstrated to be a cost effective, efficient, and environmentally sound process for extraction of a wide range of anions and cations that are commonly found in copper electro - refining and electro - winning circuits, as well as in environmental treatment operations. This paper provides an update of commercial MRT applications in the copper industry. Several recent installations and test programs are reviewed including recovery of bismuth from tank house electrolyte, and from chloride matrix selenium reduction solution which is generated in the anode slimes treatment process. Recovery and refining of platinum group metals originating in the anode slimes is also discussed. Various other base metal and other target separations of interest to the copper producer are also reviewed. The recovery products are high purity metal salts which can be marketed directly or readily reduced to metal. The use of MRT, a highly selective separations technology, has long been demonstrated to be a cost effective, efficient, and environmentally sound process for extraction of a wide range of anions and cations that are commonly found in copper electro - refining and electro - winning circuits, as well as in environmental treatment operations. This paper provides an update of commercial MRT applications in the copper industry. Several recent installations and test programs are reviewed including recovery of bismuth from tank house electrolyte, and from chloride matrix selenium reduction solution which is generated in the anode slimes treatment process. Recovery and refining of platinum group metals originating in the anode slimes is also discussed. Various other base metal and other target separations of interest to the copper producer are also reviewed. The recovery products are high purity metal salts which can be marketed directly or readily reduced to metal.

Paper #0765—14:30

Electrolytic copper deposition and oxidation from ammoniacal alkaline solution containing solution containing copper (I)

K. Koyama, M. Tanaka, AIST,
Y. Miyasaka, Chiba Institute of Technology,
J.C. Lee, KIGAM

As a study to establish a new energy-saving copper recycling process, the copper deposition at a cathode and oxidation of copper(I) at an anode from ammoniacal alkaline solutions containing Cu(I) or Cu(II) were investigated in order to examine the feasibility of electrolysis in this solution.. The current efficiencies were greater than 95% in the current density range of 200 to 1000 A m^{-2}. The current efficiency decreased with the increasing Cu(II) concentration and temperature. In the batch-type electrolysis at the anode, during the initial

stage, the current efficiencies were 100%, and the anode potentials ranged from 0 to 0.15V vs. SHE at a current density of 100 A m^{-2}. During the subsequent stage, the current efficiency decreased with time, and the anode potential was around 1.35V vs. SHE where oxygen evolution at the anode surface was observed. As a result, the present electrolytic method can be the core technology in the said copper recycling process.

Paper #0767—14:55

Electrodeposition behavior of dendritic copper from aqueous copper (I) chloride solution containing condensed sodium halides

K. Murase, Y. Awakura, Kyoto University,
Y. Abe, Nippon Mining

Potentiostatic electrodeposition behavior of dendritic copper from acidic copper(I) chloride (cuprous chloride) baths containing sodium chloride and sodium bromide was investigated. The morphology, or appearance, of copper dendrite and the sodium content in the dendrite as an impurity were both influenced by deposition potential (0 to –150 mV vs. SHE) and bath temperature (R.T. to 60 ˚C), while the current efficiency for the deposition was 99% or more irrespective of the deposition conditions examined. The bath pH did not affect the deposition behavior in the pH range of 0 to 2. Bath temperature was found to be the most important factor influencing the deposition current. The current density of the dendrite deposition on a titanium cathode was lower than that onto a copper cathode with the same substrate surface area. The reproducibility of the current for the dendrite deposition was poorer when an as-polished titanium cathode was used, although it was improved by surface treatment of the cathode with an HF-HNO_3-H_3PO_4 solution before electrodeposition. The deposition behaviors were discussed with the potential-pH diagram of the Cu-Cl-H_2O system.

Coffee Break—15:20 – 15:40

Paper #0780—15:40

Adding value to LIX / SX / EW operations by recovering copper from bleed, raffinate and other plant streams

R.E. Dixon, HATCH,
R. Fester, C. Garcia, C. Contreras, F. Romero, Compañía Minera Doña Inés de Collahuasi,
I.D. Ewart, Electrometals Technologies

Copper SX/EW plants often bleed part of their electrowinning electrolyte to control impurities and maintain consistent cathode quality. Depending on the specific situation at each site, the bleed is either returned to raffinate, to an SX extraction stage, to an SX wash stage, or to the PLS pond, to avoid losing the copper in the bleed. This practice can have undesirable effects on the overall process. An alternative is to electrowin all or most of the copper in the bleed, thus avoiding the recirculation of the copper in the bleed. In this manner, the bleed is

converted to metallic copper without interfering with the SX circuit. This in turn reduces the copper concentration in the raffinate, improving global copper recovery because of improved leaching conditions.

Paper #0784—16:05

Pilot test of EM-EW® technology application to copper electrorefinery bleed streams with high arsenic content

L. Byszynski, L. Garycki, I. Ewart, P. Rossi, KGHM Polska Miedz S.A.

The results of a three month evaluation of the application of EMEW® technology at the KGHM Głogów II Smelter tank house bleed stream are presented. The current, conventional electrolyte decopperization process has some limitations, including: only a fraction of its production is commercial grade cathode copper, significant operating costs, low current efficiency, low current densities resulting in low copper depletion rate, and arsine gas and sulphuric acid emission. The EMEW® cell technology developed by Electrometals Technologies Ltd. can overcome many of these limitations. Tests were performed on a pilot EMEW® installation comprising 30 cells at ambient temperature on electrolyte bleed, using current densities between 100 and 600 A/m^2 , with copper concentrations between 45 and <1g/dm^3. Results showed that a high grade copper can be obtained to the level of 7 g/dm^3 of copper concentration in electrolyte. The use of EMEW® technology allows the direct and efficient recovery of over 85% of the copper contained in the bleed electrolyte. Glue & thiourea addition were tested in order to improve the parameters of the copper depletion process. The behavior of Arsenic and Bismuth was observed and a means for their elimination from the system proposed. On-line copper concentration monitoring is proposed to improve control and performance.

Paper #0788—16:30

Ion exchange for electrolyte purification in copper electrowinning and electrorefining

R. Shaw, J. Illescas, FENIX,
D. Dreisinger, B. Wassink, University of British Columbia

Ion Exchange is finding a greater role in copper processing, and hydrometallurgy in general, both as a technique for removing impurities and as a means of adding value through the recovery of secondary metals. Both the gold and uranium industries use resin adsorption as a primary production technique. While hydrometallurgical processes predominantly rely on solvent extraction as the mainstay of copper recovery there are a number of projects, in particular polymetallic deposits, which are considering the use of resin recovery as an alternative or supplemental production technique. A number of applications have been developed and proven at commercial scale for the removal/control of impurities (iron, antimony and bismuth) from copper electrolytes. These are well documented ion exchange applications. Increasing metal values and scarcity of certain metals are focusing companies to look at secondary metals recovery

rather than losing these often highly valuable metals to tails residues. Bleed streams are being seen as valuable opportunities to recover contained metals; iron, copper, nickel, cobalt, bismuth, antimony and rhenium are all metals being targeted for removal or recovery from process solutions, electrolytes and bleed streams. An overview of currently applied techniques as well as some developmental technologies for impurity removal and secondary metals recovery is presented to provide insight into the advantages and flexibility of ion exchange applications in metals processing.

