



ADVANCE MAILER

2003 International Symposium on
Hydrometallurgy in Honor of Professor Ian Ritchie

August 24–27, 2003
Vancouver, British Columbia,
Canada

Combining the 2003
TMS Fall Extraction & Process
Metallurgy Meeting and the
33rd Annual Hydrometallurgical
Meeting of the Metallurgical
Society of CIM

TMS



www.tms.org

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Sponsored by the Extraction & Processing Division of The Minerals, Metals and Materials Society (TMS), and co-sponsored by the Metallurgical Society of the Canadian Institute of Mining, Metallurgy and Petroleum (MetSoc) and the Society for Mining, Metallurgy and Exploration (SME), this conference will be the Fifth International Symposium on Hydrometallurgy.

Now held every 5 years, this symposium is the preeminent forum for the exchange of recent scientific and technological developments impacting the state-of-the-art of hydrometallurgy science and technology. This conference is being held in conjunction with the Metallurgical Society of CIM, 2003 Conference of Metallurgists.

This symposium will honor Dr. Ian Ritchie for his pioneering contributions to hydrometallurgical research and his lifelong devotion to education in the field of electrochemistry, oxidation and kinetics. During his outstanding career, he has been a teacher, mentor, advisor, editor, researcher, consultant, reviewer, industrial collaborator, patent holder, etc. In addition, he has championed the creation of the A.J. Parker Cooperative Research Centre for Hydrometallurgy, a leading international research organization, and served as its first director.

CONFERENCE SCHEDULE (subject to change)

Friday, August 22, 2003:

7:00 am–8:30 am Hydro 2003 Short Course Registration
8:30 am–5:00 pm Hydro 2003 Short Course

Saturday, August 23, 2003:

7:00 am–8:30 am Corrosion Short Course Registration
8:30 am–5:00 pm Corrosion Short Courses

Sunday, August 24, 2003:

8:00 am–4:00 pm Short Courses
3:00 pm–8:00 pm Registration
5:00 pm–7:00 pm Metals 2003 Trade Show
5:00 pm–7:00 pm Opening Reception

Monday, August 25, 2003:

7:30 am–5:00 pm Registration
8:00 am–4:00 pm Companions Program
8:00 am–4:00 pm Poster Session
8:00 am–4:00 pm Metals 2003 Trade Show
8:30 am–10:20 am General Plenary Session
2:00 pm–5:00 pm Technical Program
5:00 pm–7:00 pm Industry-Student Mixer ** by invitation only**
6:00 pm–11:00 pm Hydro 2003 Dinner Cruise

Tuesday, August 26, 2003:

7:30 am–5:00 pm Registration
8:00 am–4:00 pm Companions Program
8:30 am–5:00 pm Technical Program
12:00 pm–2:00 pm MetSoc Section Lunches
6:00 pm–7:00 pm Awards Banquet Reception
7:00 pm–10:00 pm Awards Banquet

Wednesday, August 27, 2003:

7:30 am–5:00 pm Registration
8:00 am–4:00 pm Companions Program
8:30 am–5:00 pm Technical Program
12:00 pm–2:00 pm Hydro 2003 Lunch in Honor of Ian Ritchie

Thursday, August 28, 2003:

6:30 am–9:00 pm Industrial Tour 1: Cominco Trail
Smelter and Refinery
7:30 am–5:30 pm Industrial Tour 2: CESL Pilot Plant
and Canadian Autoparts Toyota



ACCOMMODATIONS:

The conference will be held at the Sheraton Vancouver Wall Centre Hotel. A limited number of dorm beds are also available at the Vancouver Youth Hostel for those on a tight budget. Please refer to the registration form for reservations.

REGISTRATION:

Delegate registration fees include:

Admission to the technical sessions and a copy of the conference program guide. Each delegate will receive a ticket to the Opening Reception, to a Technical Section Lunch on Tuesday and a ticket to the Tuesday evening Awards Banquet. Exhibitors will receive one ticket to a technical Section Lunch on Tuesday and one banquet tickets. Students will receive complimentary tickets to the Opening Reception and a Technical Section Lunch ticket. Those registered in the Companions' Program receive one ticket to the Opening Reception.

CANCELLATION POLICY:

Written notice of cancellation must be sent to the Conference Registration postmarked no later than August 11, 2003. A \$50 processing fee will be charged for all refund requests. No refunds will be issued after August 11, 2003.

GOODS AND SERVICES TAX (GST):

The Canadian Goods and Services Tax (GST) is a 7% tax that is added to all goods and services purchased while in Canada. Non-resident visitors to Canada can claim a rebate of GST paid on certain goods and accommodations. For non-resident visitors, "Tax Refund for Visitors" booklets will be enclosed with registration confirmation.

ON-SITE REGISTRATION:

Pre-registered delegates and companions may pick up their badges, programs and tickets at the Conference Registration Desk in the Sheraton Vancouver Wall Centre Hotel. Tickets for social events and industrial tours may also be obtained at the Conference Registration Desk.

The Registration Desk will be open at the following times:

Friday, August 22, 2003 7:00 am–8:30 am
(Short course registration only)

Saturday, August 23, 2003 7:00 am–8:30 am
(Short course registration only)

Sunday, August 24, 2003 3:00 pm–8:00 pm

Monday, August 25, 2003 7:30 am–5:00 pm

Tuesday, August 26, 2003 7:30 am–5:00 pm

Wednesday, August 27, 2003 7:30 am–5:00 pm

PLENARY SESSION:

Distinguished speakers will give us their views on important metallurgy and materials issues.

Confirmed speakers include:

Advanced Materials for CANDU Reactors
D.F. Torgerson
Senior Vice-President Technology
AECL
Chalk River, Ontario, Canada

Challenges for Hydrometallurgy
in Environmental and Health Stewardship
B. Conrad
Vice-President
Environmental and Health Sciences
Inco Limited
Toronto, Ontario, Canada

SYMPOSIA HIGHLIGHTS:**2003 INTERNATIONAL SYMPOSIUM
ON HYDROMETALLURGY**

Symposium in Honor of Ian Ritchie, combining the 2003 TMS Fall Extraction and Processing Metallurgy Meeting and the 33rd Annual Hydrometallurgical Meeting of the Metallurgical Society of CIM.

Chairman: Courtney Young

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

This symposium provides a forum for hydrometallurgists from around the world to gather, present papers, and network. Sessions will cover fundamentals, biohydrometallurgy, leaching, environmental applications, solution concentration and purification, cyanide and alternatives for precious metal extraction and recovery, process development and modeling, thermodynamic and kinetic evaluations, plant practices and innovations, waste treatment and minimization, waste water and resource recovery, electrometallurgy, process mineralogy, and economic evaluations.

For more information, contact:

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**INTERNATIONAL SYMPOSIUM ON
TRANSFORMATION AND DEFORMATION
MECHANISMS IN ADVANCED
HIGH-STRENGTH STEELS**

*Chairmen: Mattias Militzer, Warren Poole
and Elhachmi Essadiqi*

Sponsor Section: Iron and Steel

Advanced high-strength steels are increasingly being utilized to improve the quality of products for transportation, construction and packaging sectors. The novel properties of these steels, e.g. dual phase and TRIP steels, draw on complex transformation behavior and associated deformation mechanisms. In this symposium, the focus will be on the fundamentals of phase transformation and mechanical behavior. In addition, the application of these fundamental concepts to production and utilization of these steels will be considered.

Papers are invited related to the following topics:

- Fundamental physics of phase transformation and deformation behavior
- Modeling of phase transformation kinetics
- Mechanisms of phase transformation during deformation
- Processing of advanced high-strength steels
- Novel aspects of formability
- Microstructural evolution during welding

For more information, contact:

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LIGHT METALS 2003 METAUX LEGERS

Chairman: Jacques Masounave

Sponsor Section: Light Metals

The Light Metals Section of the Metallurgical Society will be sponsoring the Light Metals 2003 Metaux Légers in Vancouver. A special emphasis will be placed on the quality control of processes. In addition, the meeting will focus on topics related to:

- Reduction technologies
- Carbon technologies
- Alloys development
- Casting and solidification
- Properties and applications of light metals
- Hot working
- Corrosion
- Modification of microstructures
- Magnesium technologies
- Metals matrix composites

For more information, please contact:

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**SECOND INTERNATIONAL SYMPOSIUM
ON ENVIRONMENTAL DEGRADATION
OF MATERIALS AND CORROSION
CONTROL IN METALS (EDMCCM)**

*Chairmen: Jingli Luo, Mimoun Elboujdaini,
David Shoosmith and Prakash Patnaik*

*Sponsor Section: Materials Performance
and Integrity*

The first International Symposium on Environmental Degradation of Materials and Corrosion Control In Metals, held in Québec City in 1999, was very successful and there were great hopes that it would be repeated after a suitable interval. The Second International Conference on EDMCCM 2003, with extended subject coverage, is now to be held in Vancouver, British Columbia, Canada, in August 2003. The objective of this conference is to provide a forum for discussion on state-of-the-art development of a variety of approaches to the understanding of corrosion damage as well as environmental degradation of metals. The close interaction of theory and practice will be examined from chemical, mechanical and metallurgical viewpoints. This symposium is intended to foster discussion of corrosion and effects on metals and to very worthwhile exchanges and new insights.

