MONDAY, AUGUST 25, 2003, P.M.

PLENARY SESSION II: INTERNATIONAL SYMPOSIUM ON HYDROMETALLURGY IN HONOUR OF PROFESSOR IAN RITCHIE

Room: Grand Ballroom A and B

Chairmen: C. YOUNG, Metallurgical and Materials Engineering, Montana Tech, Butte, MT, USA

PLENARY 5 — 14:00

IS EXTRACTIVE METALLURGY BECOMING EXTINCT?

I.M. RITCHIE, Murdoch University, Perth, Western Australia

Right across the universities of the developed world, the traditional disciplines of physics and chemistry are losing ground. Extractive metallurgy, which depends so heavily on chemistry, is also contracting despite a clear need for people with this kind of training in the mining industry. Reasons for this loss of popularity are discussed. High on the list is one of image. The extraction of metals is widely seen as a dirty, polluting sunset industry which involves working in remote and uncomfortable corners of the earth for inadequate compensation. Ways in which the image problem can be overcome are considered. It is concluded that a concerted effort needs to be made by the universities and industry to redress this situation. The importance of extractive metallurgy, both now and in the future, when a greater emphasis will be placed on sustainability and recycling needs to be stressed. In addition, training for a career path which leads on beyond extractive metallurgy, needs to be incorporated into degree courses.

COFFEE BREAK — 14:40 – 15:00

SESSION 3: INTERNATIONAL SYMPOSIUM ON HYDROMETALLURGY IN HONOUR OF PROFESSOR IAN RITCHIE

SOLUTION PURIFICATION I: ION EXCHANGE

Sponsors: Hydrometallurgy Section of The Metallurgical Society of CIM (MetSoc), Extraction and Processing Division, The Minerals, Metals and Materials Society (TMS), and the Society for Mining, Metallurgy and Exploration (SME)

Room: Grand Ballroom A and B

Chairmen: G. STERZIK, Teck Cominco Metals, Trail, BC, Canada

K. NIKKHAH, AMEC Mining and Metals Consulting, Vancouver, BC, Canada

PAPER 3.1 — 15:00

APPLICATION OF ION EXCHANGE POLYMERS IN COPPER CYANIDE AND ACID MINE DRAINAGE.

W.H. JAY, Oretek Limited, Albury, New South Wales, Australia

The presence of iron sulphide minerals leads to acid formation. In turn, the acid generates effluents such as copper acid drainage (AMD). The Berkeley pit in Butte, Montana, U.S.A. and Mt. Lyell acid drainage in Tasmania, Australia, represent just two of the many sites throughout the world for which acceptable treatment methods are required. In the gold cyanidation process, the presence of copper creates both a significant cost impediment and a potential environmental hazard. The tailings dam failure at Baia Mare in Romania, which led to the uncontrolled release of copper and zinc cyanides, created a major environmental disaster. The application of non-toxic, water-soluble polymers and ion exchange resins to selectively recover copper from AMD solutions, and the in-plant treatment of copper cyanide solutions and slurries to recover copper and recycle cyanide preventing cyanide from entering the tailings impoundment will be discussed.

PAPER 3.2 — 15:25

EXTRACTION AND RECOVERY OF BISMUTH FROM SULPHURIC ACID ELECTROLYTES, AND EXTRACTION, RECOVERY, AND REFINING OF PALLADIUM FROM COPPER REFINERY BY-PRODUCT STREAMS USING MOLECULAR RECOGNITION TECHNOLOGY (MRT).

S.R. IZATT, N.E. IZATT, R.L. BRUENING and J.B. DALE, IBC Advanced Technologies, Inc., American Fork, Utah, U.S.A.

IBC Advanced Technologies, Inc. (IBC) has developed and commercialized SuperLig® materials based on Molecular Recognition Technology which have proven to be very effective for removal of bismuth from hydrometallurgical sulphuric acid process streams. The most common application is bismuth removal from copper refinery electrolytes, where bismuth control is extremely critical. IBC also has an MRT system for extraction, recovery and refining of palladium from a copper refinery by-product stream originating from treatment of copper tankhouse slimes. A high-purity palladium salt is produced which meets market specifications. Results are reviewed and discussed.

PAPER 3.3 — 15:50

DYNAMIC MODELLING FOR DESIGN OF ION EXCHANGE SYSTEMS.

K. NIKKHAH, AMEC Mining and Metals Consulting, Vancouver, British Columbia, Canada

Increasingly ion exchange systems are being included in design of hydrometallurgical plants for metal extraction or impurity removal. Because such systems operate sequentially and are based on resins that exchange one ion for another, store it temporarily and release it to a regenerating solution, the usual steady state heat and mass balancing tools and spreadsheets cannot be used to design them successfully. This paper outlines the role of dynamic simulation in design of ion exchange systems. Examples are given for use of dynamic simulation in design and investigation of equipment based on consideration of the effect of input criteria such as expected ion loading and elution profiles. The methodology for dynamic modelling using IDEAS® in design of multi column ion exchange trains operating in parallel is presented. Results shown include the non-steady state distribution of extracted metal and limitations imposed on operating conditions. These conditions include proposed sequencing of columns for loading and elution cycles, loading, elution and recycle flow rates as well as size and choice of related ion exchange plant equipment.

PAPER 3.4 — 16:15

THE EFFECT OF PLATING ADDITIVES ON THE RECOVERY OF COPPER FROM DILUTE AQUEOUS SOLUTIONS USING CHELATING RESINS.

W. EWING, J.W. EVANS and F.M. DOYLE, University of California, Materials Science and Engineering, Berkeley, California, U.S.A.

Copper is rapidly being adopted by the semiconductor industry as the interconnect material of choice. The aqueous processing techniques used generate wastes such as spent electrolyte from electroplating, electroplating rinse water, copper solutions from removing copper from the back of the wafer and CMP waste streams. The authors are examining the use of chelating resins as a means of recovering copper from these streams within the processing plant, thereby allowing recycling of process water and minimizing hazardous waste disposal costs. Of particular concern is the effect of plating additives (and other organic complexing agents) on the efficacy of the resins. Here, the authors report the effect of benzotriazoles, a thiopropanesulphonate, polyethylene glycol, and chloride additives on the adsorption isotherms of copper on chelating resins, and on the copper uptake kinetics. The experimental results are compared with thermodynamic and kinetic models for the system.

SESSION 4: INTERNATIONAL SYMPOSIUM ON HYDROMETALLURGY IN HONOUR OF PROFESSOR IAN RITCHIE

SOLUTION PURIFICATION II: PRECIPITATION I

Sponsors: Hydrometallurgy Section of The Metallurgical Society of CIM (MetSoc), Extraction and Processing Division, The Minerals, Metals and Materials Society (TMS), and the Society for Mining, Metallurgy and Exploration (SME)

Room: Grand Ballroom C

Chairmen: D. DREISINGER, Metals and Materials Engineering, University of British Columbia, Vancouver, BC
D. MUIR, A.J. Parker Centre for Hydrometallurgy, CSIRO Minerals, Perth WA, Australia

PAPER 4.1 — 15:00

PRECIPITATION OF IRON(III) OXY-HYDROXIDES FROM ACID LIQUORS AT AMBIENT TEMPERATURES.

D.M. MUIR, Parker CRC for Hydrometallurgy, CSIRO Minerals, Perth, Western Australia, and
E.J. JAMIESON, Alcoa Australia, Perth, Western Australia

The neutralization and precipitation of iron(III) from leach solutions and waste streams at ambient temperatures (<80%C) gives a variety of iron(III) oxy-hydroxide materials — many of which are slow settling and gelatinous. The structures of these various phases are reviewed. This is followed by the results of a systematic study comparing the precipitate characteristics produced from neutralization of Fe(III) and Fe(III)/Fe(II) solutions in chloride and sulphate media using caustic solution, dry/slaked lime and dry/slaked magnesia. It is shown that more crystalline and faster settling phases can be produced at 20°C to 70°C under specific conditions and with choice of base. Fundamental reasons for this improvement are discussed together with examples of industrial applications. Such understanding is useful for removing iron from liquors obtained from atmospheric leaching of nickel laterite ores.

PAPER 4.2 — 15:25

THE PRECIPITATION CHEMISTRY AND PERFORMANCE OF THE AKITA HEMATITE PROCESS — AN INTEGRATED LABORATORY AND INDUSTRIAL-SCALE STUDY.

T.C. CHENG, G.P. DEMOPOULOS, McGill University, Mining, Metals and Materials Engineering, Montréal, Québec, Canada,
Y. SHIBACHI and H. MASUDA, Akita Zinc Co. Ltd., Iijima Zinc Refinery, Iijima, Akita, Japan

Over the past five years, laboratory studies in batch and continuous autoclaves had been undertaken jointly by McGill University and Akita Zinc Co. on elucidating the precipitation chemistry and identifying means of improving the performance of the Akita Hematite Process in terms of product quality and throughput increase. The laboratory results have been compared to the performance of the industrial autoclaves via a comprehensive sampling campaign. All studies determined that hematite is produced directly without prior formation and transformation of basic ferric sulphate as thought originally. In this paper, a full account of these studies will be given comparing the batch to continuous reactor data along with a discussion of the underlying mechanism of the process and the factors affecting the quality of the final product.

PAPER 4.3 — 15:50

RECENT DEVELOPMENTS IN IRON REMOVAL AND CONTROL AT THE ZINC CORPORATION OF SOUTH AFRICA.

J. OCKERT CLAASSEN, J. RENNIE, W. HENDRIK VAN NIEKERK, E. HEINRICH OTTO MEYER, Zinc Corporation of South Africa Ltd., Struisbult Springs, Gauteng, South Africa, and
R. FEENSTRA SANDENB, University of Pretoria, Pretoria, Gauteng, South Africa

The Zinc Corporation of South Africa Ltd. (Zincor) operates an integrated roast-leach-electrowinning circuit. The efficient removal and control of iron forms an integral part of the process. Zincor developed its own iron removal process, which was recently shown to be unique with some similarities to the para-goethite iron removal process. Newly developed operating parameters for iron removal are in the process of being implemented. These include a change in the pH-profile and operating temperature, the recycling of seed material and the utilization of an alternative neutralizing agent. Some of these actions together with the implementation of a pre-neutralization step, new filtration equipment and control systems in the residue treatment plant have significantly reduced zinc losses associated with iron in calcine and the iron residue produced. This enabled Zincor to take a step closer to achieving world class zinc recoveries around 96% for a similar type of operation. An increase in zinc recovery will also enable Zincor to increase its slab zinc production from 110 kt/a to 125 kt/a while remaining one of the lowest cost zinc producers in the world in the years to come.

PAPER 4.4 — 16:15

IRON(II) OXIDATION BY SO2/O2 IN URANIUM LEACH SOLUTIONS.

E. HO, Australian Nuclear Science and Technology Organisation, Menai, New South Wales, Australia

The oxidation of iron(II) sulphate to iron(III) sulphate using SO_2/O_2 was carried out in a stirred tank reactor under typical uranium leaching conditions (pH 1 to 2, 20°C to 50°C). The oxidation rate was found to be dependent on the initial SO_2/O_2 volumetric ratio and the oxygen mass transfer rate, but was independent of the initial iron(III) concentration above about 500 ppm at pH 2. The maximum iron(II) oxidation rate in solution was correlated with the oxygen mass transfer coefficient (kLa) for the mixing tank system. The oxygen mass transfer rate for two commonly used impellers (Lighnin A310 and six blade disk turbine) was compared under the same mixing and gas sparging configurations. Oxidation of iron(II) in a uranium slurry was also examined.

PAPER 4.5 — 16:40

REACTIONS OF CARBON DIOXIDE WITH TRI-CALCIUM ALUMINATE.

P. SMITH and R. PENNIFOLD, CSIRO Minerals, Waterford, Western Australia

Tri-calcium aluminate (TCA) is one of the most dominant alkaline components of the red mud residue from the Bayer process. Partial neutralization of residue using CO_2 has been trialed at one of Alcoa's refineries in Australia. This paper outlines the chemistry of CO_2 neutralization of TCA under Bayer conditions. CO_2 neutralization of the liquor is fast. It results in the formation of amorphous aluminum hydroxide and dawsonite that agglomerate together. Neutralization of solid TCA by carbonation is slower and leads to the formation of calcite, dawsonite, and amorphous aluminum hydroxide. TCA dissolution in partially neutralized slurries causes pH reversion. However, the carbonated solutions contain a store of bicarbonate that can supply aqueous carbon dioxide to complete the transformation. The pH at which the carbonation is carried out is likely to affect the degree of TCA transformation during the carbonation process. In particular, if the pH of the carbonation is too low (near 7.0), calcite precipitation is inhibited and the degree of transformation is low. Controlling the carbonation pH optimizes the neutralization process.

SESSION 5: INTERNATIONAL SYMPOSIUM ON HYDROMETALLURGY IN HONOUR OF PROFESSOR IAN RITCHIE

TECHNOLOGY APPLICATION: ACID ROCK DRAINAGE

Sponsors: Hydrometallurgy Section of The Metallurgical Society of CIM (MetSoc), Extraction and Processing Division, The Minerals, Metals and Materials Society (TMS), and the Society for Mining, Metallurgy and Exploration (SME)

Room: Grand Ballroom D

Chairmen: L. MCCLOSKEY, MSE Technology Applications, Inc., Butte, MT, USA

P. SIBBRELL, US Geological Survey, Kearneysville, WV, USA

PAPER 5.1 — 15:00

REMEDIATION OF ACID MINE DRAINAGE AT THE FRIENDSHIP HILL NATIONAL HISTORIC SITE WITH A PULSED LIMESTONE BED PROCESS.

P.L. SIBRELL, B.J. WATTEN, US Geological Survey, Kearneysville, West Virginia, U.S.A.,
C. RANSON and T. BOONE, National Park Service, Point Marion, Pennsylvania, U.S.A.

A new process utilizing pulsed fluidized limestone beds was tested for the remediation of acid mine drainage at the Friendship Hill National Historic Site, in southwestern Pennsylvania. A 60 gallon per minute treatment system was constructed and operated over a fourteen-month period from June 2000 through September 2001. The influent water pH was 2.5 and acidity was 1000 mg/L as $CaCO_3$. Despite the high potential for armoring at the site, effluent pH during normal plant operation ranged from 5.7 to 7.8 and averaged 6.8. As a result of the high influent acidity, sufficient CO_2 was generated and recycled to provide a net alkaline discharge with about 50 mg/L as $CaCO_3$ alkalinity. Metal removal rates were 85%, corresponding to a removal of 70 lb of metals per day. These results confirm the utility of the new process in treatment of acid impaired waters that were previously not amenable to low cost limestone treatment.

PAPER 5.2 — 15:25

DEVELOPMENT OF SRB TREATMENT SYSTEMS FOR ACID MINE DRAINAGE.

S. NORDWICK, M. ZALUSKI, MSE Technology Applications Inc., Mike Mansfield Adanced Technology Center, Butte, Montana, U.S.A., and
D. BLESS, US Environmental Protection Agency, Cincinnati, Ohio, U.S.A.

Over the past decade, significant advances have been made in the development of sulphate-reducing bacteria (SRB) technology to treat acid mine drainage (AMD). Bench-scale testing, field demonstrations, and engineered applications of SRBs for the treatment of AMD will be presented. Designs include an insitu bioreactor installed in the subsurface workings of the Lilly Orphan Boy mine in 1994, the SRB reactive wall installed at the Calliope mine from 1998 to 2001, the integrated biological reactors built at the Surething mine in 2001, and the ongoing development of a replaceable cartridge system. SRB technology benefits include the reduction of dissolved metal ions to insoluble metal sulphides and the neutralization of the AMD resulting from the production of bicarbonate from the oxidation of organic nutrients. This paper will address engineering design criteria including the selection of organic media and system permeability and complete mitigation of AMD. Research was funded under Interagency Agreement No. DW89 9388-70-01-1 between the US EPA and the US DOE and was conducted by MSE Technology Applications, Inc., through the National Environmental Technology Laboratory (DOE Contract No. DE-AC22-96EW96405) at the Western Environmental Technology Office located in Butte, Montana.

PAPER 5.3 — 15:50

BIOLOGICAL REDUCTION TECHNOLOGY TO PRODUCE SULPHIDE FOR THE SELECTIVE RECOVERY OF METALS FROM ACID WASTEWATER — COMMERCIAL CASE STUDIES.

R.W. LAWRENCE, D. KRATOCHVIL and P.B. MARCHANT, BioteQ Environmental Technologies Inc., Vancouver, British Columbia, Canada

BioteQ has successfully developed commercial operations for treatment of acid wastewater and selective metal recovery using the patented BioSulphide and Thiopaq biological reduction technologies. The BioSulphide-Thiopaq process was developed to provide biogenic sulphide for the selective recovery of high purity metal concentrates from acidic wastewater, which are sold to recover capital costs and off-set water treatment costs. The BioSulphide/Thiopaq process can be used on a stand-alone basis or in conjunction with a conventional lime water treatment circuit. Process advantages include: selective recovery of metals, very low metal concentrations in effluent, reduced waste sludge liability, reduced lime treatment costs and, in some cases, profitable sale of metal concentrates. Three case studies are presented to illustrate operations focussed on metal recovery; at the Caribou mine, New Brunswick; Phelps Dodge Bisbee operation, Arizona; and Falconbridge Raglan mine in Quebec. A fourth case study is presented to highlight environmental control for treatment of ARD in the Leadville mining district of Colorado. Process flowsheets, capital and operating costs are presented for the four case studies.

PAPER 5.4 — 16:15

PREVENTION OF AMD GENERATION FROM OPEN PIT HIGHWALLS DEMONSTRATION.

D.M. JORDAN and A.L. McCLOSKEY, MSE Technology Applications Inc., Butte, Montana, U.S.A.

Exposed, open pit mine highwalls contribute significantly to the production of acid mine drainage (AMD) thus causing environmental concerns upon closure of an operating mine. Four innovative technologies were evaluated under the U.S. Environmental Protection Agency's Mine Waste Technology (MWTP), Prevention of AMD Generation from Open-Pit Highwalls Demonstration Project. The object of the field demonstration was to evaluate the technologies' ability to decrease or eliminate acid generation from treated areas of the highwall in comparison an untreated highwall area. The field demonstration was performed at the Golden Sunlight mine (GSM) a subsidiary of Placer Dome U.S., located near Whitehall, Montana. GSM is an operating gold mine. The highwall was divided into five plots measuring 50 ft by 50 ft and each technology was assigned a plot with the fifth plot being used for comparison as a background control plot. The four technologies were spray-applied. The applied in situ treatment technologies were: (1) a modified, furfuryl alcohol resin sealant, utilizing wood and agricultural by-products to coat the rock surface; (2) EcoBondTM ARD, a phosphate-based process that forms a stable, insoluble compound, coating the rock surface; and (3) two ARD passivation technologies, magnesium oxide and the Dupont technology developed to create an inert layer/coating on the pyrite, preventing oxidation. The technologies were evaluated using ASTMD 5744-96, Accelerated Weathering of Solid Materials using Modified Humidity Cells, residual wall rinse samples from the treated highwall plots, microscopy and other methods. The proceeding paper describes the field demonstration, the technologies used for passivation of acid generation from the highwall and the results from each technology. This project was funded under the EPA's Mine Waste Technology Program (MWTP). The MWTP is conducted under an interagency agreement, IAG ID No. DW89938513-01-0, between the US EPA and the US DOE, Contract No. DE-AC22-96EW96405.

PAPER 5.5 — 16:40

APPLICATION OF LIGNOSULPHONATES IN TREATMENT OF ACIDIC ROCK DRAINAGE.

J.M. ZHUANG and T. WALSH, Noram Engineering and Constructors Ltd., Vancouver, British Columbia, Canada

Lignosulphonates, by-products of the sulphite pulping process, have been utilized in a process to treat acidic rock drainage (ARD). This process is referred to as the Lignor process. In the present study, lignosulphonates were found to protect lime from developing an external surface coating, and hence to favour its dissociation. Further, the addition of lignosulphonates to ARD solutions increased the clotting and settling rate of the formed sludge. The capability of lignosulphonates to form stable metal-lignin complexes makes them very useful in retaining metal ions and thus improving the long-term stability of the sludge against leaching. The Lignor process involves metal chelation with lignosulphonates, ARD neutralization by lime to about pH 7, pH adjustment with caustic soda to 9.4 to 9.6, air oxidation to lower the pH to a desired level, and addition of a minimum amount of $FeCl_3$ for further removal of dissolved metals. The Lignor process removes all concerned metals (especially Al and Mn) from the ARD of the Britannia mine (located at Britannia Beach, British Columbia, Canada) to a level lower than the limits of the BC Regulations. Compared with the high-density sludge (HDS) process, the Lignor process has many advantages, such as considerable savings in lime consumption, greatly reduced sludge volume, and improved sludge stability.

SESSION 6: INTERNATIONAL SYMPOSIUM ON HYDROMETALLURGY IN HONOUR OF PROFESSOR IAN RITCHIE

LEACHING I: CYANIDE AND ALTERNATIVES I

Sponsors: Hydrometallurgy Section of The Metallurgical Society of CIM (MetSoc), Extraction and Processing Division, The Minerals, Metals and Materials Society (TMS), and the Society for Mining, Metallurgy and Exploration (SME)
Room: Junior Ballroom C
Chairmen: B. STAUNTON, A. J. Parker Centre for Hydrometallurgy, Murdoch University, Murdoch, WA, Australia, J. HOLLOW, Fairbanks Gold Mining, Inc., Fairbanks, AK, USA

PAPER 6.1 — 15:00

OPTIMIZING CYANIDATION PARAMETERS FOR PROCESSING OF BLENDED FORT KNOX AND TRUE NORTH ORES AT THE FORT KNOX MINE.

J. HOLLOW, Fairbanks Gold Mining Inc., Fairbanks, Alaska, U.S.A.,
G. DESCHENES, M. FULTON, H. GUO, CANMET, Natural Resources Canada, Ottawa, Ontario, Canada,
J. McMULLEN and E. HILL, Barrick Gold, Toronto, Ontario, Canada

The Fort Knox mine is an open-pit operation, located in Alaska, which started commercial production in March 1997. A conventional mill processes 38 000 tpd of a low-grade (1.0 g/t Au) free-milling gold ore with a low sulphide component (below 1%). Gold production (11% fro\m gravity and 89% from cyanidation) exceeds 400 000 ounces per year. Short retention time (20 h), low temperature (7°C) and low grade make high leaching kinetics critical for the performance of the process. In April 2001, the treatment of True North ore, which represented 14.4% of the mill throughput and contains more sulphide in the form of pyrite, arsenopyrite and stibnite, resulted in a substantial drop in the average gold extraction from 87% to 72.6%. Laboratory investigations indicated that the addition of lead nitrate increased gold extraction to 91.7%. Further investigations were initiated to determine the leaching parameters and the nature of the problem. Subsequently, a lead nitrate addition scheme was implemented at the Fort Knox Mill that resulted in 2002 gold production being in excess of 31 000 oz higher than that estimated for the non-lead nitrate reagent scheme. This paper presents the results of laboratory investigations and modifications in plant operating practices.

PAPER 6.2 — 15:25

EFFECT OF CARBONACEOUS COATINGS ON PREG-ROBBING OF CHALCOPYRITE.

H. TAN, D. FENG and J.S.J. VAN DEVENTER, Department of Chemical Engineering, University of Melbourne, Melbourne, Parkville, Victoria, Australia

Preg-robbing is the active adsorption of gold from cyanide solution by the ore components. The role of carbonaceous coatings on chalcopyrite surfaces in the preg-robbing of chalcopyrite has been investigated by using pure chalcopyrite and a copper concentrate. Activated carbon and graphite were chosen as representative carbonaceous contaminants. The effect of pH, initial aurocyanide concentration, contaminant contents and particle size was studied in detail. It was found that the carbonaceous coatings enhanced the preg-robbing of chalcopyrite. Activated carbon coating increased gold adsorption onto chalcopyrite to a lager extent, in comparison with graphite coating. Gold adsorption increased with a decrease in particle size, due to carbonaceous matter being readily coated on the chalcopyrite surfaces. Similarly, preg-robbing was enhanced when chalcopyrite was coated with higher carbon contents due to increased chance of coating. The preg-robbing of chalcopyrite or chalcopyrite with graphite coating was reduced or eliminated, depending on the concentrations of free cyanide. However, the gold adsorption on the carbon-coated chalcopyrite could not be avoided even at higher cyanide concentrations, and this adsorption was solely attributed to the carbon coating. Zeta potential studies indicated that the carbonaceous coatings reduced the negativity of chalcopyrite surface charge. As shown by SEM analysis, gold not only accumulated at the edges and defect sites, but was also spotted on the smooth surfaces of chalcopyrite with carbon or graphite present. XPS results revealed that gold was strongly reduced on chalcopyrite surfaces, with sulphide ions of the chalcopyrite being oxidized to elemental sulphur. Diagnostic elution indicated three mechanisms contributing to gold take-up by chalcopyrite, i.e., gold reduction, physical adsorption and chemical adsorption, which are in accordance with the reaction energies obtained by ab initio calculations.

PAPER 6.3 — 15:50

SURFACE-ENHANCED RAMAN SPECTROSCOPY OF GOLD DISSOLUTION IN CYANIDE.

K.M. WATLING, G.A. HOPE and R. WOODS, School of Science, Griffith University, Brisbane, Queensland, Australia

Electrochemically roughened silver, copper, and gold surfaces greatly enhance the intensity of Raman scattering from molecules adsorbed upon, or in close proximity to, the metal surface. The technique of surface-enhanced Raman scattering (SERS) provides an excellent in situ method of observing vibrational characteristics of surface species during gold dissolution processes. The SERS technique allows rapid acquisition of spectra during voltammetric scans, enabling real-time observation of vibrational data. The dependence of vibrational frequency upon potential, known as Stark-tuning, provides qualitative information regarding the nature of the chemical bonding and orientation of surface species. A significant variation of Raman background intensity is seen during the acquisition of potentiodynamic SERS spectra. Elucidation of relationships between Raman background and optical properties of the adsorbate-modified gold surface may facilitate development of a novel surface-sensitive technique. The potentiodynamic SERS technique is readily extended to alternative gold lixiviant systems.

PAPER 6.4— 16:15
THE LINK BETWEEN HYDROMETALLURGY AND GRAVITY RECOVERY.
A.R. LAPLANTE, Department of Mining, Metals and Materials, McGill University, Montréal, Québec, Canada, and
W. STAUNTON, AJ Parker Cooperative Research Centre for Hydrometallurgy, Murdoch, Australia, Australia
Gravity recovery is possibly the oldest means of recovering metals, whereas, hydrometallurgy has matured only in the second half of the last century. Recent advances in gravity technology and a better understanding of its benefits has increased its visibility and use, and as a result it now interfaces intimately with hydrometallurgy, in particular for gold recovery. This contribution reviews these mostly recent developments: intensive cyanidation of gravity concentrates from the grinding circuit or from cyanidation residues, the former containing largely gravity recoverable gold and the latter gold in gold carriers. Existing and developing practice is described, and its present and future impact on overall (i.e., full ore) gold recovery is discussed. Research needs are examined — response of secondary gold minerals such as tellurides to intensive cyanidation, use of alternate gold lixiviants to treat gravity concentrates, and application of the gravity-leach approach to other systems such as PGEs.

SESSION 7: INTERNATIONAL SYMPOSIUM ON HYDROMETALLURGY IN HONOUR OF PROFESSOR IAN RITCHIE

LEACHING II: ELECTROCHEMISTRY I

Sponsors: Hydrometallurgy Section of The Metallurgical Society of CIM (MetSoc), Extraction and Processing Division, The Minerals, Metals and Materials Society (TMS), and the Society for Mining, Metallurgy and Exploration (SME)

Room: Junior Ballroom D

Chairmen: A. A LFANTAZI, Metals and Materials Engineering, Univeristy of British Columbia, Vancouver, BC
K. OSSEO-ASARE, Pennsylvania State University, Materials Science and Engineering, University Park, PA, USA

PAPER 7.1 — 15:00
ELECTROCHEMISTRY: THE KEY TO UNDERSTANDING HYDROMETALLURGICAL REACTIONS.
M.I. JEFFREY, Chemical Engineering, Monash University, Clayton, Victoria, Australia,
S. ROBERTSON, Chemistry Department, James Cook University, Townsville, Queensland, Australia,
H. ZHANG, Murdoch University, A.J. Parker CRC for Hydrometallurgy, Murdoch, Western Australia, and
E. HO, Australian Nuclear Science and Technology Organisation, Menai, New South Wales, Australia
Leaching, cementation, electroplating and flotation are all electrochemical phenomenon. They are also key processes in the hydrometallurgical treatment of metals. Unfortunately electrochemical methods tend to be under-utilized when studying these processes and one possible reason for this is the confusion surrounding the large number of electrochemical techniques available. In this paper, four former Ph.D. students of Professor Ian Ritchie present an insight into how one electrochemical technique can be used to compliment rate/kinetic studies. The paper details how to perform the experiments, interpret data, and recognize complications with the results. Examples where this approach has been highly successful are presented, and include: cementation of zinc by aluminum, cementation of copper by nickel, cyanide leaching of gold and the cementation of gold thiourea by mild steel. The examples illustrate that this universal approach adopted by Ian Ritchie provides the key to understanding the mechanism of many hydrometallurgical reactions.

PAPER 7.2 — 15:25
LIMITATIONS FOR THE USE OF EVANS' DIAGRAMS TO DESCRIBE HYDROMETALLURGICAL REDOX PHENOMENA.
R.M. LUNA-SÁNCHEZ, G.T. LAPIDUS, Universidad Autónoma Metropolitana-Iztapalapa, San Rafael Atlixco, Vicentina, México, and
I. GONZÁLEZ, Universidad Autónoma Metropolitana-Iztapalapa, Vicentina, México
Electrochemical studies, particularly Evans' diagrams, have been employed in hydrometallurgy to simulate and explain the redox phenomena that take place at mineral and metal surfaces during operations such as leaching and cementation. However, despite their utility, in some cases, the combination of the cathodic and anodic branches, determined separately, does not reproduce the chemical environment present when both processes occur simultaneously on a specific surface. In the present paper, limitations of Evans' diagrams are analyzed through two examples: silver sulphide cyanidation and gold cementation on zinc. In both cases, the surface kinetics are sensitive to the local pH and cyanide levels. When the electrochemical oxidation of silver sulphide or the reduction of gold are performed in the absence of its corresponding redox reaction, the local pH obtained does not simulate the real situation and the combined reaction kinetics may be very different from those determined from the Evans' diagrams.

PAPER 7.3 — 15:50
HYDROGEN REDUCTION OF METAL IONS: AN ELECTROCHEMICAL MODEL.
K. OSSEO-ASARE, Pennsylvania State University, University Park, Pennsylvania, U.S.A.
Rate laws for the hydrogen reduction of metal ions are typically of the form:

$$r = -d[M(II)]/dt = k[M(II)] P_{H_2}$$

where k is an apparent rate constant, [M(II)] and P_{H_2} represent dissolved metal concentration and hydrogen pressure respectively, while x = 0 – 1 and y = 0.5 - 2. Half-order dependences have been reported for some M(II)/H_2 systems; however, no satisfactory explanations have been offered. In an effort to bridge this gap in our understanding, the published precipitation rate data (for M(II) = Cu(II), Ni(II), and Co(II)) are reviewed (with emphasis on the reported reaction orders) and compared with the corresponding but limited electrochemical polarization data. Based on the available literature on the electrochemical kinetics of the M/M(II) and H_2/H^+ systems it is demonstrated theoretically that, under certain conditions (e.g., in the presence of electron-conducting solids), the M(II)/H_2 reaction can be expressed as:

$$-d[M\quad]/dt = kP_{H_2}[M\quad]$$

It is concluded that electrochemical processes probably play an important role in the hydrogen reduction of metal ions, especially for systems that involve heterogeneous catalysis.

PAPER 7.4 — 16:15

ALLOY FORMATION DURING THE CEMENTATION OF GOLD ON COPPER FROM AMMONIACAL THIOSULPHATE SOLUTIONS.

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Gold-copper alloys are shown to form during the cementation of gold on copper in an ammoniacal thiosulphate solution containing 0.25 M [$S_2O_3$2-] at 25°C. The alloy composition is strongly dependent on the initial Cu:Au ratio in solution and ranges from Au_3Cu to $AuCu_3$. XPS results for Au, Cu, S, N, and O are reported as a function of depth through an entire deposited film. Underpotential deposition (UPD) theory is discussed as a mechanism for explaining the formation of these alloys. Several other systems that produce alloys during contact reduction/cementation are also discussed.

PAPER 7.5 — 16:40

CEMENTATION REACTIONS.

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Cementation or metal displacement reactions such as Cu_2+ + Zn = Cu + Zn_2 + are among the oldest known hydrometallurgical reactions. They are still used in the recovery of some metals and in the purification of process liquors and waste water streams. However, they are often more complex than the stoichiometric reaction would suggest because they involve the simultaneous deposition of one metal onto a second which is dissolving. For example, sometimes a cementation reaction will not take place, even though it is thermodynamically favoured. On other occasions, a cementation reaction will start but come to a halt as the depositing metal blankets the reacting surface. On yet other occasions, side reactions, catalyzed by the deposit, can be important. In this paper, the electrochemical basis of cementation reactions is described. The conditions for each of the complications encountered in these reactions are described and illustrated by examples drawn from a number of processes which have been used in the past, or are still in use, or have been proposed.