Paper #0789—16:55

An innovative wireless electrolytic cell monitor powered by ultra-low bus voltage

E. You, D. Kim, T. Maio, Kennecott Utah Copper,
A. Rantala, Outotec,
D. George, Rio Tinto

Kennecott Utah Copper Refinery and Outokumpu Technology have developed a wireless Electrolytic Cell Monitor (CellSensor) system to monitor cell voltage and temperature. The system is based on a robust self-organizing and self-healing wireless network with a very reliable redundant structure. The microprocessor controlled CellSensor device operates off a small amount of energy harvested from the cell bus and requires no external power source. The radio works in the 2.4 GHz international ISM band using robust Spread Spectrum technology. The CellSensor does not require end user calibration of either the voltage or temperature sensors and accuracy is superior to previous systems. The on-board computation power allows digital filtering of the cell voltage signal which results in very high quality data. The system requires much less maintenance than conventional hardwired systems and is intrinsically safer since no high voltage isolation is required. The advanced diagnostic functions allow the device to determine if the bus tap contact is degrading. The CellSensor can also be used for monitoring electrowinning (EW) cells for a variety of metals. CellSensor have been tested for over two years at the Kennecott Utah Copper and Boliden Harjavalta Pori refineries. The CellSensor system is now commercially available through Outokumpu Technology.

Cu2007: International Symposium on **Electrowinning and Electrorefining,**
Incorporating the 37th Annual Hydrometallurgy Meeting

Session 64: Fundamentals and Modeling II

Sponsors: Hydrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): G.E. Houlachi, LTE-Hydro-Québec;
J.D. Edwards, CVRD Inco
Room Toronto—13:40

Paper #0747—13:40

Monitoring the influence of additives on deposit morphology during copper refining using electrochemical noise technique

F. Safizadeh, A-M Lafront, E. Ghali, Laval University,
G. Houlachi, LTE-Hydro-Québec

The copper electrodeposition from sulphuric acid electrolytes in the presence of Thiourea and Gelatin as additives was investigated by electrochemical noise and cyclic voltammetry in conjunction with the scanning electron microscopy technique. This study was oriented to examine the utility of using electrochemical noise "EN" technique to characterize the electrowinning process and the deposit structure morphology as compared to cyclic cyclovoltammetry "CV", an electrochemical method generally used industrially. Both EN and CV techniques were successful to reveal the effect of different concentrations of Thiourea and Gelatin on copper electrodeposition process. In this study, CV has detected an excess of Thiourea leading to porous deposit. While, the electrochemical noise analysis in the time domain (skewness and kurtosis parameters) as detected the presence of nodules and has given useful information concerning the morphology of the deposit closely related to the macroscopic and microscopic studies.

Paper #0753—14:05

Numerical simulation of turbulent natural convection along a vertical plane electrode

S. Kawai, K. Nishikawa, Y. Kukunaka, S. Kida, Kyoto University

Natural convective flow of the electrolyte solution plays an important role in several electrochemical systems. Copper refining electrolysis is the most important industrial process to produce high purity copper on large scale. Turbulent natural convection develops along vertical plane copper electrodes installed in an unstirred electrolyte accompanying with the electrochemical deposition and dissolution of copper during the electrolysis. It introduces the electrolyte stratification phenomenon. Thus, the electrolyte is circulated in a special way depending on each electrorefining tankhouse. The theoretical discussion is indispensable to understand the coupling phenomenon between the ionic mass transfer rate and the morphological variations of electrodeposited copper. In present study, the mass transfer rate of both Cu^{2+} and H^{+} ions as well as the momentum transfer rate is numerically analyzed accompanying with the turbulent natural convection along 1 m high Cu metal electrode surface.

Paper #0761—14:30

Finite element modeling of an electrolysis cell

I.S. Laitinen, J.T. Tanttu, Tampere University,
H.K. Virtanen, T.M. Kumara, O.T. Järvinen, Outokumpu Technology

Outokumpu Technology has recently introduced new technology in both copper electrorefining and electrowinning. This technology includes, among other things, a new permanent cathode (Outokumpu Permanent Cathode) and new busbar technology (Outokumpu Double Contact System). The new technology has already been tested in commercial scale cells. To get a better understanding of the busbar system a multiphysical simulation model of the electrowinning and electrorefining cells was developed. A mathematical model of electrical conduction and heat transfer in a copper electrolysis cell was developed from partial differential equations. The model was expanded to a cell group including seven electrolysis cells connected electrically in series. The model was solved numerically using the finite element method (FEM). Using the model, different intercell busbar systems were simulated. Typical electrical disturbances, like loose contacts between cathodes and the main busbar and short circuits between electrodes, were included in the simulation. The results of the simulation runs with conclusions are presented in this paper.

Paper #0756—14:55

Fundamentals and effects of additives in copper electrorefining

M. Stelter, H. Bombach, TU Bergakademie Freiberg

Since the first years in copper electrorefining natural products have been used as so called “additives“ in the electrolyte. Glue as one of these additives offers a lot of different reactions with the metal ions and also with other additives like thiourea in the electrolyte. For a deep understanding of the effect of these additives it is important to know the routes of possible reactions in the electrolyte as well as the basics of electrocrystallization. Using this knowledge the interpretation of nodulation or inclusions of electrolyte in the cathodes in copper electrorefining is easier than before. Setting up on physical and chemical properties of the electrolyte and the additives practical investigations of the effects of additives in copper electrorefining and their impacts on copper crystallization and cathode quality are presented in this paper. Chemical deposition of glue against time and temperature are only few of the effects that are mainly caused by the use of natural products. In fact parameters like anodic and cathodic polarization are strongly affected by the additives as well as the effects of the additives are strongly affected by current density. This second part of the paper presents results concerning interactions of the above mentioned parameters.

Paper #0750—15:20

A precise and accurate method for glue determination in copper electrorefining process

E. Rezaei, S. Ghasemi, A. Fedaeizadeh, Sarcheshmeh Copper Complex

Glue is an animal protein that is used with other organic agent such as thiourea, in copper electrorefining. The concentration of glue has to be controlled carefully, because the electro-deposition process is often very sensitive to relating small fluctuation in the operating variable. This additive (glue) prevents rough and nodular in copper cathode electro-deposition. The nodular may grow in the cathodes and cause short circuits, which results in lose of production energy. Addition agents are effective in control metal growth; they modify the normal nucleation and lattice growth steps in refining the grain structure. In this research glue concentration was determined in an industrial copper electrolysis plant. A non linear model with high capability was architected and after optimizing its parameters, the accuracy and precision of model were evaluated. For determination of glue concentration, electrochemical voltammograms in optimum condition (Differential pulse voltammetry technique, Hpulse=50 mv, scan rate=10 mv/s) were plotted. Some information of voltammograms was transferred to model as inputs. After analyzing the information, the model determined the glue concentration with high precision and accuracy, in this way there is no need to separate or add agents to remove the interferences.This method has been successfully applied at sarcheshmeh copper complex.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 65: Vessel Integrity II (13:40 – 14:30)
Continuous Converting II (14:30 – 15:50)
Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): D. George-Kennedy, Kennecott Smelter;
S. Hills, WorleyParsons HGE
Room Territories—13:40

Paper#0796—13:40

Recycling of waste magnesia chrome bricks to produce refractory castable used at Sarcheshmeh copper complex furnaces

A. Rahimi, Sarcheshmeh Copper Complex,
F. Arianpour, F. Golestani-Fard, Iran University of Science and Technology

Refractory castables based on alumina-silicate aggregates are commonly used in casting wheel components and launders. In this research the recycling process of waste magnesia chrome bricks for production of refractory castable lining for launders and casting wheel ladles at Iranian Sarcheshmeh copper complex (I.S.C.C.) is discussed. The smelting plant of ISCC consumes 4,000 tons refractory materials and produces 2,000 tons waste refractories annually. In order to reduce the environmental pollutions and gain the economical

advantages, the recycling of waste refractories proved to be a solution [1]. In ISCC, 800 tons alumina or alumina-silicate refractory castables are used for linings of anode furnace ladles and launders annually [2]. In the present work, the spent bricks from reverberatory, converter and anode furnaces were analyzed in term of microstructural changes from hot zone to the cold end to evaluate the changes in texture and chemical composition. Different formulations based on recycled magnesia chrome aggregates and various particle size distribution and cement content were tested. Economic recycled magnesia chrome refractory mixture was prepared after crushing and sizing the non-deteriorated regions of wasted bricks. After evaluation of physical and mechanical properties of samples, one ton of refractory castable was prepared and successfully installed in the casting wheel ladles.

Paper #0820—14:05

Slag freeze layer formation in an electric smelting slag

F.J. Guevara, G.A. Irons, McMaster University

A two-dimensional mathematical model for fluid flow and heat transfer in a six-in-line electric smelting furnace was developed to study the effects of temperature on slag viscosity in both the liquid and mushy zones. The model focused on the fluid dynamics of the molten slag and the effects on the formation of a slag freeze layer on the hot face of the furnace wall. Previous experimental and mathematical work, carried out under Ra number of 10^9 and using a fluid with Pr number of 65, showed that it is possible to mathematically describe the freeze layer formation over a vertical wall using a fixed-grid model. The chemical composition of the slag was taken into account through its effect on the viscous activation energy as well the solidus and liquidus temperatures. The results show that the flow pattern is strongly modified in areas of high viscosity, in front of the cooling system and at the slag-matte and slag-calcine interfaces. The results are discussed in terms of heat flux over the refractories and their effects on cooling system design.

Paper #0806—14:30

Some topics in chemistry of direct or continuous copper converting

K. Yamaguchi, Iwate University,
A. Yazawa, Tohoku University

To contribute highly efficient and environmentally conscious copper smelting process, several topics in chemistry of the continuous converting were discussed. Through the reviewing the authors' thermodynamic simulations, it is recognized that small amount and low copper content of the coexisting slag is preferable. Some discussions were added to the Takeda's diagram for Cu_2O-FeOx-CaO ferrite slag, and the activity curves of the constituents were derived. Thermodynamic calculations were carried out on the copper contents of the slag during the blister copper formation. The dissolution of copper in slag decrease somewhat with increasing temperature, but the effects of increasing SO2

pressure and decreasing %S in copper are considerable to increase in copper content of the slag. The optimum oxygen enrichment in the supplied air, and regulation of the oxidation degree for the blister copper are important in practice. The gypsum phase separation in the calcium ferrite slag was also evaluated thermodynamically, and concluded that decreasing temperature, increasing CaO content or SO2 pressure, and extensive oxidation of the blister copper tend to separate $CaSO_4$.

Paper #0893—14:55

Relationship between slag chemistry and optimum operating conditions for the Noranda process reactor

P. Coursol, Y. Prevost, M. Zamalloa, P.J. Mackey, Xstrata

The Noranda Process Reactor (NRP) has been in operation now for more than 30 years and this mature process has attained a high level of performance. The NRP at the Horne Smelter of Xstrata Cuivre treats a wide range of feed materials and a thorough knowledge of both process control and smelting physico-chemistry has been beneficial to help meet the required plant flexibility. In this regard, some level of predictive knowledge related to slag chemistry, in particular, the liquid and solid phases such as spinels or olivines, has been found to be beneficial. In the last decade or so, the availability of commercial thermodynamic modeling packages, such as Factsage^{tm} have been utilized with advantage to help the plant optimize slag chemistry and minimize problems from difficult slags, for example, those the could arise from undue feed variability. This paper illustrates the application of this software in examining a range of operating parameters such as: %Fe in product matte, the %Fe/%SiO_2 ratio in the slag, the levels of minor slag components including CaO, Al_2O_3, ZnO, MgO and Cr_xO_y, and the level of oxygen enrichment on the operating conditions and performance of the NRP. The slag composition boundaries at the conditions affecting magnetite control and solid magnetite/other precipitated solid phases, as well the conditions influencing the slag liquidus ranges of NRP slags are also discussed with respect to the overall process chemistry.

Paper #0858—15:25

Molybdenum recovery from copper smelter slag

F. Parada, J. C. Carrasco, M. Sánchez, Universidad de Concepción,
A. Reghezza, J. Zúñiga, C. Caballero, Codelco División Norte

During copper smelting and converting processes, slag generated is pyrometallurgically cleaned and then disposed, containing around 1% of this metal. However, important amount of molybdenum initially contained in concentrates also goes to the slag phase. Research on molybdenum recovery from water granulated slags using acid leaching at low temperatures was conducted to find an efficient way for molybdenum extraction with lower magnetite in the slag. However because of the high fayalite content high acid consumption was found. Molybdenum can be recovered from solution using

ionic exchange resins, but high silica content interferes with extraction. Some studies addressed to minimize silica extraction as well as alternatives of selective silica precipitation in order to develop a technically feasible process.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 66: Fire Refining
Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): P.J. Mackey, Xstrata Process Support;
J. Liu, CVRD Inco
Room Algonquin—13:40

Paper #0840—13:40
Interactive 3D modeling of the refractory lining of an anode refining vessel
A.J. Rigby, RHI Canada Inc.

Computer generated, actual-scale furnace models have been imported into a rendering software application to provide for impressively realistic surface features and lighting. When these models are imported into a 3D engine framework, it is possible to create content-rich virtual environments allowing for complete interactivity and could provide for a powerful tool to conceptualize refractory lining designs. This technology has been applied to illustrate the optimized design concept of an anode-refining vessel, which can be expected to be completely relined in six days and to last for 4-5 years with minimal partial relining. This technology could easily be applied to other smelter furnace, converter and refining vessel designs.

Paper #0835—14:05
RAF copper production process improvement at the Caletones smelter
D. Cordero, J. Font, C. Carrasco, F. Figueroa, J. Bobadilla, CODELCO-Chile

The RAF or copper fire refining process at the Caletones smelter of CODELCO-Chile consists of several pyrorefining stages that successively lowers the levels of S, Fe, Pb, As, Sb, Te, Se and to some extent O in the copper melt, allowing the production of high quality fire-refined copper of 99.93 % purity (RAF copper). This chemical feature of the RAF copper is only achieved by quite long processing times, and a considerable consumption of fluxes and fuels in the RAF vessels. The main goal of this study was to improve the RAF process performance by thermodynamic considerations and industrial scale tests, i.e., an in situ approach for the process as featured by intensive sampling, characterization and subsequent modifications. Thus, both theoretical and industrial data were derived, and based on kinetic and thermodynamic evaluations, a higher operational standard was achieved for the RAF process. These new operational practices allowed enhancing the overall economic of the RAF process, by reducing the time and operational costs, and consequently increasing the availability of the vessels.

Paper #0819—14:30

A new paipote process of continuous fire refining of copper

G. Riveros, A. Warczok, T. Marin, Universidad de Chile,
T. Utigard, University of Toronto,
H. Schwarze, D. Smith, J. Sanhueza, A. Balocchi, Empresa Nacional de Minería ENAMI

A new, continuous fire refining process for copper has been developed and tested at the 5 tph pilot scale. During oxidation, the blister copper flows through a packed bed of crushed refractory bricks counter-current to a hot oxygen containing gas. The resulting desulphurized copper flows then directly into a packed bed of charcoal for deoxidation. By controlling the air to natural gas ratio, both temperature and reducing conditions can be controlled. Based on extensive laboratory scale measurements of the rate of copper oxidation and reduction, the process concept was developed aided by process modeling and simulation. The industrial-pilot scale installation built at the ENAMI Paipote smelter in Chile, consists of two cylindrical, compact reactors, operating in line, with a designed capacity of 5 t/h of blister copper. The results of the industrial-pilot tests confirmed the feasibility of the new process. The blister copper processing capacity was increased to 10 t/h with satisfactory sulphur removal. The degree of oxidation as well the copper temperature was controlled with relative ease. The specially designed siphon block allowed for smooth tapping of the oxidized copper and separation of refining slag. The reduction of oxidized copper in the packed bed of charcoal appeared to be very effective while control of the degree of reduction according to the height of the bed ensured control of the oxygen content in the refined copper at the required level.

Paper #0855—14:55

The Elliptical anode furnace – a metallurgical comparison - part one

M. Potesser, H. Antrekowitsch, University of Leoben,
U. Zulehner, Maerz-Gautschi Industrieofenanlagen GmbH

In the past, different furnace types have been developed for use within the copper industry, with two common anode furnace designs typically used in copper smelting plants worldwide: the tiltable reverberatory furnace (KPO) generally used for the secondary copper industry and the cylindrical or drum type anode furnace (TRO) for handling a liquid blister charge generated in primary copper production. The disadvantage of the KPO is its design related to the longer refining period, because of the low bath depth, however it provides good conditions in the melting period due to its large bath surface. On the other hand, small amounts of scrap charged into the TRO increase the melting and dissolution period, but it provides good conditions for the refining period. The newly-developed elliptical furnace concept (TRE) offers the advantages of each of these furnace types. The special design allows melting of the scrap more

efficiently than in the KPO and refining the liquid copper more efficiently than the TRO. This paper shows a metallurgical comparison of the three furnace types in regard to the melting period by heat technological considerations (optimized arch design) and of the refining period done by CFD with concentration on current, recirculation and dwell time of the gas in the melt. The paper outlines the possibilities for a reduction of the tap-to-tap time and energy consumption as well as for an increase of the production capacity, which can be achieved by applying the TRE instead of the conventional furnace designs.

Coffee Break—15:20 – 15:40

Paper #0856—15:40

Burner development chamber for the nonferrous especially the copper industry

M. Potesser, H. Antrekowitsch, University of Leoben,
B. Holleis, Messer Austria GmbH

Higher prices for natural gas or oil have motivated the copper industry to re-examine the modes of oxygen and oxy-fuel burner usage at operating plants. With rising energy costs and the growing importance of environmental protection, burner usage and burner operations have become the focus of several investigations and optimization efforts. One possible approach to lower energy usage is through combustion using tonnage oxygen. When such oxygen is used, the flame temperature increases and operational efficiency is improved. As well, with the correct technology, due to the presence of lower levels of harmful substances such as NO_x in the off gas, there is improved environmental performance. As regards copper production, furnaces are employed for both concentrate smelting or for melting and casting operations. The use of tonnage oxygen in concentrate burners for smelting provides for a higher thermal efficiency. For furnaces employed for melting, air-operated burners may in fact have an initial advantage because a long radiant flame is typically generated, thus providing for a higher degree of heat transmission. This paper describes the new experimental burner chamber of Messer Austria GmbH which provides for testing of the combustion of natural gas with oxygen or oxygen-enriched air and the use of special water cooling ducts that simulates a metal charge during melting, The operational effectiveness of the burner is determined from temperature and off-gas analysis data. The paper also discusses future trends in burner technologies including a new patented burner.

Paper #0802—16:05

Kinetics of a liquid copper oxidation and reduction in a packed bed

A. Warczok, G. Riveros, T. Marin, H. Wastawino, C. Puga, Universidad de Chile,
T. Utigard, University of Toronto

The mechanisms and kinetics of copper oxidation and reduction have been investigated in small scale thermal gravimetric experiments as well as in

laboratory pilot scale, packed bed reactors. With blister copper flowing gravitationally down through a packed bed of ceramic particles, counter-current to low oxygen containing combustion gases, the rate of oxidation was found to be very high due to the large surface area created. Similarly, reduction by flowing copper through a packed bed of charcoal lead to rapid de-oxidation. Based on these laboratory measurements, fundamental rate data have been obtained. Modeling of industrial sized packed bed reactors using the laboratory results, opened up the possibilities of developing a new, very intensive, continuous process for copper fire refining. The developed mathematical model together with a computer process simulator, allowed for the design of the industrial-pilot installation to be built and tested at the ENAMI Paipote smelter in Chile.

Paper #0879—16:30

Experimental Study for deoxidation of liquid copper with substoichimetric O_2/CH_4 flames

T. Marin, Universidad de Chile,
T. Utigard, University of Toronto

The rate of liquid copper deoxidation during top blowing of reducing flames has been investigated using a high capacity thermogravimetric unit at 1200 ^{o}C. For 1 kg copper samples, it was observed that the rate of deoxidation was proportional to the flow rate of the reducing reagent (H_2 or CO). Under similar experimental conditions, it was found that H_2 is more effective than CO even though both have similar thermodynamic potential to deoxidize liquid copper. The rate of deoxidation of liquid copper with reducing O_2/CH_4 flames was measured for O_2/CH_4 molar ratios of 1.5 to 2. The deoxidation rate depends on the O_2/CH_4 ratio and decreases as it approaches the stoichiometric ratio (O_2/CH_4 = 2). Estimation of the rate of deoxidation of liquid copper with top blowing flames based on the thermodynamic composition of H_2 and CO in the product gases, agrees well with measured values.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 67: Off Gas Handling II
Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS
Chair(s): C. Harris, WorleyParsons HGE;
C. Caballero, CODELCO Norte
Room Quebec—13:40

Paper #0860—13:40

The acid plant expansion and energy saving at Toyo copper smelter

N. Kubo, Y. Isshiki, H. Satou, H. Kurokawa, Sumitomo Metal Mining Co., Ltd.

Sumitomo Toyo Copper Smelter and Refinery was commenced in 1971, and its production capacity of sulfuric acid was 550tpd at the beginning. In 2001 Toyo Copper Smelter and Refinery projected to expand its copper production capacity

to 450,000tpy, and now the project is still in progress. To achieve this expansion project, 4,000tpd of sulfuric acid production capacity is necessary to the acid plant. So as a part of this project, the construction of the new converting and absorbing line and the improvement of the existing converting and absorbing line were carried out from 2001 until 2005. Then the production capacity of these 2 lines has already reached the target, 4,000tpd of sulfuric acid. Moreover, at the design of the new line, we adopted several latest technologies and materials in order to construct the world's leading acid plant. Basing on the operation performance of the new line, we have improved the existing line in 2005. Both of these 2 converting and absorbing lines are working quite well and contribute to big energy saving and excellently stable operation.

Paper #0812—14:05

Thermal transportation properties of copper flash smelting flue dust

E. Nurminen, Helsinki University of Technology

Thermal transport properties of copper flash smelting flue dust have been investigated. Such values of the dust are needed to correctly model the process and to optimize its heat recovery performance. Dust accretions on heat recovery boiler walls may have a significant influence on the boilers heat transfer efficiency. Measurements of the thermal transport properties have been made for industrial flue dust and for pure sulphate components. The measurements have been conducted at temperatures up to 400 ^{o}C and the effect of porosity on these properties has also been investigated. The results indicate that the flue dust and the sulphate components are effective thermal insulators and the dust build-up on the boiler walls is likely to greatly decrease the heat transfer efficiency of the boiler.

Paper #0826—14:30

Production of anhydrite from limestone with smelter gases in a three-stages fluidized bed reactor

I. Wilkomirsky, R. Parra, F. Parada, University of Concepción,
G. Godoy, M. Vera, CODELCO División El Teniente

The neutralization of SO_2 from copper smelter gases to produce calcium sulphate (anhydrite) is considered an attractive alternative to sulphuric acid production. To develop the required technology for the process, a three-stages fluidized bed reactor prototype was designed and operated using both high and low grade limestone and gases with 2, 8 and 12 vol -% SO_2. The results obtained shows that at 800ºC and up to 8 vol-% SO_2 in the gases, the capture of SO_2 reaches near 99% with limestone conversion to anhydrite of 45 to 48%. A larger pilot plant is presently being built at the CODELCO El Teniente-Caletones Smelter to demostrate the technology and to evaluate the economics of the process.

Paper #0814—14:55

Recent smelting and acid plant operation at Saganoseki smelter

F. Hashiuchi, H. Chida, H. Nakata, Nikko Smelting & Refining Co., Ltd

In 1996, the Saganoseki custom smelter & refinery successfully shifted to a single flash smelting furnace operation and increased the copper production capacity to 450,000mtpy in 1998. As the next step, Saganoseki planned to further increase the productivity, especially in the area of P.S. converters and acid plant. As the results of modifications and operational improvements, the gas washing & cooling sections of the Saganoseki acid plant were consolidated from 3 to 2 lines, and increased the gas treatment capacity. The SO_2 converters in the acid plant were also modified to increase the acid production. By increasing the matte grade from 65 to 68%, six PS converters have been successfully integrated into four, while maintaining the production capacity and reducing the environmental burden in 2005. This paper discusses recent operational conditions and the results of implementation of technological improvements.

Cu2007: International Symposium on **Mineral Processing**

Session 68: Comminution Optimization

Sponsors: Canadian Mineral Processing Society of CIM, Mineral Science and Engineering Section of Metsoc, MMIJ, GDMB, IIMCh

Chair(s): J.E. Nesset, McGill University;
D. Sbarbaro, University of Concepcíon

Room Tudor 8—13:40

Paper #0732—13:40

SABC circuit energy consumption optimization

K.G. Markkola, J. Soto G., G. Yañez G., H. Jimenez R., Minera Candelaria

Since 2005, Compañía Contractual Minera Candelaria (CCMC) has defined various strategies which aim to optimize the usage of the available energy in each of the SAG grinding circuit modules (SABC-A configuration). For this purpose, the use of larger size balls along with operating with an optimum balls/load ratio has been implemented. Additionally, in the ball mills, the amount of balls in relation to the equipment's usable diameter has been optimized. In the pebble crushing circuit, the percentage of material passing 12 mm (1/2 in) product has been increased by 15% by: (1) modifying the crusher mantle profile, (2) implementing a strategy for maximizing the power in each crusher, (3) using continuous improvement tools (Lean – Six Sigma), (4) redesigning SAG mills discharge grates, and (5) changing discharge grates in order to control the crusher feed size distribution profile. All these activities have improved plant throughput by 1,000 t/d with no significant capital investment. As part of the energy consumption optimization study, we have considered determining the optimum operational rate of each SAG mill, in relation to the mill liner life and also the improving the control strategy in conventional grinding.

Paper #0733—14:05

SAG mill operation optimization for different type of ore base on a "virtual geologist"

L. Tapia, E. Lizama, Minera Los Pelambres

The main disturbance for stability at a primary grinding using SAG mills is related to the permanent changes in the ore being fed to the plant, such as size and hardness. Searching for stability is the first step to accomplish, before undertaking the goal of maximizing the throughput. To deal with the variability of ore characteristics and be able to perform adaptive changes in the grinding process control, knowing the characteristics of the ore being fed from the mine to the plant at the correct time is a requirement; nevertheless, in day to day operation, such information is not available in real time, and on the other hand, there are transport times and inventories between the mine and the plant that makes it difficult to have the information at the convenient timing. Under this scenario, Minera Los Pelambres implemented a grinding optimization strategy, based on the real time analysis of certain process variables, such as ore size, mill current consumption, pebbles generation and throughput. As a result, both a grindability and stability indexes are inferred, which is equivalent of knowing the ore characteristics by knowing its effect on the grinding behavior. These two indexes permit controlling the SAG mill total charge level and hence, allows optimization of throughput by means of the expert control system.

Paper #0735—14:30

Power analysis of the milling process in sag mills

A. Gutiérrez, H. Espinoza, J. Guichou, L. Magne, G. Titichoca, A. Ortiz,
University of Santiago of Chile

At present, most ore milling is done in tumbling mills, consisting of huge cylinders turning on their horizontal axis. This rotational motion causes the ore charge and the grinding balls to interact by impact, compression and abrasion, to reduce the size of the ore. This method is very inefficient since only around 12% of the energy supplied is used for actual grinding, the rest being used in moving the large mass of balls and ore within the mill. This work aimed at better understanding the milling process by evaluating the movement of the load through the Discrete Elements Method (DEM). First, the number of bodies (balls and ore) moving inside the mill is determined, to correlate to the potential impacts that constitute one of the milling mechanisms. Then, the number of high energy impacts is evaluated to correlate to the bodies in motion. At this stage, a differentiation between grinding media and the ore, as well as between the types of contact taking place in the mill, has to be made. This latter issue is of great relevance since from the five identified contact types (ball–ball, ball–liner, ore–ore, ball–ore and ore–liner) only the last three actually contribute to the milling process, the other two causing structural damage to the mill.

Paper #0741—14:55

Towards AG/SAG/ball mill on-line performance prediction?

P. Radziszewski, S. Martins, B. Picard, McGill University,
S. Caron, COREM

Industrial practice in mineral processing shows that an important problem in understanding and monitoring in-mill parameters is due to the lack of fundamental knowledge and appropriate sensors. With the development and growing use of DEM charge motion simulators for mill optimisation and design, it is possible to describe the fundamentals of grinding mill behaviour, in improving the understanding of internal grinding mill dynamics and in developing solutions to industrial practice. The main challenge to bringing this DEM technology to the mill operator however was the need for substantial computing power and time. However, what about a simplified DEM charge motion model running in real-time? What about the use of sensor technologies to correct any possible drift in simulator prediction? Could such a technological system be used to predict mill performance and eventually be used for mill control and optimisation? Some of these questions are answered with the development of an "on-line" DEM charge motion simulator package (SAGTools^{TM}) along with that of a number of sensor technologies (liner wear, acoustic, instrumented ball) that can contribute to simulator precision. With the objective of bringing this modelling and sensor technology into the concentrator control room to assist operators, this paper aims to describe the main elements of this emerging and developing technology and discuss how it can lead to on-line mill performance prediction and eventual control.

Coffee Break—15:20–15:40

Paper #0734—15:40

Balance of feed split to ball mills in parallel

E. You, L. Cruz, D. King, C. Veloo, Kennecott Utah Copper Corporation

The concentrator at Kennecott Utah Copper currently has 4 lines with a configuration of one SAG mill feeding two ball mills. The slurry that reports to each ball mill will vary resulting in an unequal load of material. This configuration contains two separate sumps that receive material from a distribution box relying solely on natural slurry flow to feed each sump. The unequal split to each mill results in one mill receiving a greater amount of material. This will result in the equipment on one mill to reach limitations that may affect product quality and the operation of the equipment near maximum. The parallel mill in this condition will often have additional capacity that can be used but cannot be utilized due to the unequal split. The major consequences of this issue result in reduced throughputs and metal recovery. To resolve this condition an advanced control strategy was implemented to control the split in April of 2002 using equipment that was in place.

Paper #0736—16:05

Statistical multivariate analysis and dynamics monitoring for process control in the mining industry

L. Yacer, J. Sanzana, Contac Ingenieros Ltda.

Most metallurgical plants already have sophisticated control systems as well as a process-historian that manage thousands of real-time and historical variables. There exists a huge potential for operational improvement through the inference of patterns, correlations and cause-effect relationships within these records. The ability to run online and offline advanced multivariate statistical analyses represents a great potential for the mining industry, in various areas such as cathode quality improvement in an SX/EX plant, the analysis of the correlation between the ore characteristics and the mill throughput, the determination of early failure alerts for major equipment, etc. The background theory is described, as well as some practical experiences of operations in Chile and Peru.

Paper #0737—16:30

Dynamic simulation and model based real-time optimization of SAG mills using genetic algorithms

J. Salazar, F. Cubillos, L. Magne, G. Titichoca, G. Acuña, University of Santiago of Chile

This paper presents a dynamic simulator of the semi-autogenous grinding operation deduced from first principles (non-stationary population balances) coupled to a Model-Based Real-Time Optimization (MBRTO) system to study optimizing strategies for an industrial semi-autogenous mill using genetic algorithms. For the design of the MBRTO both a validated first-principle steady-state model adapted on-line and a dynamic model were used to study the transient effect. The objective function considered is to maximize the ore throughput or the fine-product rate by changing the power-draw. For these purposes, these two performance indexes were introduced as fitness functions in the genetic algorithms. The three decision variables used were the ore feed rate, the water feed rate and the mill rotating velocity. The optimization problem was solved using a classical genetic algorithm with constant population. Constraints in the power draw and the filling level were handled by assigning a penalty function to the fitness function. Simulation results using industrial data for a large 1800 t/h copper-ore mill show the effectiveness of the system in finding the optimum controller set-points as a function of the process-operating constraints; mainly maximum ore feed rate, power draw and filling level. Starting from non-optimum conditions, the optimizer is able to improve the global performance index by 50% relative to a base case.

Paper #0738—16:55
Ball mill overload detection Algorithms
D. Sbarbaro, Universidad de Concepción

In many modern concentrators the use of supervisory systems in their grinding circuits has meant more consistent operations and increases in capacity. These systems rely on a series of specific algorithms that uses different pieces of information and drives actions over the process. One of these algorithms is the ball mill overload detection, which plays an important role in any supervisory strategy designed to maximize ore feed rate in wet grinding circuits. This paper introduces different overload detection algorithms, and compares them in terms of the time taken to detect the overload condition. This comparative analysis is based on highly noisy power draw measurements obtained in an industrial plant.

Cu2007: International Symposium on **Process Control, Optimization and Six-Sigma**
Session 69: Pyrometallurgical Process Improvements
Sponsors: EDP of TMS, MetSoc, MMIJ, GDMB, IIMCh
Chair(s): A. Deneys, Praxair Inc.;
P. Thwaites, Xstrata Process Support
Room Confederation 6—13:40

Paper #1062—13:40
Reducing copper losses in the Mitsubishi process: a pyrometallurgical approach
F. Tanaka, Mitsubishi Materials Corp.

Copper losses to discard slag have long impacted on the profitability of copper smelters. Businesses based on the treatment of secondary materials have also revealed that copper losses are indices of precious-metals losses. Many custom smelters are thus required to obtain more reliable controls for reducing copper losses than ever before. Mitsubishi Materials Corp. has cooperated with academic research institutes in conducting research projects on the pyrometallurgical fundamentals of copper smelting systems, including mutual evaluation of magnetite behavior between synthetic and industrial slags. The state-of-the-art pyrometallurgy has subsequently been introduced to Naoshima smelter for controlling the Mitsubishi process. The revised controls function successfully and the operational results demonstrate that avoiding the discharge of solid magnetite from the S-furnace is quite effective to reduce copper losses. Magnetite behavior has been controlled over the Mitsubishi process so as to reduce copper losses while satisfying the needs of recycling businesses growing in Japan. In-situ estimation of magnetite behavior using the absorbed heat from the melts to cooling water will also be discussed.

Paper #1067—14:05

Tuyere pressure frequency measurements in a Peirce Smith converter

P. Lind, M. Kreuh, Xstrata,
M. McEwan, Perceptive Engineering Ltd.,
A.E. Wraith, McGill

An investigation of the pressure pulse spectrum generated by the gas dispersion processes in a Peirce Smith copper converter was undertaken via the simultaneous measurement of four tuyeres using high frequency pressure transducers. The data was captured, stored, and analyzed using digital data processing techniques; including power spectral density plots, band-pass filtering, and a principal component analysis (PCA). The process was characterized throughout by a dominant 3 Hz pulse signature attributed to the formation of lateral gas envelopes. In particular, test tuyeres in the tuyere line tended to operate synchronously at the dominant frequency, regardless of operating conditions tested and despite being distributed along the converter. Synchronous behavior is thought to arise from the acoustic coupling and possible resonance behavior of the gas delivery system on the converter.

Paper #1063—14:30

Hydrogen sensor for molten copper

N. Fukatsu, N. Kurita, Nagoya Institute of Technology,
K. Katahira, T. Ohshima, TYK Corporation

The recent development of galvanic cell-type hydrogen sensor for molten copper was outlined. The principle of the sensing mechanism, the fundamental structure of the sensor, and its performance as a process control device are discussed based on experimental work undertaken by the authors. Besides sensors based on usual perovskite-type proton conducting oxide, those using magnesium-doped alpha alumina, which was recently known as a proton conductor, were investigated and the results at the laboratory scale are reported. Considering the excellent sensitivity at high temperature and the stability to the disturbance from the attendant oxygen activity, magnesium-doped alpha alumina was regarded to be a superior material for the sensors used for such purposes.

Paper #1072—14:55

Mass and energy balances for metallurgical gas handling system in Chagres smelter

P. Durán, Camino Troncal S/N,
R. Bustamante, Universidad de Santiago de Chile,
A. Avila, Universidad Federico Santa Maria

The metallurgical gas handling system at Chagres Smelter, like that of many smelters, can be the limiting constraint to processing more concentrate through the smelter. Mass and energy balances for the metallurgical gas handling system processing off-gases from the flash furnace and Peirce-Smith converters

have been used by both operations and process engineering groups to help evaluate different operational scenarios in which the use of the installed capacity could be maximized and/or an operational strategy can be change with the purpose of removing a bottleneck or justifying an investment to relieve a constraint in the gas handling system. The present work describes the development of these process balances that were carried out in Excel®. The results were validated with operational data and, subsequently, some cases of industrial interest were simulated, detecting some conditions that were limiting the operation due to the present installed capacity in the Chagres Smelter.

Coffee Break—15:20 – 15:40

Paper #1075—15:40

Advances in furnace monitoring: instrumentation

R. MacRosty, S. Nitschke, T. Gerritsen, C. Crowe, N. Voermann, Hatch Ltd.

The demand to increase production levels in smelting furnaces has driven the increase in the power levels. Consequently, greater cooling capacity of the furnace shell has been necessary, resulting in the widespread use of water-cooled elements to protect the refractory linings. Since water ingress into the furnace is an explosion hazard, monitoring and maintenance of the water-cooled elements is of key importance. Some of Hatch's recent research and development efforts have been focused on methods to provide an increased level of monitoring of water-cooled furnace elements; this paper focuses on two technologies developed for this purpose. The first involves the installation of a fibre optic temperature sensor in a water-cooled tapblock. The sensor is capable of providing high accuracy temperature measurements with a fine spatial resolution throughout the tapblock. Hatch has already developed a diagnostic system that uses multivariate statistical analysis to interpret the large quantities of data generated by the sensor. A second technology under development is concerned with enhancing the operating integrity and safety through detection of leaks in the water circuits. A successful leak detection strategy requires minimal maintenance and the ability to detect minute leaks. An instrument that meets these criteria has been investigated and is currently under development. This paper focuses on the technology and results from the test work that has been completed to date.

Paper #1076—16:05

Understanding vessel integrity, a study of the thermo-mechanical behaviour of refractory lining segments

T. Prietl, Metallurgy of Non Ferrous Metals,
O. Zach, B. Drew, RHI Refractories AG

Metallurgical vessel linings are multilayered, consisting of refractory bodies, insulation materials, joints, and additional space to control for thermal expansion. A unique biaxial hot testing press (BHTP) was installed at the RHI Refractories

Technology Center Leoben, Austria to enable the three-dimensional behaviour of complex vessel lining segments to be investigated under simulated service conditions. Using the BHTP, the heat up and thermo-mechanical behaviour of magnesia chromite brick lining segments with and without mortar filled joints were examined. The results obtained during the initial heat up provided validation of CFD modelling of the lining system. In addition, after the heat up and under steady state conditions, the lining behaviour during deformation-controlled compression and relaxation was examined. These analyses generated important data regarding the stiffness, joint compressibility, and brick damage of the lining segments after cyclic loading and unloading as well as the benefits of using mortar joints in the lining. These investigations were performed in collaboration with the Christian Doppler Laboratory for Secondary Metallurgy of Nonferrous Metals, University of Leoben, Austria. The BHTP has been operational since November 2004 and is providing information regarding the thermo-mechanical behaviour of different lining segments.

Paper #1074—16:30

Integrity monitoring of Xstrata Copper's Kidd Metallurgical division Mitsubishi 3-line furnaces using multivariate methods

P. Nelson, A. Hyde, Xstrata Process Support,
M. McEwan, Perceptive Engineering,
D. Sandoz, Eryl Meirion

Extending the campaign life of the Mitsubishi furnaces at Xstrata Copper's Kidd Metallurgical Division Copper Smelter has been a major focus of attention for many years. One aspect of this effort is real time monitoring to detect abnormal conditions and safely shut the furnaces down before significant damage occurs. Traditional real time methods of monitoring the integrity of refractory furnaces containing molten metal include alarms on individual temperatures of the refractory or cooling water. The need to set alarm limits which are not exceeded across the range of normal operating conditions leads to a system that only provides a limited warning, if any, before a failure occurs. Integrity monitoring systems that look at many different signals and alarm only changes in the relationships between the signals have been implemented on the smelting and converting furnaces. The systems are based on principle components analysis (PCA) models and implemented with the monitorMV software package. These provide much more sensitive and selective alarms so that changes in integrity are alarmed well in advance of any event. At a critical alarm level, the converting furnace is set to automatically shut down so that operating and technical personnel can review the situation. The configuration of the systems and operating experience with them will be discussed.

Cu2007: International Symposium on **Sustainable Development, HS&E, and Recycling,** Incorporating the 6th Waste Processing and Recycling Symposium
Session 70: Sustainable Development
Sponsors: The Environmental Society of CIM, the Environment Section of Metsoc, MMIJ, GDMB, IIMCh
Chair(s): K. Montalban A., Servicio Nacional de Geologia y Mineria
Room Confederation 3—13:40

Paper #1105—13:40
The copper recovery from cupric oxide catalysts by plasma reduction process
I. Imris, A. Klenovcanova, Technical University of Kosice

The chemical industries are using different type of catalysts, which after application usually produced many tons heap of residues. One of them is cupric oxide catalyst with high content of copper and silica. The recovery of copper from the waste has become major interest from a viewpoint of environmental protection and recycling of resources. The thermodynamic analysis and experimental results suggest that the copper from cupric oxide catalyst can be extracted by plasma reduction process. By plasma reduction process the inert slag and copper with following chemical composition: 99.04 % Cu, 0,042 % Fe could be obtained.

Paper #0896—14:05
A novel process in the integral processing of residues and effluents generated in the copper industry
A. Robles-Vega, J. Lopez-Garcia, Southern Copper,
V.M. Sanchez-Corrales, Universidad de Sonora

Personnel of Mexicana de Cobre, a subsidiary of Southern Copper located in Nacozari, Sonora Mexico have been working in the past few years on the development of a process to treat and manage, in an environmentally accepted practice, the residues and effluents generated during the process. To date, this team has been reviewing existing technologies and also has explored new alternatives. At the end of this phase, a novel, efficient and complete process has been configured which will be able to treat some solid and liquid streams such as Teniente converter dust, Peirce Smith converter dust, a Sb-rich precious metals slag, copper refinery electrolyte bleed, acid plant blowdown and an acid bleed of the precious metals plant. The process will consist of a leaching stage, followed by a very selective copper precipitation using novel technology which has been named as back reactions. After copper precipitation, impurities (As, Sb and Bi) will be precipitated mainly as arsenic trisulfide (As_2S_3) using $H_2S(g)$ which will be generated by means of a new process developed in our company. At the end of the process, small volumes of arsenic trisulfide will be vitrified and then disposed as a stable residue.

Paper #0905—14:30

Water availability for mining usage in Northern Chile, a challenging scenario

M. Marchese, J. Arrueste, Hatch Inc.

It is no secret that scarcity of fresh water is an issue that at a global level in the years to come will have a major impact on the business landscape. A number of projects, beyond the mining sector, could remain on paper only due to this. At the same time, this situation is seeing the rise of new business opportunities, such as development of technologies for more efficient usage of water, water recycling, and desalinization of sea water. Despite that most of Chilean mining facilities are located in the driest area of the world, business has developed strongly and actively for more than a century. However, the negative effect on the water reservoirs and the environment is, lately, resulting in the reduction of the authorized water rights. Holding *Water Rights* for any given volume does not guarantee that the resource will be available when needed. A recent report from the United Nations on global climate change indicates that global warming can be directly related to changes in the natural and human environment. Chile would not be an exception. The reduction in snow levels in the high Andes and reduced rainfall during the so called “Bolivian winter”, have directly affected the replenishing of the underground water reservoirs in the lower parts of the valleys, where most of the extraction of the resource takes place. Mining facilities shall be designed to reduce potential environmental effects, using proven technologies, and considering the best practices available. These measures shall constitute a complete structural framework for the environmental impact assessment (EIA) of the Project. The measures to prevent and mitigate the impacts on the water resources shall be considered during the design stage of a mining project. Current and future mining projects in Chile are conscious that the increasing pressure on the limited water resources is becoming unsustainable, and are already facing the water scarcity and social pressure by implementing sea water desalination plants, including long pressurized pipelines to the mine sites (e.g. *Escondida, Candelaria, El Morro, Regalito*). This paper presents, in summary, an analysis of the present and potential future scenarios.

Paper #0908—14:55

Seawater as a resource for sustainable copper operations

R. Niechcial, R. Radakovic, Hatch Ltd.

As populations grow and industry expands, the limited fresh water resources available are increasingly under stress. This situation creates conflict between communities and industry; and the sustainability of both is threatened. The symbiotic relationship between community and industry highlights the need to develop innovative solutions to these water shortages. The sea may hold the key to providing the resource to permit the development of industry, the sustainability of communities, and the protection of the dwindling legacy water resources around the world. Desalination technologies have developed to where it is now

economically viable to create industrial and potable water quality from seawater. Nowhere is this development more important than in the arid region of Northern Chile, where high copper prices have encouraged a boom in mine development.