The following topics will be covered at the conference. However, papers on the other topics are equally welcome.

- Corrosion
- Stress-corrosion cracking and hydrogen embrittlement
- Corrosion fatigue
- Localized corrosion
- Wear and erosion corrosion
- Tribology
- High temperature corrosion
- Pulp and paper industry
- Light metals
- Composite materials
- Surface coatings and advanced coatings
- Corrosion monitoring techniques

For more information, contact:

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**SECOND INTERNATIONAL SYMPOSIUM
ON ECOMATERIALS AND ECOPROCESSES**

Chairman: Hamid Mostaghaci

Sponsor Section: Materials Science and Engineering

- Materials Life Cycle Analysis
- Design technologies for materials recycling
- Design materials for environment
- Green materials processing technologies
- Technologies for remediation of green house gases
- Sustainable development criteria for metals and minerals
- Global environmental policy initiatives regarding sustainable development

For more information, please contact:

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**FUTURE EDUCATION NEEDS
AND DELIVERY STRATEGIES FOR THE METALS
AND MATERIALS SECTOR**

Chairmen: Robin Drew and Chris Twigge-Molecey

Sponsor Section: Management in Metallurgy

Metals and Materials Education and Delivery Strategies Metallurgy and Materials Engineering education is going through a period of transition in Canada as the economy evolves into more downstream and high-tech activities. The future educational needs of the discipline will be explored from both the academic and industrial perspective. In addition, the need, potential and required support for the use of distance education for teaching and learning, in particular, for the primary processing and extractive industry, both nationally and internationally, will be addressed.

For more information, contact:

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PLENARY SESSION:

CHALLENGES FOR HYDROMETALLURGY IN ENVIRONMENTAL AND HEALTH STEWARDSHIP:

Dr Bruce R. Conard

Consideration of environmental and human health issues in metallurgy is growing rapidly. While not all metallurgists need to have detailed expertise in environmental and health questions, they should be aware of the challenges the metals industry faces, be able to interact with colleagues in other sciences and contribute to sound metal resource management. Hydrometallurgists occupy a unique position among metallurgists because of their knowledge of the behaviour of metals in aqueous systems, which are of fundamental importance in understanding environmental chemistry and human toxicology. As a result, hydrometallurgists should more frequently and passionately lend their expertise in assessing environmental and health risks of metals and in helping to develop effective global guidelines, regulations and process and product stewardship strategies, thereby enabling metals to continue their beneficial service to society.

BIOTECHNOLOGY FOR SUSTAINABLE HYDROMETALLURGY:

Johannes Boonstra

High rate bacterial catalyzed processes can serve to improve hydrometallurgical operations. These solutions are not only economical but also environmental sustainable. With references around the globe, the value of this new approach is recognized by industry worldwide. For instance, metals can safely and economically be recovered from process and waste streams using biotechnologically produced sulfide, resulting in a valuable product instead of a waste stream for disposal. Both the natural biological sulfur and nitrogen cycles offer bacterial routes that are applied to advantage on industrial scale. The shared advantage of these processes is that waste compounds are converted in either a reusable raw material or in a harmless product. This way, natural product cycles can be closed. Sulfur cycle: Bioleaching, reduction of oxidized sulfur compounds to elemental sulfur, thio-salts regeneration, metal recovery with biogenic produced H₂S, SO₂ removal from gas streams, etc. Nitrogen cycle: Ammonia removal using the anamox-process, biological removal of NO_x from gas streams, nitrate removal from water streams, etc. Besides the applications mentioned above, bacterial processes for reduction of metals such as uranium, selenium and manganese have proven to offer great potential for clean-up of groundwater streams. The paper and presentation will contain a description of the above applications. Further, a short introduction on the fundamentals of microbial conversions, the design of engineered high rate bioreactor systems and a techno-economical description of an industrial application of biotechnology in metallurgy will be provided.

BUSINESS ASPECTS AND FUTURE OUTLOOK FOR HYDROMETALLURGY:

Doug Halbe

"Many are called, but few are chosen." The biblical adage applies not only to life, but also to hydrometallurgical processes. There have been, in the past, many outstanding successes with new processes - and also some dismal failures. What are the odds of success for a new process? When there have been problems, why? What can you do to make sure these problems don't occur with your process? What effect will a slow start-up have on project economics? How do banks - the people who loan your company money for the project - feel about new processes, and why? Is it possible to predict or estimate the time required to reach design parameters...and if so, how do you sell this estimate to management - and banks? Probably most important - when do you start thinking about the answers to these questions?

IS EXTRACTIVE METALLURGY BECOMING EXTINCT?

Prof. Ian M. Ritchie

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.



SHORT COURSES:

Hydrometallurgy

The Hydrometallurgy 2003 Short Course is designed to provide broad and deep instruction in the fundamentals and application of hydrometallurgy. The course will start at 8:00 AM on Friday August 22, 2003 and run through Sunday August 24th. The fee for this 3-day course is \$1000 (CDN), or \$500 for students. You may register via the conference registration form.

Friday, August 22, 2003

- Introduction to Hydrometallurgy (1 hr), (Ian Ritchie - Parker Centre)
- Thermodynamics of Hydrometallurgical Systems (1 hr), (Vlad Papangelakis - University of Toronto)
- Thermodynamic and Computational Modeling of Aqueous Systems (1hr), (H.H. Huang - Montana Tech)
- Leaching Kinetics (1 hr), (Corby Anderson - CAMP)
- Engineering Theory of Leaching (1 hr), (Lynton Gormely - AMEC)
- Mixing Theory for Hydrometallurgy (1 hr), (David Dixon - UBC)
- Liquid Solids Separation (1 hr), (Ben Pocock - Pocock Industrial)
- Cementation and Purification (1 hr), (George Demopoulos - McGill University)

Saturday, August 23, 2003

- Solvent Extraction and Ion Exchange (1 hr), (Kathy Sole - Anglo American Research Laboratory)
- Electrowinning and Refining Practice (1 hr), (Alberto Gonzalez - Teck Cominco)
- Hydrogen Reduction of Metals (1 hr), (Roman Berezowsky - Dynatec)
- Nickel and Cobalt Electrowinning and Refining (1 hr), (Bruce Love - INCO Limited)
- Applications of Biohydrometallurgy - Leaching (1 hr), (David Drew - BHP Billiton Research)
- Applications of Biohydrometallurgy - Environment (1 hr), (Rick Lawrence - Bioteq)
- Hydrometallurgy and the Environment (1 hr), (Courtney Young - Montana Tech)
- Case Study 1: Copper Leach/SX/EW Practice. (1.5 hr), (Jim Sorensen - AMEC Engineering)

Sunday, August 24, 2003

- Case Study 2: The Hydrometallurgy of Zinc Sulfide and Oxide Ores. (1.5 hr), (Dan Ashman - Teck Cominco)
- Case Study 3: The Hydrometallurgy of Nickel Sulfides and Laterites. (1.5 hr), (Roman Berezowsky - Dynatec)
- Case Study 4: The Leaching and Recovery of Gold from Ores and Concentrates. (1.5 hr), (Chris Fleming - Lakefield Research)
- Case Study 5: The Leaching of Bauxites and Recovery of Alumina in the Bayer Process. (1.5 hr), (Peter Smith - CSIRO Minerals)
- Case Study 6: The Leaching of Magnesium from Various Feedstocks and the Recovery of Product for Electrolysis. (1.5 hr), (Bryn Harris - Consultant).

For further information on this course:

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Corrosion And Its Control

This course will offer two-days (Saturday and Sunday) of technical sessions by experts in corrosion. It is intended for scientists, engineers, technologists, maintenance personnel and managers who need an overview of current knowledge on corrosion science and technology. This course theme will be focused on the whole range of corrosion-resistant alloys, and the contents will be geared to the day-to-day practice of materials engineers in different fields and process industries. Presentations and workshops will give you answers to questions related to corrosion and material degradation. More importantly, key instructors are invited to share their expertise on how you can best manage your materials costs while improving materials performance and reliability.

Saturday, August 23, 2003

AM Basic Corrosion

- Overview of Corrosion
- Electrochemical Corrosion
- Types of Corrosion (general, localized, bi-metallic)

- Metallurgical Aspects of Corrosion and Its Control
- Environmental Induced Cracking
- Cathodic and Anodic Protection of Municipal Infrastructure
- Methods of Corrosion Control
- Corrosion Control in Soils
- Detecting and Monitoring Corrosion. PM Hydrogen-induced Cracking and Hydrogen Embrittlement in Steel
- Introduction and Definitions
- Extent of Problem
- Mechanism
- Laboratory Testing Methods
- Field and Plant Monitoring Techniques
- Inspection and Techniques
- Metallurgical Control
- Environmental Control Options
- References; including references to failures in pipelines and pressure vessels, plus references to hydrogen damage in pipelines, other tubular goods, and pressure vessel plates.

Sunday, August 24, 2003

Microbiologically Influenced Corrosion (MIC) of Metals

- What is MIC?
- What Micro-organisms are responsible?
- MIC in water systems, fire protection systems, oil pipelines, cooling water, etc.
- Detection and Diagnosis
- Monitoring
- Prevention and Mitigation.

For further information on this course contact:

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Short courses will be held between Friday, August 22 and Sunday, August 24, 2003.

All short courses will have a limited number of people to ensure adequate opportunity for all participants to ask questions, engage in discussions and converse on a one-to-one basis with the experts. To ensure that you are on the leading edge of technology, register early.

Hydrometallurgy Short Course (3 days)- \$1,000 Regular, \$500 Students (Proper ID required) Corrosion and it's Control Short Course (2 days) - \$700 Regular, \$350 Students (Proper ID required)

The registration fee includes all applicable taxes, the course notes, coffee breaks and lunches. The number of participants is limited and individuals and organizations are urged to register early as places are limited and on-site registration is not guaranteed. Substitutions are encouraged.



PROCEEDINGS:

HYDROMETALLURGY 2003:
5th International Symposium in Honor
of Professor Ian Ritchie

*C.A. Young, A.M. Alfantazi, C.G. Anderson,
D.B. Dreisinger, B. Harris, and A. James, editors*

The preeminent forum for the exchange of recent scientific and technological developments impacting the state-of-the-art of hydrometallurgy science and technology, the 2003 International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie combines the 2003 TMS Fall Extraction & Process Metallurgy Meeting and the 33rd Annual Hydrometallurgical Meeting of the Metallurgical Society of the Canadian Institute of Mining, Metallurgy and Petroleum.

This collection of papers, available as a set of two hardcover volumes and a text-searchable CD-ROM, documents presentations from this influential forum for industry, government, academic, and administrative personnel interested in all facets of hydrometallurgy and its application to metal recovery and water purification.

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METALS 2003 TRADE SHOW:

For more information, please contact:

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SOCIAL PROGRAMS:

Reception:

All delegates are invited to attend the Opening Reception on Sunday, August 24 and to visit the Metals 2003 Trade Show.

Industry-Student Mixer:

On Monday evening, representatives from industry and students are invited to meet informally.

Hydro 2003 Boat Cruise:

Enjoy your Monday evening watching the sights of Vancouver – the infamous Kitsilano “Muscle” Beach, Jericho Sailing Club, “Millionaire Row”, which is the wealthiest region in Canada, and Stanley Park, the second-largest urban park in North America. Tickets must be purchased separately (see registration form) and are not included in the general conference registration fee.

Section Lunches:

On Tuesday, August 26, MetSoc’s technical sections, along with several standing committees will host special lectures and business meetings, between 12:00pm and 2:00pm.

Awards Banquet:

On the evening of Tuesday, August 26, the MetSoc will honor its outstanding contributors by presentation of the Society Awards and Fellowships. The evening will feature the inauguration of the new Metallurgical Society President, Andre Allaire.

Hydro 2003 Lunch:

Sit down lunch on Wednesday, August 27 for Hydro 2003 participants in honor of Ian Ritchie. Tickets for this lunch must be purchased separately (see registration form) and are not included in the general conference registration fee.

COMPANIONS PROGRAM:

Price: \$275 per person

Each tour includes a guided deluxe motorcoach, admission fees where applicable, meals where indicated, taxes and gratuities. This program requires a minimum of 13 attendee to proceed. Awards banquet tickets for companions may be purchased at the registration desk or through the registration form.

Sunday, August 24, 2003

- COM 2003 Opening Reception.

Monday, August 25, 2003

- Light breakfast.
- Welcome to Vancouver Orientation Tour – get acquainted with West Coast style and the beauty of Vancouver. You will be introduced to the colorful shopping of Robson Street, the vastness of the Pacific Ocean at English Bay, the spectacular beauty of Stanley Park, the scents and sounds of bustling Chinatown, and the history of Gastown.
- Lunch at “Bridges” on Granville Island and free time to explore/shop Granville Island, home to artists’ galleries and shops, quaint boutiques, an amazing market, and lots of street entertainment.
- Return to hotel.

Tuesday, August 26, 2003

- Light breakfast.
- North Shore Tour – This tour of the North Shore of Vancouver will leave you astounded by the majestic mountains and trees that surround the city. Crossing the Lion’s Gate Bridge, travel to the top of Capilano Road to Grouse Mountain where you will be invited to boar the skyride to the “Peak of Vancouver”. Nature walks and a fantastic film presentation will beckon you to the top of the mountain. Next, travel down Capilano Road to the Capilano Suspension Bridge. Crossing the bridge, you will have amazing views of Grouse Mountain and the valley below. Across the bridge, interactive nature and interpretive walks are available to take at your leisure.
- Lunch at the “Bridge House” (Capilano Suspension Bridge).
- Return to hotel.

Wednesday, August 27, 2003

- Light breakfast.
- Stanley Park Nature Tour – Experience the wonders of Vancouver’s Stanley Park with an informative, entertaining and multi-lingual guide. Learn all about British Columbia’s rain forest ecosystem. See the steam rise from the forest floor and discover lichen, moss, fern, and flowering plants that grow under the mantle of some of the oldest and largest Douglas-Fir, Cedar and Hemlock trees.
- Snack and drink. ■ Return to hotel.
- Free afternoon.

INDUSTRIAL TOURS:

Industrial tours will take place on Thursday, August 28th, 2003. Each tour includes transportation and lunch and is limited to a maximum number of participants. Tours will be filled on a first-come, first-served basis.

Industrial Tour 1:

Cominco Trail Smelter and Refinery

Cominco Trail is the world’s largest fully-integrated zinc and lead smelting and refining complex with capacities of 300,000 t/a zinc and 120,000 t/a lead. The Trail complex is also a significant producer of silver, gold, indium, germanium, bismuth and copper products.

This tour includes a flight to Castlegar, chartered bus and meal and requires a minimum of ten (10) participants. Participants will be selected on a first-come first-served basis.

Departure:

6:30 from Vancouver Sheraton Wall Centre entrance

Return:

21:00 at the Vancouver Sheraton Wall Centre entrance

Price: \$600

Industrial Tour 2:

CESL Pilot Plant and Canadian Autoparts Toyota

CESL has developed a hydrometallurgical process for the refining of copper and/or nickel from sulphide concentrates. The pilot plant serves to determine the process feasibility for a given concentrate.

Canadian Autoparts Toyota employs 230 people and produces over a million wheels per year by low pressure die casting, TDP die casting, machining and painting.

Departure:

7:30 from Vancouver Sheraton Wall Centre entrance

Return:

17:30 at the Vancouver Sheraton Wall Centre entrance

Price:

\$77

For more information contact:

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Order the Official Proceedings of the Hydro 2003 Conference!

**HYDROMETALLURGY 2003:
5th International Symposium in Honor of Professor Ian Ritchie**

C.A. Young, A.M. Alfantazi, C.G. Anderson, D.B. Dreisinger, B. Harris, and A. James, editors

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Sale Price: \$40

EPD CONGRESS 1998

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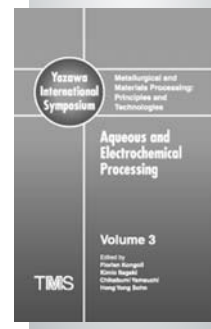
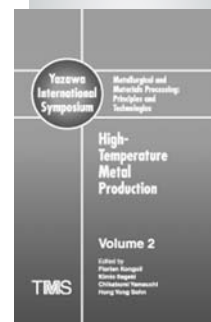
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REGISTRATION FORM

COM 2003 – August 24-27, 2003
Vancouver, British Columbia, Canada

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CONFERENCE FEE		Before June 30	After June 30
A.	CIM Member (includes events 1,3,4)	\$700	\$800
B.	Sister Society Member (incl. events 1,3,4)	\$700	\$800
C.	Author / Session Chair (incl. events 1,3,4)	\$700	\$800
D.	Non-member (incl. events 1,3,4)	\$850	\$950
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I.	Exhibitor (incl. events 1,3,4)		
	Booth # _____ (1 free/booth)	Free	Free
J.	Companions Program (incl. event 1 only)	\$275	\$275

Companion's Name: _____

ADDITIONAL SOCIAL EVENT TICKETS

- Sunday Reception (included with registration) \$ 30
- Monday Night Hydro 2003 Boat Cruise Dinner \$ 80
- Tuesday Section Lunch (included with reg.) \$ 30
- Tuesday Awards Banquet (included with reg. except for students, retirees, life and companions) \$ 80
- Wed. Hydro 2003 Lunch in honour of Ian Ritchie \$ 40

I plan to attend the International Symposium on Hydrometallurgy

Dietary Restrictions: _____

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SHORT COURSES (August 22, 23, 24, 2003)

	Student	Regular
15. Corrosion and Its Control (23 rd & 24 th)	\$350	\$700
16. Hydrometallurgy 2003 (22 nd to 24 th)	\$500	\$1000

INDUSTRIAL TOURS (Thurs. Aug. 28, 2003)

	Fee
17. Tour 1: Cominco Trail Smelter & Refinery	\$600
18. Tour 2: CESL Plant & Canadian Autoparts Toyota	\$ 80

TOTAL REGISTRATION FEE (CAN\$) \$ _____

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PLEASE RESERVE YOUR ACCOMMODATIONS EARLY AS THIS IS HIGH TOURISM SEASON IN VANCOUVER.

	Single	Double
A) Sheraton Wall Centre – deluxe room	<input type="checkbox"/> \$230	<input type="checkbox"/> \$230
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REGISTRATION FORM

COM 2003 – August 24-27, 2003
Vancouver, British Columbia, Canada



YOUR REGISTRATION INCLUDES:

- ✓ **Coffee Breaks:** coffee, decaf coffee and tea for Monday August 25, Tuesday, August 26 and Wednesday, August 27. *VALUE \$30*
- ✓ **Sunday Reception:** one free drink and complimentary hors d'oeuvres at the Sheraton Vancouver Wall Centre Hotel, on the evening of Sunday, August 24. *VALUE \$30*
- ✓ **Presenters Breakfast:** all presenting authors must attend the Presenters Breakfast on the day of their presentation.
- ✓ **Internet Café:** free access to e-mail and the Internet... bring your password. *VALUE \$15*
- ✓ **Poster Session:** see the latest research projects in progress, meet colleagues in a lively discussion environment. The Poster Session will be held in the Trade Show area (Pavilion Ballroom) on Monday, August 25.
- ✓ **Metals 2003 Trade Show:** featuring 30 booths – this is the single best way to meet the Canadian metallurgy and materials industry in person.
- ✓ **Tuesday MetSoc Technical Section Lunches:** join fellow metallurgists for lively discussions and presentations about your specialization. Includes beer, soft drinks and box lunches. *VALUE \$30*
- ✓ **MetSoc Awards Banquet:** on the evening of Tuesday, August 26, the Society will honour its outstanding contributors by presentation of the Society Awards and Fellowships. *VALUE \$80*
- ✓ **Technical Program:** over 250 state-of-the-art technical presentations. Meet metals and materials experts from 40 countries. Complimentary program guide, name badge and gift. Many of the presentations will use computer projection.
- ✓ **All applicable taxes.**

IMPORTANT NOTES:

- **DEADLINES** – Hotel accommodation requests must be received by **July 22, 2003**. Conference registrations must be received by **August 11, 2003** – otherwise, they will be processed on-site at the Sheraton Vancouver Wall Centre Hotel during the conference.
 - **TAXES** – GST is included in all prices where applicable, GST # R106861644. For non-residents of Canada, a GST refund brochure will be included with your registration package on-site.
 - **FUNDS** – All prices are listed in Canadian dollars.
 - **PRE-REGISTRATION** – To pre-register, this form must be received by MetSoc of CIM before **August 11**, after this date, delegates must register on-site.
 - **REGISTRATION HOURS** – The conference registration desk will be open:

Sunday, August 24	15:00 – 20:00
Monday, August 25	7:30 – 17:00
Tuesday, August 26	7:30 – 17:00
Wednesday, August 27	7:30 – 12:00
 - **REFUNDS** – Refund requests must be received by **August 11**; a \$50 cancellation fee will apply. No refunds after that date.
 - **HOTEL ACCOMMODATIONS** – Sheraton Vancouver Wall Centre Hotel room rates are subject to a 7% GST and 10% provincial tax. **After July 22, 2003**, registrants must make their own hotel reservations, quoting the conference's name to obtain the conference rate (space permitting).

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- **YOUTH HOSTEL ACCOMMODATIONS** – A limited number of dorm room beds (price inclusive of taxes) have been reserved at one of the Vancouver Youth Hostels. The location is:

Vancouver Central – 1025 Granville St.

*Note – First night charged immediately but refundable until July 22. After July 22 one night will be charged for all cancellations.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie

Monday AM	Monday PM	Tuesday AM	Tuesday PM	Wednesday AM	Wednesday PM
Plenary Session I	Plenary Session II				
	Solution Purification I: Ion Exchange	Solution Purification I: Adsorption & Solvent Extraction I	Solution Purification I: Solvent Extraction II	Solution Purification I: Solvent Extraction III	Solution Purification I: Solvent Extraction IV
	Solution Purification II: Precipitation I	Solution Purification II: Precipitation II	Solution Purification II: Precipitation III & Electrowinning I	Solution Purification II: Electrowinning II	Solution Purification II: Electrowinning III
	Technology Application: Acid Rock Drainage	Technology Application: Arsenic	Technology Application: Environment	Technology Application: Recycling	Technology Application: Operations
	Leaching I: Cyanide & Alternatives I	Leaching I: Cyanide & Alternatives II	Leaching I: Thiosulfate I	Leaching I: Thiosulfate II	Leaching I: Heap Leaching
	Leaching II: Electrochemistry I	Leaching II: Fundamentals I	Leaching II: Fundamentals II	Leaching II: Chloride Leaching	Leaching II: Pressure and Autoclave



TECHNICAL PROGRAM

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Plenary Session I

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday AM
August 25, 2003

9:30 AM Plenary

Challenges for Hydrometallurgy in Environmental and Health Stewardship: *Bruce R. Conard*¹; ¹Inco Limited, Environml. & Health Scis., 145 King St. W., Ste. 1500, Toronto, Ontario L5H 4B7 Canada

Consideration of environmental and human health issues in metallurgy is growing rapidly. While not all metallurgists need to have detailed expertise in environmental and health questions, they should be aware of the challenges the metals industry faces, be able to interact with colleagues in other sciences and contribute to sound metal resource management. Hydrometallurgists occupy a unique position among metallurgists because of their knowledge of the behaviour of metals in aqueous systems, which are of fundamental importance in understanding environmental chemistry and human toxicology. As a result, hydrometallurgists should more frequently and passionately lend their expertise in assessing environmental and health risks of metals and in helping to develop effective global guidelines, regulations and process and product stewardship strategies, thereby enabling metals to continue their beneficial service to society.

10:10 AM Break

10:40 AM Plenary

Business Aspects and Future Outlook for Hydrometallurgy: *Doug Halbe*¹; ¹Doug Halbe Consultant, P.C., PO Box 58667, Salt Lake City, UT 84158 USA

“Many are called, but few are chosen.” The biblical adage applies not only to life, but also to hydrometallurgical processes. There have been, in the past, many outstanding successes with new processes - and also some dismal failures. What are the odds of success for a new process? When there have been problems, why? What can you do to make sure these problems don't occur with your process? What effect will a slow start-up have on project economics? How do banks - the people who loan your company money for the project - feel about new processes, and why? Is it possible to predict or estimate the time required to reach design parameters...and if so, how do you sell this estimate to management - and banks? Probably most important - when do you start thinking about the answers to these questions?

11:20 AM Plenary

Biotechnology for Sustainable Hydrometallurgy: *Johannes Boonstra*¹; Cees J.N. Buisman¹; ¹Paques B.V., PO Box 52, 8560 AB Balk The Netherlands

High rate bacterial catalyzed processes can serve to improve hydrometallurgical operations. These solutions are not only economical but also environmental sustainable. With references around the globe, the value of this new approach is recognized by industry worldwide. For instance, metals can safely and economically be recovered from process and waste streams using biotechnologically produced sulfide, resulting in a valuable product instead of a waste stream for disposal. Both the natural biological sulfur and nitrogen cycles offer bacterial routes that are applied to advantage on industrial scale. The shared advantage of these processes is that waste compounds are converted in either a reusable raw material or in a harmless product. This way, natural product cycles can be closed. Sulfur cycle: Bioleaching, reduction of oxidized sulfur compounds to elemental sulfur, thiosalts regeneration, metal recovery with biogenic produced H₂S, SO₂ removal from gas streams, etc. Nitrogen cycle: Ammonia removal using the anammox-process, biological removal of NO_x from gas streams, nitrate removal from water streams, etc. Besides the applications mentioned above, bacterial processes for reduction of metals such as uranium, selenium and manganese have proven to offer great potential for clean-up of groundwater streams. The paper and presentation will contain a description of the above applications. Further, a short introduction on the fundamentals of microbial conversions, the design of engineered high rate bioreactor systems and a techno-economical description of an industrial application of biotechnology in metallurgy will be provided.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Plenary Session II

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday PM August 25, 2003

2:00 PM Plenary

Is Extractive Metallurgy Becoming Extinct?: *Ian M. Ritchie*¹; ¹Murdoch University, Perth, WA 6150 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.

2:40 PM Break

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification I: Ion Exchange

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University

of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday PM August 25, 2003

3:00 PM

Application of Ion Exchange Polymers in Copper Cyanide and Acid Mine Drainage: *W. H. Jay*¹; ¹Oretek Limited, 566 Englehardt St., Albury, NSW 2640 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, USA 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.

3:25 PM

Extraction and Recovery of Bismuth from Sulfuric Acid Electrolytes, and Extraction, Recovery, and Refining of Palladium from Copper Refinery By-Product Streams Using Molecular Recognition Technology (MRT): *Steven R. Izatt*¹; Neil E. Izatt¹; Ronald L. Bruening¹; John B. Dale¹; ¹IBC Advanced Technologies, Inc., 856 E. Utah Valley Dr., American Fork, UT 84003 USA

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 sulfuric 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.



3:50 PM

Dynamic Modeling for Design of Ion Exchange Systems: *K. Nikkhal*¹; ¹AMEC Mining and Metals Consulting, Vancouver, BC V6B 5W3 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 modeling 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.

4:15 PM

The Effect of Plating Additives on the Recovery of Copper from Dilute Aqueous Solutions Using Chelating Resins: William Ewing¹; James W. Evans¹; *Fiona M. Doyle*¹; ¹University of California, Matls. Sci. & Engrg., Hearst Mining Bldg., Berkeley, CA 94720-1760 USA

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. We 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 we report the effect of benzotriazoles, a thiopropanesulfonate, 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.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification II: Precipitation I

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday PM

August 25, 2003

3:00 PM

Precipitation of Iron(III) Oxy-Hydroxides from Acid Liquors at Ambient Temperatures: *David M. Muir*¹; Evan J. Jamieson²; ¹Parker CRC for Hydrometallurgy, CSIRO Minerals, PO Box 90, Bentley, Perth, WA 6982 Australia; ²Alcoa Australia, Kwinana, Perth, WA Australia

The neutralisation and precipitation of iron(III) from leach solutions and waste streams at ambient temperatures (<80C) 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 neutralisation of Fe(III) and Fe(III)/Fe(II) solutions in chloride and sulfate 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 20-70C 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.

3:25 PM

The Precipitation Chemistry and Performance of the Akita Hematite Process — An Integrated Laboratory and Industrial Scale Study: *Terry C. Cheng*¹; George P. Demopoulos¹; Yutaka Shibachi²; Hitoshi Masuda²; ¹McGill University, Mining, Metals, & Matls. Engrg., 3610 University St., Montreal, Quebec H3A 2B2 Canada; ²Akita Zinc Co. Ltd., Iijima Zinc Refinery, 217-9 Shimo-Kawabata, Furu-michi, Iijima, Akita 011-0911 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.

3:50 PM

Recent Developments in Iron Removal and Control at the Zinc Corporation of South Africa: *Johann Ockert Claassen*¹; John Rennie¹; Willem Hendrik Van Niekerk¹; Ewald Heinrich Otto Meyer¹; Roelof Feenstra Sandenbe²; ¹Zinc Corporation of South Africa Ltd., Recovery Sect., Plover St., Struisbult Springs, Gauteng S. Africa; ²University of Pretoria, Fac. of Engrg., Build Environ. & Info. Tech., Pretoria, Gauteng S. 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 utilisation of an alternative neutralising agent. Some of these actions together with the implementation of a pre-neutralisation 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 110kt/a to 125kt/a whilst remaining one of the lowest cost zinc producers in the world in the years to come.

4:15 PM

Iron(II) Oxidation by SO₂/O₂ in Uranium Leach Solutions: *Elizabeth Ho*¹; ¹Australian Nuclear Science and Technology Organisation, PMB 1, Menai, NSW 2234 Australia

The oxidation of iron(II) sulfate to iron(III) sulfate using SO₂/O₂ was carried out in a stirred tank reactor under typical uranium leaching conditions (pH 1-2, 20-50°C). The oxidation rate was found to be dependent on the initial SO₂/O₂ 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.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Technology Application: Acid Rock Drainage

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday PM

August 25, 2003

3:00 PM

Remediation of Acid Mine Drainage at the Friendship Hill National Historic Site with a Pulsed Limestone Bed Process: *Philip L. Sibrell*¹; Barnaby J. Watten¹; Constance Ranson²; Tamara Boone²; ¹US Geological Survey, Leetown Sci. Ctr., 11700 Leetown Rd., Kearneysville, WV 25430 USA; ²National Park Service, Friendship Hill Natl. Historic Site, Point Marion, PA USA

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 CaCO₃. 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 CO₂ was generated and recycled to provide a net alkaline discharge with about 50 mg/L as CaCO₃ 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.



3:25 PM

Development of SRB Treatment Systems for Acid Mine

Drainage: *Suzzann Nordwick*¹; Marek Zaluski¹; Diana Bless²; ¹MSE Technology Applications, Inc., Mike Mansfield Advd. Tech. Ctr., PO Box 4078, Butte, MT 59702 USA; ²US Environmental Protection Agency, 26 W. Martin Luther King Dr., Cincinnati, OH 45268 USA

Over the past decade, significant advances have been made in the development of sulfate-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 in-situ 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 sulfides 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.

3:50 PM

Biological Reduction Technology to Produce Sulphide for the Selective Recovery of Metals from Acid Wastewater

- Commercial Case Studies: *R. W. Lawrence*¹; D. Kratochvil¹; P. B. Marchant¹; ¹BioteQ Environmental Technologies Inc., 355 Burrard St., Ste. 1150, Vancouver, BC V6C 2G8 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 offset 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 focused 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.

4:15 PM

Prevention of AMD Generation from Open Pit Highwalls

Demonstration: *Diane Madalyn Jordan*¹; *A. Lynn McCloskey*¹; ¹MSE Technology Applications, Inc., Engrg., 200 Technology Way, PO Box 4078, Butte, MT 59702 USA

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' x 50' 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 byproducts to coat the rock surface. 2) EcoBond™ ARD, a phosphate based process that forms a stable, insoluble compound, coating the rock surface. 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 ASTM D 5744-96, Accelerated Weathering of Solid Materials using a 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 USDOE, Contract Number DE-AC22-96EW96405.

4:40 PM

Application of Lignosulfonates in Treatment of Acidic

Rock Drainage: *J. Ming Zhuang*¹; Tony Walsh¹; ¹Noram Engineering and Constructors Ltd., Vancouver, BC Canada

Lignosulfonates, by-products of the sulfite 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, lignosulfonates were found to protect lime from developing an external surface coating, and hence to favor its dissociation. Further, the addition of lig-

nosulfonates to ARD solutions increased the clotting and settling rate of the formed sludge. The capability of lignosulfonates 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 lignosulfonates, ARD neutralization by lime to about pH 7, pH adjustment with caustic soda to 9.4 - 9.6, air oxidation to lower the pH to a desired level, and addition of a minimum amount of FeCl₃ 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.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching I: Cyanide & Alternatives I

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday PM
August 25, 2003

3:00 PM

Predicting the Leaching Behaviour of Preg-Robbing Gold Ores: *Jim Avraamides*¹; *Bill Staunton*¹; *Michelle Helm*¹; *Jeff Vaughan*²; *Scott Davies*³; *Bianca Pietrass*⁴; ¹Murdoch University, Parker Ctr., Loneragan Bldg., South St., Murdoch, WA 6150 Australia; ²Curtin University of Technology, Parker Ctr., GPO Box U1987, Perth, WA 6845 Australia; ³Sons of Gwalia Ltd, Marvel Loch Gold Mine, 16 Parliament Pl., W. Perth, WA 6005 Australia; ⁴Barrick Gold of Australia, Plutonic Gold Mine, Locked Bag 12, Cloisters Sq., Perth, WA 6850 Australia

Re-adsorption of cyanide-soluble gold by certain ore types is a common problem in the gold industry, which has been studied for over thirty years. The current research, designed to understand the nature of the preg-robbing component in gold ores, involves a wide range of ores from around the world. A data base is being generated which comprises information on the ore mineralogy, elemental composition (including carbon speciation), leaching behaviour, general physico-chemical adsorption properties of

the ore and some specific characteristics of the graphitic component. The ores studied to date have gold adsorption capacities ranging from a few grams per tonne to many tens and even hundreds of grams per tonne. Equilibrium loading capacity is not always directly related to the amount of carbonaceous/graphitic matter present. Spectroscopic analysis suggests that the crystalline form of the graphitic material which is a result of its geological history (or degree of metamorphism), plays an important part in determining the degree of preg-robbing an ore will demonstrate. A greater understanding of the phenomenon of preg-robbing in carbonaceous gold ores could lead to better choice of treatment methods to maximise gold recovery and minimise costs. Additionally, there is the possibility of developing predictive tools to allow early characterisation of an ore's preg-robbing potential during exploration and for orebody development and mine planning.

3:25 PM

Effect of Carbonaceous Coatings on Preg-Robbing of Chalcopyrite: *H. Tan*¹; *D. Feng*¹; *J. S.J. van Deventer*¹; ¹The University of Melbourne, Dept. of Chem. Eng., Melbourne, Parkville, Vic 3010 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 larger 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 oxidised to elemental sul-



phur. 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.

3:50 PM

Optimizing Cyanidation Parameters for Processing of Blended Fort Knox and True North Ores at the Fort Knox Mine:

*John Hollow*¹; Guy Deschenes²; Jacques McMullen³; Hai Guo²; Mike Fulton²; Eric Hill³; ¹Fairbanks Gold Mining, Inc., PO Box 73726, Fairbanks, AK 99707-0326 USA; ²CANMET, Natural Resources Canada, Mining & Mineral Scis. Labs., 555 Booth St., Ottawa, ON G1K 7P4 Canada; ³Barrick Gold, Royal Bank Plaza, 200 Bay St., Toronto, ON M5J 2J3 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% from 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 ounces higher than that estimated for the non-lead nitrate reagent scheme. This report presents the results of laboratory investigations and modifications in plant operating practices.

4:15 PM

The Characterization of Manganiferous Silver Ores and its Relevance to Silver Recovery by Cyanide Leaching:

*Aragón Piña*¹; I. Gallegos¹; Zapata Velázquez¹; *A. Lopez Valdivieso*¹; ¹Universidad Autónoma de San Luis Potosí, Inst. de Metalurgia, Av. Sierra Leona 550, San Luis Potosí, S L P 78210 Mexico

Cyanidation of silver from manganese-bearing silver ores is a problem due to low silver recoveries. It has been claimed that silver is in the manganese oxide crystal lattice, needed to be dissolved for high silver recoveries. Several manganiferous silver ores were cyanide leached. The recovery of silver was confirmed to be low and increased proportionally to the dissolution of manganese dioxide. Scanning and transmission electron microscopy studies showed that silver occurs as argentite, cerargirite, embolite, native silver, and freibergite of less than 2 microns in size, present as free par-

ticles and particles attached to the surface of johannsenite (CaMnSi₂O₆) and quenselite (PbMnO₂(OH)). These oxides display a highly porous structure made up of globular and needle-like crystals. Silver was not detected in the porous structure neither in the crystal lattice of the oxides. The low recovery of silver is explained in terms of adsorption of dissolved silver-cyanide species at the manganese dioxide/water interface.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching II: Electrochemistry I

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Monday PM

August 25, 2003

3:00 PM

Electrochemistry: The Key to Understanding Hydrometallurgical Reactions:

*Matthew Ian Jeffrey*¹; Sherryl Robertson²; Honguang Zhang³; Elizabeth Ho⁴; ¹Monash University, Chem. Eng., Clayton, Vic 3800 Australia; ²James Cook University, Chmst. Dept., Townsville, Qld 4811 Australia; ³Murdoch University, A.J. Parker CRC for Hydrometall., WA 6150 Australia; ⁴Australian Nuclear Science and Technology Organisation, Environml. Div., PMB 1, Menai, NSW 2234 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 PhD students of Professor Ian Ritchie present an insight into how one electrochemical technique can be used to complement 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 aluminium, 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.

3:25 PM

Limitations for the Use of Evans' Diagrams to Describe Hydrometallurgical Redox Phenomena: *R. M. Luna-Sánchez*¹; *I. González*²; *G. T. Lapidus*¹; ¹Universidad Autónoma Metropolitana-Iztapalapa, Depto. de Ingeniería de Procesos e Hidráulica, Av. San Rafael Atlixco, 186 Col. Vicentina, México D.F. 09340 México; ²Universidad Autónoma Metropolitana-Iztapalapa, Depto. de Química, Av. San Rafael Atlixco, 186 Col. Vicentina, México D.F. 09340 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 sulfide 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 sulfide 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.

3:50 PM

Hydrogen Reduction of Metal Ions: An Electrochemical Model: *Kwadwo Osseo-Asare*¹; ¹Pennsylvania State University, Dept. of Matls. Sci. & Engrg., 208 Steidle Bldg., University Park, PA 16802 USA

Abstract not available.

4:15 PM

Cementation Reactions: *Ian M. Ritchie*¹; ¹Murdoch University, Sch. of Math. & Physl. Scis., Perth, WA 6150 Australia

Cementation or metal displacement reactions such as $\text{Cu}^{2+} + \text{Zn} = \text{Cu} + \text{Zn}^{2+}$ 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, catalysed by the deposit, can be important. In this paper, the electrochemical basis of cementation reactions is described. The conditions for each of the com-

plications 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.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification I: Adsorption & Solvent Extraction I

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Tuesday AM

August 26, 2003

8:30 AM

Magnetic Adsorption/Filtration Process for Wastewater Treatment: *James Dale Navratil*¹; ¹Clemson University, Environml. Engrg. & Sci., 342 Computer Ct., Anderson, SC 29625-6510 USA

Magnetite ($\text{FeO}\cdot\text{Fe}_2\text{O}_3$) has been used to separate a wide variety of substances, such as dissolved metal species, particulate matter, and organic and biological materials. In the absence of an external magnetic field, activated magnetite readily adsorbs numerous metal species including actinide elements. In the presence of an external magnetic field, a synergistic effect was observed in using supported magnetite in a fixed-bed for removal of plutonium and americium from wastewater. These observations may be explained by a nanolevel high gradient magnetic separation effect, as plutonium and americium are known to form colloidal particles with satisfactory magnetic properties at elevated pH. The process has been tested for the removal of other metal ions including cobalt, iron and manganese. This paper will review results to date on testing the process for wastewater treatment and outline potential applications in hydrometallurgy.



8:55 AM

The Effect of Pore Size Distribution on Gold Adsorption by Magnetic Activated Carbons: *G. A. Munoz*¹; S. Duyvesteyn¹; J. D. Miller¹; ¹University of Utah, Dept. of Metallurgl. Engrg., 135 S. 1460 E., Rm, 412, Salt Lake City, UT 84112-0114 USA

Activated carbons owe their adsorption properties to their highly developed pore network structure. As a result, these adsorbents generally exhibit high specific surface areas. Currently, granular activated carbons produced from coconut shells are extensively used for gold recovery by adsorption from cyanide leaching solutions. Magnetic activated carbons (MACs) for gold recovery from cyanide solutions produced from sources other than coconut shells have been developed at the University of Utah by mixing a magnetic precursor with a carbon source, and treating the mixture under controlled conditions of temperature and gas composition. The pore size distribution of the activated carbons is dependent, among other factors, on the degree of activation. The significance of the MAC pore size distribution on gold adsorption kinetics and gold adsorption capacity is presented.

9:20 AM

Solvent Extraction of Halides from Metallurgical Solutions: Juris Harlamovs²; *Cash Mason*²; Baruch Grinbaum³; David B. Dreisinger¹; ¹University of British Columbia, Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada; ²Teck Cominco Metals, Teck Cominco Rsch., PO Box 2000, Trail, BC V1R 4S4 Canada; ³IMI Institute for Research and Development, PO Box 10140, Haifa Bay 26111 Israel

Extraction of halides (fluoride, chloride) from metallurgical solutions can reduce corrosion rates and improve hygiene from decreased anodic chlorine evolution. This is particularly true for zinc sulphate electrowinning solutions. This paper describes the chemistry of a new process for the removal of halides from such solutions by solvent extraction. In this process, the halide species are loaded directly from commercial zinc sulfate solutions and are stripped into a form suitable for disposal. The method of optimizing the solvent composition is demonstrated.

9:45 AM Break

10:05 AM

Piloting of a Halide Extraction Process with Mixer Settlers and Bateman Pulsed Columns: *Juris Harlamovs*¹; *Cash Mason*¹; *Jeff Kuhn*²; *Mike Bell*³; *Eliyahu Buchalter*⁴; ¹Teck Cominco Metals, Teck Cominco Rsch., PO Box 2000, Trail, BC V1R 4S4 Canada; ²Teck Cominco Metals, PO Box 1000, Trail, BC V1R 4L8 Canada; ³Bateman Engineering Inc., 4047 Brockton Crescent, N. Vancouver, BC V7G 1E5 Canada; ⁴Bateman Advanced Technologies Ltd., Hamada St., PO Box 15, Industl. Zone, Yokneam 20692 Israel

A new solvent extraction process for the removal of halides from zinc sulphate solution was tested in pilot plants

at both a 0.1 L/min scale and at a 3 L/min scale. Mixer settlers were used for the 0.1 L/min pilot scale and a 100 mm diameter Bateman pulsed columns for the higher rates. Pilot testing was performed with commercial zinc sulfate solutions containing variable amounts of chloride and fluoride. The deleterious halides were loaded and stripped into a form suitable for disposal. The engineering aspects and economics of this solvent extraction process for halide removal are reported.

10:30 AM

Synergistic Solvent Extraction and its Potential Application for Metal Recovery: *Chu Yong Cheng*¹; Mark Urbani¹; Michael Davies¹; Martin Houchin¹; ¹CSIRO, Div. of Minls., PO Box 90, Bentley, WA 6982 Australia

Since commissioning, Bulong Nickel has experienced gypsum formation in its nickel solvent extraction circuit. To solve this problem, the A J Parker Cooperative Research Centre for Hydrometallurgy/CSIRO Minerals conducted laboratory batch tests using Bulong plant solutions and Acorga DS5443A or Acorga CLX50 as synergist. The results showed that at an A/O ratio of 1.0, the $\text{pH}_{50}(\text{Ca-Ni})$ value increased 1.29 pH units with 20% Acorga CLX50 addition. This would largely improve the separation of nickel from calcium if synergist Acorga CLX50 is used. The nickel extraction and stripping kinetics were very fast and there was no noticeable difference in kinetics between the two organic solutions with and without Acorga CLX50 addition. The use of intermediate precipitation, solids/liquid separation and re-leach in the three WA nickel plants make these processes complicated and costly in capital and operation. The research carried out by the SX group at the AJ Parker Cooperative Research Centre for Hydrometallurgy/CSIRO Minerals has led to the development of DSX processes to recover nickel and cobalt from leach solutions using synergistic solvent extraction. By using a new synergistic organic system in semi-continuous tests with a pilot plant leach solution from a BHP-Billiton project (after iron precipitation), the metal values (Ni and Co) together with zinc and copper were separated from the major impurities (Mn, Mg and Ca, together with Cl) in the first SX circuit. The co-extracted manganese, magnesium and calcium were easily scrubbed out. After stripping, the metal values (Ni and Co) together with zinc and copper were concentrated, resulting in a much smaller second SX circuit and equipment in the down stream processes. The extraction and stripping kinetics of the metals with the new synergistic organic solution were very fast. Within 0.5 minutes, the extraction and stripping almost reached steady state.

10:55 AM

Flexibility Trends in Copper Solvent Extraction: *Hans C. Hein*¹; ¹Cognis Corporation, Casilla 35, Correo 35, Santiago Chile

In its early stage of copper solvent extraction development, SX plants were designed in a series configuration and gradually the copper industry reduced SX staging for keeping capital investments reasonably low. Mixer settlers were built bigger and the number of SX trains were diminished, whenever possible, for producing copper cathodes through solvent extraction followed by electrowinning. At a later date of its development, series parallel configuration was applied in some copper SX plants, increasing copper production at limited layout space and/or economics improved particularly under circumstances of low copper tenor in pregnant leach solutions. A gap between series and series parallel configuration had been observed for years, whereby conventional SX plants did not have sufficient flexibility for maintaining designed or expected production level, whenever copper concentrations in pregnant leach solutions diminished, as parallel or series parallel flow schemes virtually require to double SX feed flows for achieving optimum results. A combined SX configuration breaks the gap and its application potentials are extensively explained.

11:20 AM

Selective Extraction of Metal Ions with Monoazapolythioether as Extractant and poly(N-isopropylacrylamide) as Extraction Media: Kenji Chayama¹; Kentaro Inagaki¹; Haruo Tsuji¹; ¹Konan University, Dept. of Chmst., Faculty of Sci. & Engrg., Okamoto 8-9-1, Higashinada, Kobe Japan 658-8501

Polymer extraction using poly(N-isopropylacrylamide) of noble metal ions with monoazapolythioether derivatives were examined. Temperature sensitive polymer such as poly(N-isopropylacrylamide) is soluble in water below the lower critical solution temperature. This polymer extracts some hydrophobic compound such as ion paired complex of metal ion, aromatic hydrocarbons and some environmental hormone such as alkylphenols and phthalic esters when the solution is heated and the temperature is going up to be above the lower critical solution temperature. On the other hand, polythioether derivatives are used as the selective reagents for the liquid-liquid extraction of noble metal ions such as silver, palladium, and gold ion. In this study, selective extraction of noble metal ions as the ion pair of the metal-monoazapolythioether complex cation and anion such as picrate ion into polymer phase of poly(N-isopropylacrylamide) were examined. The results obtained were compared with that of liquid-liquid extraction using the solvent 1,2-dichloroethane. The results obtained show that there is a possibility of separation of noble metal ions such as silver, copper and gold ion from the transition metals such as nickel, cobalt, iron, manganese and cadmium ion without using any organic solvent which are easily vaporized and have a highly toxic character.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification II: Precipitation II

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Tuesday AM
August 26, 2003

8:30 AM

Removal of Thallium from Wastewater: *Larry G. Twidwell*¹; Catherine Williams-Beam¹; ¹Montana Tech of University of Montana, Metallurgl. & Matls. Engrg., 1300 W. Park, Butte, MT 59701 USA

Thallium is more toxic to humans than mercury, cadmium, lead, copper or zinc. Its chemical behavior resembles the alkali metals (K, Rb, Cs). It occurs almost exclusively in natural waters as a monovalent cation. The solubilities of thallos compounds are relatively high so that thallium is readily transported through aqueous routes into the environment. The major sources of thallium are the base metal sulfides and precious metal bearing sulfides. Therefore, it is often present as a contaminant constituent in waters emanating from heavy metal sulfide bearing deposits. Viable technologies for reducing thallium concentrations to less than two micrograms per liter (USEPA maximum concentration level) do not presently exist. An innovative technology has been developed at Montana Tech that does achieve lowering the thallium concentration to below the maximum concentration level. The technology is based on reductive precipitation of thallium sulfide. Effective precipitation requires a controlled solution potential/pH combination that can be achieved by utilizing a particulate iron slurry or a packed column environment. Experimental results will be presented and discussed.



8:55 AM

Adaptation of Dilute Mode Lime Dual Alkali Scrubbing at Stillwater Mining Company's PGM Smelter: R. R. Lunt¹; D. K. Modrow²; G. K. Roset²; ¹FOCIS Associates, Inc., 7 Wells Ave., Newton, MA 02459 USA; ²Stillwater Mining Company, PO Box 1209, Columbus, MT 59115 USA

The Stillwater Mining Company (SMC) has operated platinum-group-metals (PGM) smelter in Columbus, Montana since 1990 to process concentrates produced at its nearby mines. In 1998, SMC embarked on a two-phase project to triple smelter capacity through essentially a complete replacement of the existing facility. Dilute mode lime dual alkali (LDA) technology was selected for meeting the stringent control requirements established for both sulfur dioxide and sulfur trioxide emissions. This same technology had been used in the existing plant and had demonstrated the capability for meeting similar, difficult challenges of handling very high peak levels of sulfur dioxide and sulfur trioxide as well as wide and rapid fluctuations in gas flow and concentrations. Unlike the dilute mode LDA system in the existing facility, though, a streamlined dilute mode LDA concept was envisioned for the new facility. The approach would greatly simplify the design and at the same time significantly reduce both capital investment and operating costs, plus achieve both objectives without sacrificing environmental performance. A joint effort of SMC, the technology supplier and the engineering/design firm has resulted in the successful implementation of this new adaptation of dilute mode LDA technology. The first phase of the expansion was completed in November 1999, and the second phase in November 2001. Over this period, several operational adjustments have been undertaken to optimize process performance such that it is now meeting or achieving all performance expectations 99.5% sulfur dioxide removal and greater than 90% sulfur trioxide removal. Production of a high-purity gypsum byproduct is now being sold as an agricultural soil amendment and has been qualified for use in cement manufacture.

9:20 AM

Gypsum Fouling in Neutralization Reactors and Aqueous Streams: Jeffrey F. Adams¹; Vladimiro G. Papangelakis¹; ¹University of Toronto, Dept. of Chem. Engrg. & Appl. Chmst., 200 College St., Toronto, ON M5S 3E5 Canada

Gypsum fouling is a common problem in the hydrometallurgical industry. It is a particular problem in free sulphuric acid neutralization, or iron removal operations where sulphates are removed from aqueous solutions by the addition of calcium-containing bases. Previous work revealed a strong correlation between the degree of gypsum supersaturation in the reactor and the rate of scale growth indicating that scale formation and growth are primarily controlled by chemical phenomena. However, the chemical behaviour of gypsum is variable and unpredictable with solution chemistry and temperature. Many of the "rules of thumb" that are used to predict its behaviour

(and avoid fouling) are in fact based on gypsum solubility in water, rather than on real mixed metal sulphate systems. However, despite this unconventional solubility behaviour, we have been able to accurately model it in Ni, Mg, and Zn containing solutions over a wide range of temperature (25°C-90°C) and solution concentration (0-6 m) using the OLI simulation software. Furthermore, by studying fouling rates in a simulated continuous neutralization reactor, the relationship between process conditions and fouling rates were explained for the first time. This has led to an understanding of how techniques for minimizing gypsum fouling work.

9:45 AM

The Behaviour of Lanthanide Group Elements During Jarosite Precipitation: John E. Dutrizac¹; ¹CANMET, 555 Booth St., Ottawa, Ontario K1A 0G1 Canada

The behaviour of the lanthanide group elements La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu, during the precipitation of sodium and potassium jarosites at 98° Celsius from sulphate media was systematically investigated. Solutions of the lower atomic weight lanthanide elements (La to Gd) are characterized by the limited solubility of alkali-lanthanide sulphates, such as Na₂Gd₄(SO₄) * xH₂O, which commonly contaminates the jarosite precipitates. Hence, single phase jarosite-type compounds were precipitated only from solutions containing <0.2-0.3 g/L of the La to Gd lanthanides. The heavier atomic weight lanthanide elements (Tb to Lu) have significantly higher solubilities such that solutions containing up to 10 g/L of the individual lanthanide could be investigated without the precipitation of alkali-lanthanide sulphate species. Even at the highest lanthanide concentrations, however, none of the jarosite precipitates incorporated more than 0.3 wt% of any of the lanthanide elements. Comparable levels of lanthanide incorporation were noted in both Na-jarosite and K-jarosite. Although the mass of the jarosite precipitate increased with increasing ferric sulphate concentration or with increasing pH, the extent of lanthanide incorporation was not significantly affected. Clearly, the trivalent lanthanide elements do not substitute extensively for trivalent iron in the jarosite structure, and end-member lanthanide analogues of jarosite-type compounds could not be synthesized. This behaviour likely reflects the significantly lower hydrolyzability of trivalent lanthanide ions relative to ferric ions.

10:10 AM Break

10:30 AM

Selective Precipitation of Cobalt from Ammonia Leach Solutions, Recent Experience at the Coreco Refinery in Fort Saskatchewan: Gavin K.W. Freeman¹; ¹Sherritt International Corporation, 1000 333-11 Ave. SW, Calgary, Alberta T2R 1L9 Canada

The efficient separation of cobalt from nickel (and other impurities) is a fundamental objective in the refining of cobalt. Based on recent experience at the Fort Saskatchewan refinery, the identification of a novel process for the selective precipitation of cobalt from an aqueous ammonia leach was discovered. The addition of calcium sulphate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (gypsum), to an aqueous solution containing cobalt(III)hexammine sulphate, $[\text{Co}(\text{NH}_3)_6]_2(\text{SO}_4)_3$, will result in the precipitation of a sparingly soluble double salt having the stoichiometry, $[\text{Co}(\text{NH}_3)_6]_2(\text{SO}_4)_3 \cdot 2\text{CaSO}_4 \cdot x\text{H}_2\text{O}$ where $x = 4$ or 6 . Leach residues, which may contain a significant quantity of cobalt associated with the cobalt calcium double salt, can be washed with process solutions that contain ammonium carbonate to recover the contained cobalt. The simplicity of this elemental separation and its high selectivity for cobalt, as well as its demonstrated usefulness in improving cobalt recoveries, are the basis for the potential applications of this process.

10:55 AM

Selective Precipitation for Cobalt and Molybdenum Recovery from a Synthetic Industrial Waste Effluent:

*J. H. Huang*¹; *M. Oliazadeh*²; *C. Kargl-Simard*¹; *A. M. Alfantazi*¹; ¹The University of British Columbia, Dept. of Metals & Matls. Engrg., Vancouver, BC V6T 1Z4 Canada; ²The University of Tehran, Dept. of Mining Engrg., Tehran Iran

In this investigation, the selective precipitation of cobalt and molybdenum from Co-Mo aqueous solutions was studied in order to recover efficiently valuable elements from industrial effluents generated from a novel electrodeposition of nanocrystalline Co-based alloys and reduce the effluent impact on environment. It was found that the behavior of cobalt in aqueous solution was substantially affected with the presence of molybdenum. When adding 11.6 to 46.6g/L molybdenum to a 50g/L cobalt solution, the co-precipitation of molybdate and cobalt occurred when pH was increased to less than 4. However, without the presence of molybdenum, cobalt could only be precipitated out from the solution at about pH 6. Most of the molybdenum was found in the solid phase when the pH reached 5. After further increasing pH to greater than 7, the molybdenum dissolved back into solution. Cobalt kept precipitating as the pH increased. When pH was greater than 7, most of the cobalt was present in the solid phase. The chemical and physical characteristics of the precipitated materials were investigated by SEM, XRD, AAS and EDX. It was revealed that the precipitate was initially present as cobalt molybdate oxide hydrate and subsequently transformed as sodium cobalt molybdenum oxide. With further increasing solution pH, the precipitate was changed into cobalt hydroxide. Further investigation implied that most of molybdenum was chemically tied to the precipitate produced at the low pH, yet at the same time, physically entrapped at the high pH. The paper also presents the influence of reaction temperature and time on the precipitation process and kinetics.

11:20 AM

Recovery of Cerium by Oxidation/Hydrolysis with $\text{KMnO}_4 - \text{Na}_2\text{CO}_3$:

*Carlos Antônio Morais*¹; *J. S. Benedetto*¹; *A. C.Q. Ladeira*¹; *V. S.T. Ciminelli*²; ¹Centro de Desenvolvimento da Tecnologia Nuclear-CDTN/CNEN, Campus UFMG-Pampulha, Belo Horizonte, MG 941 Brazil; ²Universidade Federal de Minas Gerais-UFMG, Dept. of Metallurgical & Matls. Engrg., Rua Espirito Santo 35, Belo Horizonte, MG 30160-030 Brazil

Cerium has important applications in catalysts, green phosphors and magneto alloys. The separation of this element from RE mixtures is generally based on the oxidation of Ce(III) to Ce(IV). In acid solution, only stronger oxidants, such as persulfate, bismuthate, are capable of oxidising Ce(III) to Ce(IV). In basic medium, otherwise, the trivalent cerium is readily oxidised to the tetravalent state. The present work describes the development of a process to obtain high grade CeO_2 . The process involves cerium oxidation and hydrolysis by addition of a mixture of $\text{KMnO}_4 - \text{Na}_2\text{CO}_3$ solution. The results indicated that the major parameters affecting cerium recovery are the KMnO_4 excess and the liquor acidity. In this case, cerium was precipitated as a mixture with manganese. Further purification was carried out by the dissolution of $\text{Ce}(\text{OH})_4 \cdot x\text{H}_2\text{O}$ in HCl, followed by cerium precipitation as oxalate. The final product, assaying 99.5% CeO_2 , was obtained with a recovery nearly 100%.

11:45 AM

Compartmental Modelling of a Well-Mixed and an Inhomogeneously-Mixed, Batch Gibbsite Precipitators:

*Tian Li*¹; *Iztok Livk*¹; *Dean Ilievski*¹; *Greame Lane*¹; ¹CSIRO Minerals, A J Parker CRC for Hydrometall., PO Box 90, Bentley, Western Australia 6982 Australia

The behaviours of a well-mixed and an inhomogeneously-mixed particulate phase batch gibbsite precipitators were studied in this work. The precipitation experiments were conducted at the same "chemistry", i.e. the same temperature, initial liquor composition, seed type and charge, and mean shear rate. The inhomogeneously-mixed vessel had a larger tank height to diameter ratio and a smaller impeller diameter to tank diameter ratio than the well-mixed vessel. Comparisons of the experimental precipitation responses showed that both precipitator configurations have the same desupersaturation profiles but have significantly different crystal size distribution (CSD) evolution (Li and Ilievski, 2002). The potential of compartmental modelling for describing the behaviours of the well-mixed and inhomogeneously-mixed gibbsite precipitators was investigated. Different compartmental configurations, comprising various combinations of zones of uniform energy dissipation and solids concentration, based on computational fluid dynamics (CFD) characterisation, were used to simulate both precipitators.



International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Technology Application: Arsenic

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

**Tuesday AM
August 26, 2003**

8:30 AM

The Removal of Arsenic from Process Solutions: Theory and Industrial Practice: *Bryn Harris*¹; ¹Consultant, 3670 Sainte Famille, Montreal, Quebec H2X 2L4 Canada

Much has been written over the past twenty years on the removal and stabilization of arsenic from metallurgical process solutions. This paper reviews again the latest developments in this field, and concludes as before that the high-iron arsenical ferrihydrites, together with the high temperature arsenic minerals, scorodite and Type II, remain as the best and most viable vehicles for industrial control and disposal. Data are also presented on a survey of industrial practice, which shows that arsenical ferrihydrite is by far the most widely-practiced and accepted method used worldwide. Finally, the disaster in Bangladesh is briefly discussed with reference to lessons that the metallurgical might learn from this.

8:55 AM

Sorption of Arsenate from Aqueous Solution with Manganic Ferric Oxyhydroxide: *Gautam R. Chaudhury*¹; *Radhanath P. Das*¹; *David M. Muir*²; *Pritam Singh*³; ¹Regional Research Laboratory, Bhubaneswar, Orissa 751 013 India; ²CSIRO, Minls., Conlon St., Waterford, Western Australia 6982 Australia; ³Murdoch University, Div. of Sci. & Engrg., South St., Murdoch, Western Australia 6150 Australia

Arsenic contaminated drinking water drawn from groundwater is a major health problem in West Bengal, adjoining Bangladesh and other parts of the world such as Taiwan, Thailand, Chile, Argentina, China and Mexico. Due to its extreme toxicity, there is a need to remove the arsenic from contaminated drinking water. There have been various methods developed to treat hydrometallurgical process solutions

and effluents and some of these can be applied to arsenic contaminated drinking water. Adsorption techniques are probably most appropriate and these can be comparatively low cost and effective. Various adsorbents such as alumina, ferrihydrite and manganese ores have been used. There is a great deal of literature concerning the removal of arsenic from aqueous solution using ferrihydrite as an adsorbent, but there has apparently been little investigation of modifying the structure of ferrihydrite to improve its adsorptive efficiency. In the present study the incorporation of manganese to replace iron in ferrihydrite was attempted by several techniques and the prepared materials used in arsenic adsorption experiments. The compounds were X-ray amorphous, but TGA/DTA and FTIR analysis showed some structural characteristics. Sorption studies reported in this paper indicate the excellent arsenic removal properties of the manganese/iron compounds. Adsorption rates are reported and the results fitted to adsorption and mass transfer models.

9:20 AM

Preparation, Characterization and Solubilities of Adsorbed, Co-Precipitated and Crystalline Iron (III)-Arsenate Solids: *Yongfeng Jia*¹; *G. P. Demopoulos*¹; *N. Chen*²; *J. Cutler*²; ¹McGill University, