

TUESDAY, AUGUST 28, 2007, AM

Cu2007 **Plenary Session 3 and 4**

Sponsors: Metsoc, IIMCh, GDMB, MMIJ, TMS, SME

Chair(s): C. Twigge-Molecey, Hatch;

A. Fuwa, Waseda University

Room Canadian—08:00

Paper #1099—08:00

Supply and demand, technological development, and future prospect of copper in Asia

M. Okada, President and Chief Executive Officer, Nippon Mining and Metals Co., Ltd.

Consumption of refined copper in Asia, especially in China and India, has soared, and the copper price is at its historic height. New smelters and refineries have been built in the region with state-of-the-art technology to meet the unprecedented demands. Supply of copper concentrate, on the other hand, has fallen short of the growing demand for concentrate by the smelters and refineries with expanded production capacities. The shortage of copper concentrate is attributable to the delay in the mining development, caused by the prolonged price slump of before 2005. The mismatch between supply of concentrate and smelting and refining capacities may cause disorderly movement of copper price, and hamper the sound development of the industry. The recent high copper price may prompt substitution with alternate materials. With electrical and thermal conductivity and workability, copper is one of the most customer-friendly materials. It is regrettable for both customers and suppliers if the high copper price would become an impediment to promoting copper use. Some outdated and environmentally unfriendly facilities still operate. In view of recent lower-grade copper concentrate with higher sulfur content, these facilities must reform their equipment to environmental-responsive one. The current level of per capita consumption of refined copper in Asia shows that the demand of copper will further grow. It is necessary to realize stable supply of refined copper and stable copper price, to help developing countries including China and India to economically take off. Hence, it is essential that the development of the copper industry be accompanied by environmentally friendly facilities, and harmoniously increased capacities between mining and smelting and refining.

Paper #1100—08:45

Technology development in the copper industry

J.O. Marsden, Senior Vice President, Technology & Product Development, Freeport-McMoran Copper & Gold Inc. (formerly Phelps Dodge Mining Company)

Over the past decade, the copper industry has been through an extended downturn followed by several years of sustained high copper price. A number of new technologies have been developed over the past 10 years aimed at reducing

costs by decreasing energy, labor, and materials requirements, or by increasing metal recovery. The energy intensity of different copper extraction routes and different technologies varies considerably and this has a significant impact on the economics of extraction. Based on average ore grade materials, the total energy for the extraction of copper typically varies from about 24-26 MJ/lb (6.7-7.2 kWh/lb) for the mining, crushing, milling, flotation, smelting and refining route to about 14-16 MJ/lb (3.9-4.5 kWh/lb) for the mining, crushing, heap leaching, solution extraction and electrowinning route. New technology developments are providing opportunities for significant reductions in energy consumption for copper extraction, representing energy savings up to 20-25% in some cases. In addition, in many cases, these new technologies have introduced environmental, safety and health benefits over the incumbent technology. Some of these technology developments have been more successful than others, and many hold great promise for application in the coming decade. This paper provides an overview of the technology developments that have occurred, and explores the underlying reasons behind successful implementation.

COM 2007: International Symposium on **Light Metals** in Transport Applications
Session 25: Advanced Materials and Processing

Sponsors: Light Metals Section of MetSoc, TMS
Chair(s): M. Sahoo, CANMET, R. Drew, McGill
Room Confederation 5—09:50

[Paper #1126—9:50](#)

Investigation of the sintering fundamentals of magnesium powders

P. Burke, G.J. Kipouros, Dalhousie University,
D. Fancelli, Institut Supérieur de Technologies Midi-Pyrénées

Magnesium and its alloys are attractive materials for use in automotive and aerospace applications because of the low density and good mechanical properties. However, difficulty in forming magnesium and the limited number of available commercial alloys limit their use. The present paper reviews the efforts to improve the attractiveness of magnesium through non-traditional processing, and presents preliminary results of current work on producing magnesium alloys via powder metallurgy P/M. P/M can be used to alleviate the formability problem through near-net-shape processing, and also allows unique chemical compositions that can lead to new alloys with novel properties.

[Paper #1124—10:10](#)

Combustion synthesis of TiC/Al₂O₃ composite and its oxidation behaviour

Z.I. Zaki, M.M. Younis, M.B. Morsi, Central Metallurgical Research and Development Institute (CMRDI)

Synthesis of TiC /Al₂O₃ Composite from TiO₂, Al and graphite using combustion technique has been investigated at different initial temperatures; room, 400 and

600 °C. The effect of initial temperature on the composition of the product, wave velocity and combustion temperature of the reaction was studied. The measured combustion temperature and wave velocity were increased with increasing the initial temperature of the combustion reaction. The maximum wave velocity obtained was 5.9mms^{-1} when conducting the combustion reaction at initial temperature of 600 °C. Oxidation resistance of the obtained composite was also studied at the temperature range 300-800 °C. No oxidation is detected before 400 °C while it takes place effectively at 700 °C forming different titanium oxides. Wave velocity measurements method was used to calculate the activation energy of the reaction between the starting materials. It was found to be $316.34\text{ kJ mol}^{-1}$ at the studied temperature range.

[Paper #1122—10:30](#)

Effect of preheating temperature on the combustion synthesis of TiC/Al₂O₃ composites

I. Zaki, M.M. Younis, M.B. Morsi, Central Metallurgical Research & Development Institute

Combustion synthesis of TiC/Al₂O₃ composite from low cost powders (TiO₂, Al and graphite) has been investigated at different initial temperatures from room temperature up to 600 °C. The dependence of microstructure, composition of products, as well as combustion temperature and the wave velocity, on initial temperature of the reaction was studied. The measured combustion temperature and wave velocity increased with increasing the initial temperature of the combustion reaction. It reached 2179 °C and 5.99 mms^{-1} respectively at 600 °C. X-ray diffraction analyses of the combustion products indicated the formation of TiC and Al₂O₃. No peaks corresponding to the starting materials could be detected. As the initial temperature increased, the microstructure of the products tended to form interpenetrating phases as indicated by SEM investigation. Wave velocity measurement method was used to calculate the activation energy of the combustion reaction between TiO₂, Al and graphite. The obtained value of activation energy (316.34 kJmol^{-1}) was compared with that one calculated in case of adiabatic conditions (348.36 kJmol^{-1}).

[Paper #1129—10:50](#)

A new rheoforming processing of semi-solid aluminum alloys

J-L. Tang, X-C. Qi, P-F. Feng, S-S. Li, D-B. Zeng, Tsinghua University

A new rheoforming processing of Al alloys with component shaping systems apart from slurry preparation systems is experimentally exploited, using the reversible multilevel-speed electromagnetic stirrer, the slurry transfer tool and its coating, the thin plate sample with five steps and rheocasting mould, all of which are independently developed. The results show that semi-solid A356 alloy slurry with shape factor of about 0.85 and particle size of 70~80 μm (under air-cooling condition) could be prepared in 20~25 s, fully meeting the production rate of high

pressure die casting. The slurry could be smoothly transferred from the slurry preparation equipment to the rheocasting shot chamber while the slurry temperature of slurry decreases by no more than 3°. The tensile strength and elongation of the semi-solid rheocasting samples could be respectively increased by 11.6~18.2 % and 42.5~50 % compared with the traditional liquid die casting ones, and the rheoforming processing has close affinity with the traditional hot working processes.

[Paper #1164—11:10](#)

Creep properties of an over-aged Al2024 composite reinforced with SiC particles prepared by hot powder extrusion

N. Bakhshi Zadeh, S.M. Seyed Reihani, F. Khomamizadeh, A. Aryanpour, Sharif University of Technology

In this investigation, the aging effect on creep behavior of Al2024-10%SiC composite fabricated by powder metallurgy was studied. P/M bars were manufactured by hot powder extrusion method at 450°C with a ratio of 16 to 1. Creep specimens were over-aged at 187°C for 43 h. It was found that almost full density composite with relatively homogenous distribution of reinforcing particles throughout the aluminum alloy matrix could be attained by direct powder extrusion process. Creep tests were conducted at temperatures from 275 to 325°C under stresses from 25 to 60 MPa. The analysis of the creep mechanism determined that dislocation glide was the predominant mechanism of plastic deformation. The activation energy of the creep process was found to be higher than that of lattice self-diffusion in pure aluminum.

[Paper #1138—11:30](#)

In-situ production of Al/Al₂O₃ composite

M. Meratian, M. Hosseini, Isfahan University of Technology

The in-situ methods have been developed in production of aluminum matrix composites. A commonly adopted in-situ method involves reaction between a metal oxide and aluminum to produce alumina particles or whisker reinforcements. Aluminum-alumina particle composite was fabricated by in-situ method where alumina particles were produced from reduction of copper and silicon oxides by melting and casting aluminum. Aluminum matrix composites reinforced by Copper and Silicon alloying elements and alumina particles have been obtained. The size and shape of alumina particles were studied by scanning electron microscopy (SEM). The size of alumina obtained from mixture of SiO₂ and CuO was bigger than the alumina particles obtained from CuO.

[Paper #1149—11:50](#)

Continuous casting of magnesium alloy sheet using semisolid slurry produced by an inclined cooling plate

T. Motegi, Chiba Institute of Technology

Semisolid casting provides grain refinement of the cast structure and prevents macro-segregation. The conventional semisolid slurry is obtained by electromagnetic or mechanical stirring. In our process, the magnesium alloy (AZ31) slurry is made using an inclined cooling plate instead of the conventional methods. The slurry obtained is cast into a twin-roll caster and makes a continuous sheet of 2 or 3 mm thick. The most important factors that influence the sheet casting are the casting temperature and twin-roll speed.

[Paper #1155—12:10](#)

Tantalum, niobium and titanium coating for biocompatibility improvement of stainless steel dental implants

M.H. Fathi, Isfahan University of Technology,
V. Mortazavi, Isfahan University of Medical Sciences

The aim of this work was to prepare the metallic coatings on 316L stainless steel dental implant and evaluate the corrosion characteristics and thus the biocompatibility of the uncoated and metallic coated dental implants and comparison of the effect of the type of coatings on biocompatibility. Three types of metallic coatings including Tantalum, Niobium, and Titanium coatings were made using physical vapor deposition process on 316L stainless steel dental implant. Structural characterization techniques including; X-ray Diffraction, Scanning Electron Microscopy and Energy Dispersive X-ray Analysis were utilized to investigate the microstructure and morphology of the coatings. Electrochemical potentiodynamic tests were performed in two types of physiological solutions at 37 ± 1 °C in order to determine and compare the corrosion characteristics. All three types of metallic coatings had a positive effect on improvement of the corrosion behavior so that the coatings could increase the corrosion resistance of 316L stainless steel and this trend was independent to the type of physiological environment. Biocompatible metallic coatings could decrease the corrosion current density that is a distinct advantage for prevention of ion release. This can improve the biocompatibility of the implant and, consequently prevention of tissue damages, inflammation and irritation and obtained desirable histopathological response.

[Paper #1169—12:30](#)

The effect of mechanical activation of Al-Mn powder on the dissolution behavior of Al-Mn compacts in molten aluminum

R. Molaie, M. Soltanieh, M.R. Aboutalebi, Iran University of Science & Technology

There are several methods for introducing manganese in molten aluminum. Manganese may be added as powder, master alloy or compacted mixture of manganese-aluminum powder. It has been shown that compacting manganese and aluminum powders could improve the kinetics of dissolution of manganese in molten aluminum. In this investigation the mixture of manganese-aluminum powder was mechanically activated using a low energy ball mill then the powders were compacted and added to the molten aluminum. It has been observed that the mechanical activation of powders enhanced the rate of the dissolution process significantly. The effect of milling time and Al/Mn ratio was investigated on the dissolution rate of Mn in molten aluminum.

[Paper #1135—12:50](#)

Effect of mechanical and thermal conditions of SIMA process on final microstructural and mechanical properties of AZ91 magnesium casting

F. Khomammizadeh, H.D. Ashkezari, Sharif University of Technology

In this study the effect of primary mechanical treatment conditions on kinetics of formation of a globular microstructure in AZ91 alloy after semi-solid casting process was investigated. The results show that a fine grain structure which can be obtained through optimal conditions of mechanical and thermal treatments during SIMA process improves mechanical uniformity of the alloy in its final shape. Segregation of the eutectic liquid phase during semi-solid forming of the alloy toward the upper sections of the casting part resulted inhomogeneous mechanical properties in its different sections which may be minimized by appropriate design of SIMA process parameters.

COM 2007: International Symposium on [Light Metals](#) in Transport Applications
Session 26: Deformation

Sponsors: Light Metals Section of MetSoc, TMS

Chair(s): S. Yue, McGill University

Room Confederation 6—09:50

[Paper #1123—09:50](#)

Influence of cold rolling and recrystallization on the microstructure and hardness of aluminum plate

Z. Huda, O.S. Peng, University of Malaya

The effect of various percentages of cold-working and recrystallization on the microstructure and hardness of commercially-pure aluminum plate, has been studied. The % critical deformation for the aluminum, has been determined. Experimentation involved cold rolling and recrystallization processes followed by quantitative metallographic practice and the hardness measurements. The raw material chosen was a plate of commercial aluminum which was cold rolled to different percentage of cold-work and then recrystallized by heat treatment at 150°C. The critical deformation percentage of aluminum was computed to be around 30% of cold-worked.

[Paper #1143—10:10](#)

Natural aging kinetics and XRD characterization of intermetallics in AA6111 aluminum

G.K. Quainoo, Southern Oregon University,
S. Yannacopoulos, UBC Okanagan

Investigation by researchers on the application of various thermo-mechanical process histories on 6000 series aluminum alloys have found improvements in mechanical properties of these alloys. However, natural aging, which is unavoidable in the automotive processing line, has been found to have deleterious effect on subsequent artificial aging properties in these alloys. In this study, the evolution of yield strength during natural aging modeled by Lloyd and Gupta has been adapted to investigate the effect of cold deformation on the natural aging kinetics in AA6111 by means of tensile testing, differential scanning calorimeter (DSC) and scanning electron microscopy (SEM). Also, intermetallic particles in the alloy were extracted from the matrix and XRD performed on them to ascertain their composition and their role on the kinetics in the alloy. The results show that cold work effect on the natural aging kinetics of AA6111 is in very good agreement with the model proposed by Lloyd and Gupta. The kinetics of natural aging in AA6111 aluminum also decreases with increasing level of cold work. This is attributed to dislocations serving as sinks which consume quenched-in vacancies formed during the early stages of clustering. The phases of the intermetallic particles identified in AA6111 are those of α -Al₅Mn₁₂Si₇ and α -Al₅MnSi.

[Paper #1174—10:50](#)

Substructural changes in aluminum subjected to reversing strain paths

H.J. McQueen, A. Balakrishnan, Concordia University,
G. Avramovic, McMaster University

Aluminum was hot worked at 400 - 500°C and strain rates ($\dot{\epsilon}$) of 0.004 - 0.1s⁻¹, under reversing strains (ϵ) of 0.5 to 0.2 or 0.5 to 0 and also advancing from 0.5 to 1 or 0.5 to 5. Under similar test conditions for different parts of the strain paths, the average measured flow stresses are found to agree with each other. In the forward and backward strain path tests, the almost identical steady state plateaus affirm the occurrence of dynamic recovery (DRV). On reversal of strain direction at constant $\dot{\epsilon}$, there was generally negligible Bauschinger effect. In specimens annealed at 400°C, static recrystallisation (SRX) was followed microstructurally, mainly by disappearance of elongated grains with serrated boundaries because the new grains were only little finer than the old due to low strain energy. The only influence of reversing strain path observed was the effect of change of grain boundary area as grains elongated or returned towards equiaxed.

[Paper #1183—11:30](#)

High-temperature deformation of Fe₃Al

A. Shen, H.J. McQueen, Concordia University

Fe₃Al intermetallics are potential inexpensive candidate for hot applications. In this project, torsion tests on hot-rolled and annealed Fe₃Al (Fe-15.5Al-5.8Cr-1.0Nb-0.05C) were carried out over the ranges 750-950°C and 0.01~1s⁻¹. The experimental results showed that when peak stress $\sigma_P > 90\text{MPa}$ ($\text{Log}Z > 16\text{s}^{-1}$, Z: temperature-compensated strain rate), specimens cracked at randomly low strains. Optical microscopy exhibited original elongated grains and many grain boundary cracks associated with segregation. With $\sigma_P \leq 40\text{MPa}$ ($\text{Log}Z \leq 16\text{s}^{-1}$), specimens deformed with low random σ_P but considerably high fracture strains; slowly propagating cracks may explain the reduced flow stress. Optical microscopy showed both elongated grains and equiaxed subgrains with some indications of geometric dynamic recrystallization (gDRX) and of static recrystallization (SRX). Compression tests gave higher stress with little effect of the preexisting cracks. The activation energy Q_{HW} of current material in satisfactory torsion and compression tests is about 10% higher than previously published. Fe₃Al has body-centered cubic structure in the experimental range, so it was compared with ferritic stainless steel 434C (Fe- 16.55Cr-0.96Mo-0.21Ni). Constitutive constants and restoration mechanism are compared between these materials.

Cu2007: International Symposium on **Economics and Markets**
Session 27: Economics and Markets II

Sponsors: The Management and Economics Society of CIM, MMIJ, GDMB, IIMCh

Chair(s): A. Fuwa, Waseda University;
M. Ospina, Canadian Trade Office
Room Saskatchewan—09:50

Paper #1100B—09:50

Progress by the mining and metals industry on sustainable development

D. Rodier, Hatch

The mining and metals industry's approach to Sustainable Development has dramatically evolved in response to growing concerns for the future ability of the industry to continue as a vital contributor to the sustainability of society. This paper will review recent trends, including the overriding global issues impacting the sustainability of society and what the Global responses to these issues have been. This will be followed by the response of the mining and metals industry to better contribute to sustainable development, starting with the landmark independent study the MMSD Study and the creation of a global policy voice for the industry, the International Council for Mining and Metals (ICMM). The tenants of the ICMM's Sustainability Framework guide this organization's work with the overall themes of performance improvement, leadership and leverage through partnerships. The paper will then conclude with a brief description of an example of what, an individual company, a service provider to the industry, is doing to assist in the industry's efforts.

[Paper #1096—10:15](#)

Senior financing for major copper projects

P. Reimnitz, HVB Corporates & Markets

Unlike gold mine financings, copper projects tend to involve significant capital costs and, as a consequence, are very much driven by economies of scale. The second half of the 1990's saw a downturn in investments in particular in the copper sector. Today's comparable lower stock piles are a function of this underinvestment and, consequently, partly a reason for the relative and absolute high copper prices. What view does a debt financier take on the projects being developed and financed today? What are the main risks associated with a copper mine financing? How are these risks addressed and mitigated? The presentation aims to show the risk profile from a banks perspective with a focus on the construction, operating and environmental risks as well as the various sources of funds available for meeting the usually high capital requirements. Philipp Reimnitz heads up HVB's Resources department within the banks Project & Structured Finance division. HVB is Germany's second largest bank and part of UniCredit, a banking group with a market cap of € 70 billion. HVB has financed precious and base metal projects around the world for almost 20 years.

[Paper #1098B—10:40](#)

Changing corporate structure of the global copper industry

M. Ericsson, D. Brett, RMG

The authors will present their view on corporate structures and where copper supply is going to be over the next decades. For many years, Raw Materials Group has been mining and refining data to develop the world's most extensive mining database, containing more than 17,000 entities covering mine and project details for over 35 commodities. The paper is based on market and industry surveys, regional exploration and project reviews, analysis of production, ownership and mergers and acquisitions, government exploration, mining and policy studies.

[Paper #1094—11:05](#)

Prospecting the future: meeting human resources challenges in the minerals and metals industry

P. Hébert, Mining Industry Human Resources Council (MiHR)

MiHR is the recognized leader in the development of solutions to national human resources challenges facing the mining industry. This presentation will provide insights into Human Resources Challenges in the Minerals and Metals Industry with a focus on Canada's experience. The presentation includes in-depth assessments of current and emerging human resource needs and gaps, and highlights recommendations and best practices designed to maintain the strength of the minerals and metals sector well into the future. Highlights:1. An aging

workforce 2. Significant retirements on the horizon 3. Human Resources demand growth 4. Slowing Labour force growth 5. Productivity challenges 6 .Supply challenge – Education and training programs 7. Supply challenge – Non-traditional groups 8. Supply advantage – Attractive features of mining 9. Supply and demand gap.

[Paper #1081—11:30](#)

A venture capital perspective on junior exploration companies

C.A. Moscoso, University of Chile,

A. Ebersperger, Atacama Resource Capital Project, InverChile S.A.

By venture capital we mean a professionally managed pool of capital that is invested in equity-linked securities of private ventures at various stages in their development. Venture-capital partnerships enter into contracts with both, the outside investors who supply their funds and the entrepreneurial ventures in which they invest. Venture capitalist acts as agents for the general partners, who choose to invest in entrepreneurial ventures through an intermediary rather than directly. In this industry, the agency problem is likely to be particularly difficult, and must be addressed in the contracts and other mechanisms that govern their relationships. There are as well an operating cost problem and a sorting problem. The copper and minerals exploration industry raises funds from private placements, specialized capital markets and other sources, to implement minerals exploration programs on a global basis. This paper examines the norms and regulations over minerals exploration companies listing in two different capital markets, the London Alternative Investments Market (AIM) and the Toronto Stock Exchange (TSX); with a focus in the agency problem, the operating cost problem, and the sorting problem; and compare this arrangements with the contractual provisions and regulations that attempts to resolve the same problems in the venture capital industry.

Cu2007: The John Dutrillac International Symposium on Copper
[Hydrometallurgy](#), Incorporating the 37th Annual Hydrometallurgy Meeting
Session 28: Process Development II

Sponsors: Hydrometallurgy Section of MetSoc, IIMCh, MMIJ, GDMB, EPD of TMS

Chair(s): J. Marsden, Freeport-McMoran Copper & Gold Inc.;

V. Papangelakis, University of Toronto

Room Alberta—09:50

[Paper #0979—09:50](#)

Hydrometallurgy of copper sulfide concentrates - an update

V. Ramachandran, Consultant,

V.I. Lakshmanan, Process Research ORTECH Inc.,

P.D. Kondos, Barrick Gold Corporation

The successful advent of solvent extraction (SX) reagents for copper recovery and improvements in electrowinning of copper to produce LME grade A copper cathode have paved the way for the hydrometallurgical treatment of copper oxide and low grade sulfide ores. This has resulted in about 25-30% of the world's copper being produced today by the Leach-SX-EW process. The obvious next step was to develop processes for the hydrometallurgical treatment of copper sulfide concentrates, as an alternative to a typical smelter-refinery complex. The current paper updates the processes that have been developed to date with emphasis on processes that are being commercialized or that are seriously under consideration for commercialization. Most of the discussions relate to the hydrometallurgy of chalcopyrite concentrates, which account for about 70% of the world's known copper reserves. In summary, in the last thirty years, the hydrometallurgical treatment of copper sulfide concentrates has attained full maturity and will be a serious option to contend with while evaluating any future new copper plant.

[Paper #1021—10:15](#)

The boleto copper-cobalt-zinc-manganese project

D. Dreisinger, W. Murray, E. Norton, Baja Mining Corp.,
K. Baxter, M. Holmes, Bateman Engineering Pty Ltd.,
R. Molnar, SGS Lakefield Research

The Boleto project is located in Mexico close to the town of Santa Rosalia on the Baja Peninsula. The Boleto deposit contains copper, cobalt, zinc and manganese values as oxides with minor sulfides. The Boleto deposit is metallurgically challenging due to: 1) the requirement to recover four separate metals; 2) the presence of high levels of clay in the deposit resulting in difficult solid-liquid separations, and; 3) the need to use seawater for the bulk of the processing. Baja Mining, Bateman Engineering and SGS Lakefield Research have collaborated to develop and test a process flowsheet to recover copper, cobalt, zinc and manganese products at Boleto. The key steps in the flowsheet are:

- Feed preparation (scrubbing and ball milling of oversize) in copper raffinate
- Ore leaching using oxidative and reductive leaching
- CCD washing using high rate thickening technology
- Copper SX/EW
- Treatment of a bleed solution for cobalt, zinc and manganese recovery.

The process for cobalt, zinc and manganese recovery involves iron and aluminum removal followed by cobalt/zinc bulk extraction using CSIRO's DSX solvent extraction system and selective zinc and cobalt stripping. The zinc strip solution is evaporated to produce zinc sulfate monohydrate crystals to market and cobalt is recovered via a further SX/EW process as high purity metal. Manganese is precipitated as manganese carbonate from the DSX raffinate solution. This paper will review the Boleto process flowsheet and provide detailed results from the 2006 pilot plant operation conducted at SGS Lakefield in Canada.

[Paper #1009—10:40](#)

Recovery of copper from oxide waste by leaching, ion exchange and electrowinning

G.B. Harris, McGill University,
C.W. White, Consultant,
Z. Liu, Consultant

A process for the recovery of copper from the waste oxide copper of a mined-out sulphide orebody is described. Hydrometallurgical recovery of copper from this and similar wastes has been tried several times previously without success. Leaching is carried out by sulphuric acid in columns under conditions that minimise the iron content of the pregnant leach liquor, and copper is then recovered by ion exchange rather than the more conventional solvent extraction. The resin is stripped by spent electrolyte and copper is electrowon. Results are presented for testwork originally carried out in 1993, and repeated in 2006, and the novel aspects of the process, leaching and ion exchange, are discussed. Finally, preliminary order of magnitude capital and operating costs are given, demonstrating that the process is cost effective.

[Paper #1011—11:05](#)

Simplified copper production from primary concentrates: the direct electrorefining of white metal/matte

M. Olper, M. Maccagni, Engitec S.r.l.,
R. Matuszewicz, Ausmelt Limited

Commercial copper plants utilising current best technology are tending towards ever increasing scale, the concentrate requirements of which cannot be serviced by a single mine. In such cases, raw materials are often sourced from different mines, which are often far away from the production plant and usually with very different ore compositions. These plants tend to use the traditional thermal processing steps of smelting, converting to blister, anode refining and casting to produce copper anodes that are then refined in a sulphate electrorefining operation. These thermal steps are in some cases troublesome and require the recycling of considerable quantities of material. A new process was developed taking advantage of the latest developments of the first thermal step of the classic loop, the smelting of copper concentrate to high grade matte or white metal using the well known AUSMELT Top Submerged Lancing Technology. The white metal and/or high grade matte product is converted directly to copper cathode and elemental sulphur using the ECUPREX technology. This approach provides an alternative to the traditional thermal steps of conversion to blister, thermal refining and anode casting, which, especially at small scale, can be expensive and problematic in terms of technical and environmental concerns. At first evaluation, this new process can be operated at low capacities, thereby, changing the traditional approach to copper production. Instead of taking the concentrate to the copper production plant, the copper production plant is taken close to the mine with some significant economic and technical advantages.

[Paper #0975—11:30](#)

Hydrometallurgical process for treating copper concentrates at Sumitomo Metal Mining

S. Asano, M. Imamura, K. Takeda, K. Ando, N. Nagase, Sumitomo Metal Mining Co. Ltd.

Hydrometallurgical processes for treating copper sulfide concentrates have attracted considerable attention over thirty years and many processes have been developed. However there have been still problems in those processes because of difficulties of iron removal and high purity copper production with low operating cost. Although SX-EW is highly cost effective method, it is difficult to process the chalcopyrite. Sumitomo Metal Mining Co., Ltd. (SMM) conducted a review of hydrometallurgical copper concentrate processing and has successfully developed a novel process for the hydrometallurgical production of copper from copper concentrate. In this process, copper sulfide is leached by chlorine gas under atmospheric pressure. Most of hydrometallurgical processes can leach only some of chalcopyrite under atmospheric pressure then they need high pressure leaching facility like autoclave. In this process, copper in chalcopyrite can be leached completely by controlling oxidation reduction potential and chloride ion concentration. Cu(I) ion in leached liquor is separated from Fe(II) ion by SX using TBP then pure copper powder is produced by electrowinning. Results in batch and continuous testworks and pilot plant tests at Niihama Research Laboratories are presented in this paper.

Cu2007: The John Durtizac International Symposium on Copper
[Hydrometallurgy](#), Incorporating the 37th Annual Hydrometallurgy Meeting
[Session 29: Leaching II](#)

Sponsors: Hydrometallurgy Section of MetSoc, IIMCh, MMIJ, GDMB, EPD of TMS

Chair(s): S. Bouffard, Barrick Technology Centre;
M. J. Collins, Dynatec Corporation
Room Manitoba—09:50

[Paper #1013—09:50](#)

The effect of the redox potential on the leaching of chalcopyrite in chloride media

K. Yoo, J.C. Lee, Korea Institute of Geoscience and Mineral Resources,
N. Hiroyoshi, R. Diaz Alorro, M. Tsunekawa, Hokkaido University

Chalcopyrite is the most abundant copper sulfide mineral, which is normally processed using pyrometallurgical methods (i.e., smelting) to produce copper metal. Smelting has several major disadvantages, such as high gas-handling costs, high capital costs, saturation of sulfuric acid market, and inability to treat low-grade concentrates and to recover some by-products, such as zinc, nickel and cobalt. The development of hydrometallurgical processes for chalcopyrite is

desirable to overcome the problems of smelting. Because chalcopyrite is refractory, the leaching rate for chalcopyrite is very low. Therefore, increasing the leaching rate has been extensively investigated, both in sulfate and chloride media, as well as in the presence of bacteria. Chloride leaching processes have shown relatively high leaching rates. The mechanism of the chloride leaching process has been investigated, but the behavior of chalcopyrite leaching in chloride solution is not clear. Therefore, the effect of the solution redox potential on the leaching rate of chalcopyrite in chloride solution was investigated. In the present study, leaching experiments were carried out using 0.1 M chloride solutions and the results indicate that high leaching rates of chalcopyrite can be achieved at relatively low solution redox potentials.

[Paper #0968—10:15](#)

Experimental prediction of the potential range to leach chalcopyrite in acidic ferric sulphate media

G. Viramontes-Gamboa, B.F. Rivera-Vásquez, D.G. Dixon, University of British Columbia

Approximately 70% of world copper reserves consist of the mineral chalcopyrite, and much international effort has focused on its study. Ultimate objectives include the development of environmentally friendly alternatives to smelting, and technologies to treat low-grade ores, for which concentration and smelting are economically unviable. Unfortunately, chalcopyrite leaching is inefficient in $\text{H}_2\text{SO}_4\text{-Fe}_2(\text{SO}_4)_3\text{-FeSO}_4$ solutions, which is considered to be the most desirable oxidizing medium for leaching of copper sulfides, since the chemistry is well known, corrosion of industrial equipment is negligible, subsequent copper recovery by SX/EW is well established, and environmental impact is minimal. The main reason for this inefficiency is the self-passivation of chalcopyrite. We have devoted considerable effort in the understanding of this phenomenon, and have developed a predictive electrochemical methodology capable of establishing a priori the precise range of potentials within which chalcopyrite leaches and where it is passivated. Since potential control is a critical parameter in chalcopyrite leaching, this experimental methodology can be very useful for establishing the best conditions to leach chalcopyrite. In this paper, the scientific foundations of this predictive experimental technique are presented, and its practical application is demonstrated by comparing its predictions with leaching experiments from the literature.

[Paper #0996—10:40](#)

Redox potential measurement and control in chalcopyrite heap leaching

N. Hiroyoshi, M. Tsunekawa, Hokkaido University,
H. Okamoto, R. Nakayama, S. Kuroiwa, Sumitomo Metal Mining Co. Ltd.

In the leaching of chalcopyrite with sulfuric acid solutions, the copper extraction rate reaches a maximum at a given redox potential. This article reviews our studies on the determination of the optimum redox potential for chalcopyrite leaching. Shaking flask and column leaching experiments for a chalcopyrite

concentrate were performed under various conditions, and the results were analyzed using a normalized redox potential defined from a reaction model assuming the formation of an intermediate Cu_2S from chalcopyrite. Factors, such as metal ion concentrations, solid/liquid ratio, and presence of iron-oxidizing bacteria, caused significant variations in the copper extraction versus time plots. However the copper extraction rate versus normalized redox potential plots were independent of the above factors and the copper extraction rate reached a maximum at the normalized redox potentials around 0.43. Converting the normalized redox potential to the solution redox potential gives the optimum redox potential for chalcopyrite leaching as a function of cupric and ferrous ion concentrations. This semi-empirical equation can be used to predict the optimum redox potential during leaching operation, and is useful to design the redox-controlled heap leaching for chalcopyrite.

[Paper #1023—11:05](#)

The influence of the $\text{Fe}^{3+}/\text{Fe}^{2+}$ redox couple on chalcopyrite leaching

E.M. Córdoba, J.A. Muñoz, M.L. Blázquez, F. González, A. Ballester,
Complutense University of Madrid

The effect of the $\text{Fe}^{3+}/\text{Fe}^{2+}$ redox couple on the chemical and biological dissolution of chalcopyrite was studied. All the tests were carried out in stirred flasks with 100 mL of a ferric/ferrous sulphate solution, in the absence or in the presence of bacteria (iron- or sulphur-oxidizing) and at low (35°C) and high (68°C) temperature. The initial redox potential was controlled between 300 and 600 mV Ag/AgCl and silver was used as chemical catalyst. The results showed that the oxidizing action of ferric ion on the chalcopyrite was controlled, in all cases, by nucleation and precipitation of jarosites on unreacted particles. The tendency of $\text{Fe}^{3+}/\text{Fe}^{2+}$ solutions towards equilibrium favours the activities of both ions to be equal. Consequently, the dissolution rate was faster at relatively low redox potentials (between 400 and 500 mV) than at high values (600 mV). In this sense, the presence of ferrous ion in the system is a key factor to control hydrolysis and precipitation of ferric ion. Unlike jarosite, the elemental sulphur produced during dissolution of chalcopyrite was porous and did not act as a diffusion barrier.

[Paper #0982—11:30](#)

Interaction of silver ions with sulfide minerals with special emphasis on the chalcopyrite/pyrite galvanic couple

J.A. Muñoz, Complutense University of Madrid,
D.B. Dreisinger, W.C. Cooper, The University of British Columbia,
S.K. Young, Versitech Inc.

In this work, short and long-term tests were performed using different massive mineral sulfide specimens (chalcopyrite, pyrite, sphalerite, galena, covellite and chalcocite) of museum grade and quartz of analytical grade in an acid medium containing silver ions. After attack, the samples were observed by SEM and

products characterized by EDS. Parallel, massive specimens of pyrite (FeS_2) and chalcopyrite (CuFeS_2) were embedded in an epoxy resin, either electrically isolated or in electrical contact, and treated with silver ions in the presence of bacteria. Finally, massive chalcopyrite and pyrite electrodes were subjected to electrochemical measurements in an acid medium under different experimental conditions (addition of silver ions and inoculation). The results showed that silver deposition takes place preferentially on specific mineral surfaces: chalcopyrite, galena, covellite and chalcocite. The chemical reaction of silver ions with pyrite and sphalerite was negligible at low silver concentration (8 ppm). But sphalerite reacted with silver ions at higher silver concentration (100 ppm). In a mixture of chalcopyrite and pyrite, silver was deposited on the former surface creating new cathodic sites which sped up the electrochemical reactions of chalcopyrite dissolution.

Cu2007: International Symposium on **Electrowinning and Electrorefining**,
Incorporating the 37th Annual Hydrometallurgy Meeting
Session 30: Electrorefining Plant Practices and Design I
Sponsors: Hydrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of
TMS
Chair(s): R. Abel, Codelco;
M.S. Moats, University of Utah
Room British Columbia—09:50

[Paper #0786—09:50](#)

Electrolytic copper refining – 2007 world tankhouse operating data

M. Moats, University of Utah,
W. Davenport, University of Arizona,
T. Robinson, Freeport-McMoRan Copper & Gold,
G. Karcas, Outotec,
S. Demetrio, Smeltec

World copper refining tankhouse practices have been surveyed. This survey is a supplement to previous surveys that have been carried out in 1987, 1991, 1995, 1999, 2001 and 2003. On a world basis, process technology trends include the further installation of automated electrode handling systems including permanent cathode systems, automatic anode preparation and cathode handling machines, section switches, fully automatic cranes and polymer concrete cells. General plant process control has increased with more automation of material handling in the copper refining tankhouse. The general trend for most Greenfield copper refining projects remains in eastern Asia.

[Paper #0754—10:15](#)

The effect of inactive glue batches identified by using the collamat system

P. Stantke, Norddeutsche Affinerie AG

Glue, thiourea and chloride are the common reagents which are used in copper electrorefining to achieve fine-grained and smooth copper deposition. While thiourea and chloride are clearly defined chemical substances, glue is a natural product consisting of a mixture of amino acids in different constituent parts. The amino acids are continually degraded in the electrolyte by hydrolysis until they finally become completely inactive. This effect is well-known, largely constant and balanced by the continuous dosing of glue. In contrast, the behaviour of glue in the batch container is not always foreseeable. The glue can become partly or completely inactive by contamination with acid or bacteria, for instance. Usually this is not noticed, and partly or fully inactive glue is added to the electrolyte over a longish period, with the result that the copper growth is significantly impaired. Examples from operational practice show that, with the help of the CollaMat system, partly or fully inactive glue batches can be quickly detected.

[Paper #0757—10:40](#)

35 years of the KGHM copper refinery plant: Głogów 1

S. Orzecki, L. Olewinski, KGHM

The KGHM Copper Refinery Plant, Głogów 1, has operated for 35 years and increased its capacity almost ten times. Cathode quality, expressed in terms of the total impurity content, has undergone a five-fold improvement. The present refining capacity is equivalent to 240,000 metric tonnes of copper cathode, with a total impurity content of 20 ppm, inclusive of 10 ppm Ag. These accomplishments result from combined implementation of current technological progress in electrolytic refining and KGHM's own solutions applied to the Głogów Refinery. The quality improvement measures feature both lowering actual current density, despite an increase in nominal current density, and diminishing the role of non-ion mechanisms which transfer impurities to cathodes. The paper contains a detailed discussion of these issues and outlines possible measures aimed at further production and quality improvements.

[Paper #0760—11:05](#)

Operations control in ISA process tank houses

C. Phan, G.W. Whebell, Xstrata Technology,

M. Oellermann, VRT Systems

This paper outlines opportunities provided for enhanced management and process control by ISA PROCESS™ technology. ISA PROCESS™ technology has the core advantage of offering the potential for vastly improved electrode handling systems. This fundamental characteristic has enabled ISA PROCESS™ technology to develop management and process control systems that are modular, minimalist in their complexity and tailored to a tankhouse operating environment. A review will be presented on the current status of management and process control in ISA PROCESS™ tankhouses covering the central issue of electrode handling as well as electrolyte circulation systems, voltage monitoring, cathode plate tracking, and product tracking. Particular reference will be made of

the recent development by Xstrata Technology (XT) and their technology partners, VRT Systems, of an Radio Frequency Identification (RFID) based solution for tracking ISA PROCESS™ cathode plates. The system encompasses fixed readers which identify plates passing through the stripping machines and the use of sophisticated tracking and database software enabling the development of cathode asset management and operational strategies. The performance of individual plates and batches of plates can be tracked through a full service history.

[Paper #0771—11:30](#)

Recent improvements at Hitachi refinery

M. Matsuda, T. Goda, K. Takebayashi, Y. Maeda, Nikko Smelting & Refining Co., Ltd.

The Hitachi refinery of Nikko Smelting & Refining Co. Ltd. began its electrolytic copper refining operations in 1911. In December 2002, the refinery changed its operation scheme by introducing the ISA permanent cathode technology for the first time in Japan. The change resulted in higher productivity, better cathode quality, and lower operational costs. The operation has been continuously improved to reach a 20% higher production capacity than the original one. For the electrolyte purification process, the Hitachi refinery has developed a new process for removing impurities. The process involves As, Sb and Bi adsorption from the electrolyte by means of chelating and ion exchange resin. The new resin process will achieve higher efficiency in removing impurity.

Cu2007: The Carlos Díaz Symposium on [Pyrometallurgy](#)

[Session 31: PS Converting](#)

Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS

Chair(s): T. Warner – WorleyParsons HGE;

I. Kojo, Outokumpu Technology

Room Territories—09:50

[Paper #0830—09:50](#)

A theory for the slopping resulting of gas injection in Peirce-Smith and teniente converters

M. Rosales V., C. León, R. Fuentes, A. Moyano, CODELCO-Chile,

A. Valencia, Universidad de Chile

Slopping is the formation of waves in the converter due to the gas injection by tuyeres. Those waves produce a premature wearing of the refractory lining of the reactor due to its great amplitude. The affected zones are the tuyere line (outlet gas from tuyeres) and the front of this line. In the present work, a theoretical and experimental study is made to develop a theory that determines the variables involved in slopping, characterizing the more important parameters of operation in the phenomenon of slopping. In addition, this theory will allow for

determination of new technological alternatives of the blast injection permitting to depress the slopping phenomenon.

[Paper #0846—10:15](#)

Simulation in the primary metals industry

K. Concannon, E. Tackie, Visual8 Corporation

The use of simulation modeling in the primary metals industry (including mining, smelting, and metals processing) is expanding as significant cost-benefits can be realized by companies employing capital intensive processes. The economic scale and complexity of operations found in this industry is well-suited to applications using this “what-if” computer modeling technique, ranging from proof-of-concept projects to testing facility design or configuration, and determining resource requirements. More recently this technique is being used to support on-going planning and scheduling for operations using the simulation as the engine to derive the best schedule. With increased computer processing capability, deterministic models are now being developed to capture the workings of a production system or conversion process, allowing real-time monitoring and scheduling of these operations. This paper presents a sample of some recent discrete-event simulation modeling applications that demonstrate the capability and benefits of this technique in the primary metals industry. These include the use of simulation to support the long-range planning of underground mining operations; the modeling of a metals supply chain network that employs a multi-modal distribution system; the scheduling of a metals coil finishing process using a deterministic simulation model; and a more detailed description of the use of simulation to model furnace and converter aisle activities within a smelter operation in Northern Canada.

[Paper #1154—10:40](#)

Daily production planning efforts at Phelps Dodge Miami smelter

V. Ushakov, P. Bogdan, Phelps Dodge Miami Inc.

Daily production scheduling in a highly dynamic smelter environment has always been a great challenge for the operation management due to a significant amount of uncertainties. Planned and unexpected equipment failures, various energy outages, inaccuracies in flow and mass balancing, manpower availability conflicts and other constraints make the job of daily production planning exceptionally difficult. This paper discusses a general scheduling approach utilized by the production management of the Phelps Dodge Miami Smelter (the Smelter). It also describes logical assumptions and some practical software solutions that have been exploited by the Smelter managers to assist the front line supervisors in dealing with daily planning activities for several years.

[Paper #0871—11:05](#)

Study of effective parameters on splash phenomenon in Peirce- Smith converter

M.R. Sarhardi, M. Ashouri, H Namavari, National Iranian Copper Industries Company,
S.H. Mansouri, Shahid Bahonar University of Kerman

The splash phenomenon and its effective parameters in metallurgical converters have been studied thoroughly for decades. The detailed studies of processes such as tuyere blockage, wave formation during air injection, entrapped phases, and also processes which control the formation of bubbles in viscous fluids are not feasible yet. In this research, we have used a converter-shaped vessel made of flexi-glass. Water and oil have been used as matte and slag phases respectively. The effective operational factors responsible for creation of splashing have been studied such as air flow rate, tuyere angles, depth of tuyere submergence, tuyere blockage, density and viscosity of liquids, liquids heights, etc. The results have been found as follows: the amount of splashing increases slowly as air flow rate increases. However, as the air flow rate reaches a critical value (depending on the physical specification of converter) the amount of splashing rises sharply, because the flow of air inside the liquid changes from bubbling into a jet stream; and most of the splashed materials are in the form of filaments instead of droplets. Changing tuyere angle from horizontal towards vertical position will increase the turbulence level on the fluid surface and causes an increase in the amount of splashing. The effect of tuyere submergence is related to the converter opening angle. As the converter opening angle is shifted towards the hood position, the amount of tuyere submergence and splashing will increase. As density of the liquid increases, the number of droplets splashing increases with a decrease in drop size. Therefore, the total amount of splashing decreases. However, as viscosity of the liquid increases, the splashing material increases due to the changes in the splashed material from droplet shape into filament form. The height of liquid inside the converter, depending on the relative height of heavy phase and light phase, is an important parameter regarding splashing. As the relative height of heavy phase to light phase increases the splashing will decrease. The tuyere blockage will cause the pressure in the inlet manifold to increase; and in real cases will increase the splashing. Finally, we have development a model based on dimensional analysis to relate the above parameters in order to calculate the amount of splashed material.

[Paper #0815—11:30](#)

Computer simulation of the early stages of blown in a Pierce – Smith converter

D. Jaramillo, G. Plascencia, CIITEC,
M.A. Barrón, J. González, C. López, UAM

Air jet and molten matte interaction within a Peirce – Smith converter is analyzed during the first stages of blowing using Computational Fluid Dynamics (CFD), by means of the Large Eddy Simulation and Reynolds Stress turbulence models. Jet velocities ranging from 5 to 150 m/s, which involve the bubbling and open jet regimes, were considered in 2 and in 3-D numerical simulations. As a result of

the computer simulations, it was found that low velocities results in gas bubbling in the molten copper, whereas higher gas velocities results in well defined plumes. The consequence of such different behaviours results in an increment in the rate of refractory wear or in copper splashing respectively. The analysis of the results may lead to improve the design of the tuyeres currently used in copper converting. Bottom blowing of air is also explored in this work. Numerical results show a strong non-linear parabolic behaviour of the jet velocity on the average velocity of copper; which means that beyond certain jet velocity, the copper de-accelerates thus reducing its velocity. This may be due to the open nature of the jet, which prevents the momentum transfer from the injected gas to the molten copper.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 32: Alternative/Other Technologies I

Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS

Chair(s): C. Newman, Hatch;
M. Syamujulu, KCM Zambia
Room Algonquin—09:50

Paper #0833—09:50

New approaches for treatment the blister copper at the CODELCO Norte smelter

M. Rosales, A. Moyano, C. Caballero, J. Font, CODELCO-Chile

New approaches for the fire refining process of blister copper have been carried out at the CODELCO Norte Smelter. These have been mainly focused on modification and improvement of the process configuration based in fluid-dynamic and metallurgical studies of the oxidation and impurity treatment stages. This paper presents the results of the laboratory simulations and industrial tests performed in the 250 t anode furnace, evaluating two different process configurations:

- Bottom Bath Agitation System in the vessel during the oxidation stage,
- Dual Flux Injection System during the impurity treatment stage.

The results show the possibilities of effective removal of high content of sulfur from the melt during the oxidation stage by using the bottom bath agitation. The use of the dual injection system demonstrated the significant improvement in the removal efficiency of impurities.

Paper #0800—10:15

MPV reactors cleaning from oxides mush by the reduction and slagging with calcium carbide

A. Warczok, University of Toronto,
D. Hall, L. Molino, J. Liu, A. Vahed, CVRD Inco

Chalcocite concentrate obtained by magnetic separation and flotation of Bessemer matte is processed in the Inco top blowing bottom stirring MK reactor into semi-blister copper. The semi-blister is then converted into blister copper in the multi-purpose vessels (MPV) by oxidation of iron, nickel and sulphur. High melting point NiO and Fe₃O₄ are formed inside the MPVs, which together with Cu₂O and smaller amount of fayalite are the major constituents of the solid mush. The accumulation of solid mush and buildup requires periodic MPV cleaning by adding reductant and copper-nickel matte, a unique process called “washout”. Various reductants and their combinations, such as pig-iron, 15%Si Ferro-silicon and 50%Si Ferro-silicon, have been used for the reduction of solid mush and buildup. The possibilities of using calcium carbide as a reductant and slagging flux were examined experimentally at the crucible scale. The rate of reduction of MPV buildup was determined by continuous measurement of CO and CO₂ contents in the off-gas and the flowrate of argon carrier gas. The rate of the buildup reduction with calcium carbide was approximately five times faster than the rate of reduction with coke. Additionally, the formation of CaO results in the melting of reduced buildup and formation of a slag at 1300°C and higher temperatures. It was found that simultaneous silica addition enhanced the melting and slag formation. The results showed the strong dependence of the reduction rate on temperature. Activation energy is approximately 225 kJ/mol. Expected benefits of using calcium carbide are related to cost saving on reductant, significant acceleration of solid mush reduction, and reduced amount iron input from reductant.

[Paper #0837—10:40](#)

Develop new reductants for CVRD Inco multi-purpose vessels

J. Liu, D. Hall, L. Molino, R. Makela, D. Wong, CVRD Inco,
A.E.M. Warner, WorleyParsons HGE,
S.A. Argyropoulos, University of Toronto

At its Copper Cliff Smelter, bulk nickel and copper concentrate is processed in two Inco flash furnaces and Peirce Smith converters to produce Bessemer matte containing 0.6%Fe. After slow cooling and Matte Separation, Bessemer matte is converted into three main products using magnetic separation and flotation technology: (1) a nickel containing chalcocite concentrate (MK); (2) two types of copper containing nickel sulfide (ME and MR); (3) metallics (MYN). MK is further processed in the Inco top blowing bottom stirring MK Reactor to produce semi-blister copper containing ~4%Ni and ~3±1%S. The semi-blister copper is then purified in the multi-purpose vessels (MPV) to produce blister copper by reducing Ni, Fe and S content through oxidation. High melting point NiO is formed inside the MPVs. The accumulation of solid NiO and other oxides requires periodic cleaning by adding reductant and furnace matte, a unique process called “washout” at Inco. For many years, the reductant used for the “washout” process has been 15%Si Ferro-silicon. With increasing cost and limited suppliers for 15%FeSi, alternative reductants were pursued. This paper summarizes the

development and commercialization of new alternative reductants for MPV “washout”.

[Paper #0847—11:05](#)

Modeling of the direct-to-copper flash smelting process

M. Kucharski, AGH University of Science and Technology

The model of the Outokumpu direct-to-copper process deals with a steady-state process the parameters of which do not depend on time. To give a prediction for the process outcome, “a modified black box” method, which ignores most of the chemical reactions in the furnace, was used. This method takes input and output parameters into consideration. The presented model describes the Outokumpu direct-to blister process in the form of the set of linear equations which give mass and enthalpy balances as well as the distribution of elements between blister copper and slag. However, only major substances where quantities in the feed charge exceed a certain level (for example 0.5 kg/ 1Mg of smelted concentrate) are taken into consideration. Minor elements are distributed among slag and metal phases in a different way. Some of the equations are derived from distribution coefficients. The value of distribution coefficients can be calculated from plant production data.

Cu2007: The Carlos Díaz Symposium on **Pyrometallurgy**
Session 33: Feed Preparation / Materials Handling, Fuels / Gases

Sponsors: Non-Ferrous Pyrometallurgy Section of MetSoc, MMIJ, GDMB, IIMCh, EPD of TMS

Chair(s): C. Nexhip, Rio Tinto;

A. Vahed, CVRD Inco

Room Quebec—09:50

[Paper #0799—09:50](#)

Copper smelter projects: installation and operation of large Kumera steam dryers

S. Chen, H. Mansikkaviita, Kumera Technology Center

Kumera Technology Center developed a unique type of steam dryer for drying copper concentrate in the mid 1990s. The dryer has been chosen in several copper smelter projects since 1999. To expand production capacities, Norddeutsche Affinerie, Pirdop Smelter of Cumerio, Toyo Smelter of Sumitomo Metal Mining, and Tamano Smelter of Hibi Kyodo Smelting have carried out their projects in which Kumera Steam Dryers were installed. The capacity of a single steam dryer varies from 70 t/h to 160 t/h. This article summarizes the latest operation results of the Kumera Steam Dryers in these smelters and introduces the progresses of the ongoing projects in Yanggu Xiangguang Copper, Guixi Smelter of Jiangxi Copper, Jinlong Copper, Boliden Harjavalta, and Onsan Smelter of LS-Nikko Copper.

[Paper #0795—10:15](#)

Industrial gases for copper production

A. Deneys, Praxair, Inc.

This paper reviews industrial gases used in primary copper production. Copper smelting industrial gas demand has steadily increased since the first commercial oxygen-concentrate smelting in 1952 [1]. In copper production oxygen for smelting is the dominant industrial gas use followed by oxygen for converting. Nitrogen is finding increased use in copper smelters. Nitrogen is used for porous plugs for copper converting and anode refining [2-5]. Nitrogen can be used for concentrate drying [6,7] and is also used in some Ni-Cu smelters as a coolant in Peirce-Smith converting [8,9]. Industrial gas supply options of cryogenic or adsorbent based on-site plant or cryogenic liquid delivery are detailed.

[Paper #0838—10:40](#)

Study of elemental sulfur formation in the fluid bed dryer baghouse

J. Liu, R. Yotingco, B. Macnamara, A. Vahed, CVRD Inco,
A.E.M. Warner, WorleyParsons HGE

Inco Copper Cliff Smelter commissioned two new Inco flash furnaces in 1991/1993 as part of its SO₂ abatement program. Each flash furnace is equipped with a fluid bed dryer. The ~12 wt% water content in the concentrate filter cake, flux, reverts and sludge is removed in the fluid bed dryer. The dry solids are discharged from the dryer together with exhaust gases into the baghouses where they are separated. The dry solids are transferred to four storage bins. In September 2003, for the first time since startup in 1991/1993, a large amount of elemental sulfur accumulation was discovered on the walls, roofs and floors of the outlet side of the baghouse chambers. Several baghouse fires were experienced during cleaning and conducting maintenance work in the elemental sulfur contaminated baghouses. Laboratory scale test work at the Inco research lab was conducted to understand the mechanism. A plant solution to minimize elemental sulfur formation was implemented with success. This paper summarizes the efforts to understand and minimize elemental sulfur formation in the baghouse chambers.

[Paper #0862—11:05](#)

**Start up and operational optimization oxygen plant oxial™ Caletones
Copper smelter – El Teniente division of CODELCO-Chile**

P. Reyes F., B. Martinich, R. Maluenda, CODELCO-Chile,
P. Adell, Air Liquide Chile

The start up and operational optimization of the No. 3 Oxygen Plant at the Caletones Copper Smelter of the CODELCO - Chile El Teniente Division is summarized. In addition, the economic impact of such optimization on the production cost of oxygen and others aspects associated to the operational robustness as well is detailed.

Cu2007: International Symposium on **Mineral Processing**
Session 34: Dewatering and Mineral Characterization

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

Chair(s): A.E. Peres, Federal University of Minas Gerais UFMG

Room Tudor 8—09:50

Paper #0716—09:50

Filter.SIM: a new tool to optimize industrial filtering plants

L.E. Gutiérrez, J.M. Menacho, E.A. Peñaloza, De Re Metallica Ingeniería

A new filtration model based on porous media transport theory is presented. It predicts capacity and final moisture content in the filtered cake as a function of design and operational variables at the plant. FilterSim® is the computer code where this new model is programmed. Application of FilterSim® to ten-month operation of an industrial copper concentrate filtration plant is shown on a daily basis and using a single set of internal parameters for the whole period. Average error is less than 5%, both in capacity and moisture estimation. FilterSim® abilities to optimize industrial filtration plants as well as to estimate future budgets are illustrated with several real examples.

Paper #0717—10:15

Optimisation of cake moisture at the leached sludge filter press

P. Belley, F. De La Durantaye, STS Canada Inc.

Prior to 2006, the filtration unit for leached sludge treatment (filter press) permitted the filtration, washing and drying of cake to 17% (w/w) moisture. That year saw moisture content abruptly increase to 20% (w/w), drastically changing the rheological properties of the cake. The cake became sticky and agglomerated. This led to major disruptions of operations and plant capacity (cake release and cake conveyor problems, complicating the subsequent steps of the process). The conditions for the filtration, washing and drying, were simulated to ease cake unloading without aggravating dust emissions (moisture about 17% (w/w)). All of the laboratory tests yielded a moisture content above 17% (w/w). Therefore, we concluded that the moisture problems were not due to a recipe change in primary material, but to an operational problem in the filter press. Through the laboratory results, the filter press operating conditions (washing ratio, drying pressure and drying time) were optimized to enable a reduction in cake moisture to 17% (w/w).

Paper #0703—10:40

Ore characterization and the value of QemSCAN

C. Hamilton, Barrick Technology Centre,

C. Martin, J. Zhou, SGS Lakefield Research

The use of QemSCAN in providing mineralogical input to detailed ore and product characterization has proved of immense value in recent years. In this paper, a brief review of selected Cu-case studies is presented to demonstrate the versatility of automated, quantitative mineralogy by QemSCAN. This versatility ranges from measurement and analysis strategies through to data processing and presentation. As a rapid diagnostic service, it is common to find that only grain size, the degrees of liberation and/or ore mineral modal mineralogy are of interest. By contrast, the detail afforded by the simultaneous determination of both gangue and ore minerals can alert mineral engineers to fatal flaws and attributes deleterious to processing that are directly a function of silicate and other gangue mineralogy. Examples of the latter effects include the influence of micaceous minerals and acid consuming species, while the former include fluorine minerals, which can provide both processing and environmental challenges.

[Paper #0704—11:05](#)

QemSCAN characterization of selected ore types for plant optimization

R. Zahn, W. Baum, R. Magnuson, D. Jensen, Phelps Dodge,
P. Thompson, Dawson Metallurgical Laboratories Inc.

The need for quantitative mineralogical data to characterize ore types before they are processed is becoming increasingly necessary. Mineralogical data (modal abundances, grain size, liberation/locking characteristics, mineral textures and associations) can provide invaluable information to facilitate the identification of metallurgical issues that may arise during processing of a particular ore. This paper will discuss the use of QEMSCAN analysis in conjunction with bench scale flotation test work to determine metallurgical characteristics for several ore types that will be fed to the Morenci concentrator upon commencement.

Cu2007: International Symposium on **Sustainable Development, HS&E, and Recycling**, Incorporating the 6th Waste Processing and Recycling Symposium
Session 35: Life Cycle, Recycling And Risk Management I

Sponsors: The Environmental Society of CIM, the Environment Section of
Metsoc, MMIJ, GDMB, IIMCh

Chair(s): W.J. Adams, Rio Tinto
Room Confederation 3—09:50

[Paper #0910—09:50](#)

Past and future cycles of copper, regional and global

M.D. Gerst, T.E. Graedel, Yale University

The degree to which copper will continue to be in an integral part of the world economy in the future will depend largely on the dynamics of global economic development, the primary and secondary copper resource stock, technological change, and potential environmental constraints. We have characterized the copper cycle of 1994 for all of Earth's regions and for the planet itself (T. Graedel

et al., *Environmental Science & Technology*, 38, 1242-1252, 2004) and recently updated that cycle to year 2000. In this paper, we compare various features of the 1994 and 2000 cycles. The three largest-using regions, Asia, Europe, and North America, all increased their absolute rate of copper use between 1994 and 2000, and all increased the per-capita rate of copper use as well. Globally, the use of copper increased by about 32%, from 11.7 to 15.3 million metric tons, while population increased by only 8%. Various changes are seen in scrap trade, finished products trade, and other parameters of the cycle. We conclude by considering how the rates of technological change and growth in demand, especially in Asia, may influence the copper cycle in the years ahead.

[Paper #0911—10:15](#)

Recirculation of Chilean copper smelting dust with high impurities contents to smelting process

H. Sano, T. Fujisawa, V. Montenegro, Nagoya University

Most of the dust generated from the copper smelting process in Chili has been stored after the stabilization by hydrometallurgical process because it contains high concentrations of arsenic. However, in recent years, the dust generation has increased because of degrading the quality of concentrate. In addition, the environmental regulations become stricter. On the other hand, valuable metals such as copper and zinc are contained in the dust at high concentrations and it is desirable to recover them. In this study, the effect of dust recirculation to the smelting process was examined in order not only to decrease the amount of dust but also to recover copper. Dust generation and the distribution of arsenic, lead, zinc etc. among the matte, slag and gas phases were evaluated as a function of the amount of recirculated dust, partial pressure of oxygen and temperature. It was found that the direct dust return to the smelting process was quite effective for the recovery of copper and the reduction of dust generation, but the acceptable dust amount was limited by the produced matte quality.

[Paper #0914—10:40](#)

Exploring metal recycling business in China

K. Soga, DOWA Environmental Management Co. Ltd.

DOWA has long been specialized in the treatment of complex massive sulfide ores from exploration through smelting. Its competitive advantage derived from ore dressing technology to dress and concentrate complex ore to various kinds of metals concentrates. With this technology, the company recovers as many as seventeen different nonferrous metals. Therefore, it is crucial for the environment management and recycling business both to recover valuable elements like gold, silver, copper etc. and to handle hazardous elements in safety. From this view point, the nonferrous metal industry has a potential to play an important role; that is “The Anchor of Recycling” or “The Joint of Recycling Loop”. By utilizing these mining, smelting and refining technologies, know-how and facilities, DOWA

became a leading waste treatment, soil remediation and metal recycling company in Japan. This knowledge is now being applied in China.

[Paper #0915—11:05](#)

Life cycle methodology and its future for copper

S.Goessling-Reisemann, L. Tikana, H. Sievers, A. Klassert, University of Bremen

Most copper ores contain valuable co-products such as molybdenum, gold, silver, nickel, etc. Sulphuric acid and steam are valuable by-products, which are generated during copper production. The environmental impacts from mining and refining therefore need to be shared between these by-products and co-products, an issue in Life Cycle Assessment (LCA) referred to as allocation. There are different, recognised methodologies for doing so: burdens can be allocated based on the market values of these commodities, they can be allocated by mass, volume, molar amount, functionality, or other physical, technical or economic factors. All of these methodologies have their respective merits and restrictions, and the choice is usually case specific. Nevertheless, the choice between alternative methodologies can have dramatic effects on the LCA results. Recycling in LCA has to be handled in a similar way, as it essentially constitutes a special case of coproduction. The existing standards (ISO 14040 ff.) allow different methods for implementing recycling and allocation into metal LCAs (open loop, closed loop, value corrected substitution, etc.), which are still a subject of discussion in the scientific community. However, the methodology used can significantly influence the ecological profile of copper and copper products. We will present an overview of the different methodologies available for including recycling and allocation and give an analysis of how the methodological choice affects the final LCA results. This work will be followed up by quantitative case studies.

[Paper #0916—11:30](#)

Using LCA to support decision-making and sustainable plant design in primary copper production

M.H. Ali, Hatch Ltd.,

M. Velasco-Reyes, Instituto de Innovación en Minería y Metalurgia SA

CODELCO, a multi-process primary copper producer, is undertaking a full life cycle inventory (LCI) of all its commercial products based on copper and molybdenum. During this work, many questions have surfaced regarding the contribution of process unit design to specific aspects of a product's LCI and, more importantly, how such designs could be improved using a life cycle perspective. Management strategy efforts were undertaken to improve the LCI footprint, however it was found that the corrective actions were almost impossible to apply at the operation level in plant, given the ongoing timing pressures of extractive mining, and costs saving priorities. Additionally, it was found that most of the important comparative differences between operations had structural reasons. In this circumstance, the LCI practitioner group from IM2, and the

environmental managers from CODELCO, decided to shift its efforts to place the critical LCI aspects to the design process of future developments. Hatch Associates has developed unique tools in their Sustainable Plant Design (SPD) package that compliment and enhance LCA methods; these effectively drive sustainability into the heart of the design process. By using LCA and SPD in a project design phase, you cannot only address potential hotspots, but also decide on materials, location and size of certain facilities to optimize for energy efficiency. Moreover, you can avoid the shifting of environmental burdens upstream or downstream within the plant and finally it is extremely useful in identifying opportunities for greenhouse gas reduction.

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Room Tudor 7—9:50

[Paper #1034—9:50](#)

Prevention of oxide formation on stored copper rod

G. Spence, Encore Wire Ltd.

Prevention of cuprous and cupric oxide formation on stored ETP copper rod is a major concern for copper rod and wire producers. During normal storage periods copper oxide layers can increase from less than 100 Å to more than 1000 Å exceeding ASTM specifications and discoloring the rod surface. Various types of corrosion inhibitors are tested and compared in effectiveness for prevention of copper oxide formation on stored copper rod. Aromatic triazole compounds are also compared to a non-azole containing compound.

[Paper #1055—10:15](#)

Application of SPAL(TM) surface protection by Air Liquide technology at Riverside Brass and Aluminum Foundry Limited

M. I. Bouet, Air Liquide Canada Inc.

This paper discusses Air Liquide's patented SPALTM (Surface Protection Air Liquide) technology and process for the inerting of coreless induction furnaces using cryogenic liquid gas. Air Liquide Canada Inc., in collaboration with Riverside Brass and Aluminum Foundry Limited (Riverside Brass), conducted plant trials to demonstrate the applicability of the SPALTM technology for copper-based alloys. Results showed that with SPALTM, Riverside Brass benefited from a significant increase in metal yield as the level of dross formation was drastically reduced. Together with the many other benefits of this technology, SPALTM demonstrated to be a non-negligible cost-effective solution to reduce metal production costs. In an effort to optimize the argon flow, different flow rates were used and the oxygen level above the metal bath was measured to pinpoint

optimal flow. The results of metal yield, charge mix, dross formation, and melt temperature are compared with and without argon. The metal yield improvements are dramatic and calculated net savings are presented hereunder.

[Paper #1051—10:40](#)

Testing technology in the copper semi-finished products industry

S. Theobald, Wieland-Werke AG

Semi-finished copper and copper-alloy products are typically produced by casting, subsequent hot rolling or extruding and further cold working by rolling and drawing. The technological properties of the products depend not only on the chemical composition of the alloys but also on process parameters such as annealing conditions and degree of deformation. In each production step, measuring and control technology is an important tool for optimizing processes and ensuring constant high quality. This paper follows the product all the way from testing incoming scrap packages, chemical analysis of melts, mould level control in casting, non-destructive testing technologies in cold forming processes, controlling geometrical properties in the production process, to the final tests of technological properties. All test methods are focused on the applications and requirements of our customers, as the examples show.

[Paper #1044—11:05](#)

Macroseggregation in continuous casting of phosphor bronze – impact on properties and modeling of formation

M. Gruber-Pretzler, University of Leoben

Technical Sn- bronzes tend to form both macroseggregations and microseggregations during DC-casting due to the particular thermodynamic properties and kinetics of phase transformation. As a result a heterogeneous cast microstructure forms that is sometimes a reason for a decrease in workability. The extent of macroseggregations in DC-casting can effectively be influenced by casting parameters like casting velocity, primary cooling or inlet geometry which in fact change the relative flow between the melt and the forming solid. In order to understand the influence and interaction of the related phenomena, simulation methods are applied. The solidification of the strand as well as the formation of macroseggregation are simulated with a two phase volume averaging model. The velocity field of the melt flow is explicitly calculated by solving the corresponding momentum conservation equations. Within the mushy zone the local formation of microseggregations in the presence of feeding flow is estimated. The thermodynamics of the Cu-Sn system is accounted for and it is distinguished explicitly between interface and average concentrations. To investigate the influence of feeding flow on the formation of macroseggregations, a study has been performed. Based on this result, the phenomena of macroseggregations are described in a detailed discussion.

[Paper #1040—11:30](#)

Topics relative to filtration for continuous cast copper and aluminum

J. Scalise, Filtertech Inc.

The paper covers a wide range of topics relative to filtration for continuous cast copper and aluminum. Subjects include system concepts, filtration concepts, system components, filter types, filter media selection, caster water filtration, coolant disposal, and recommended materials of construction.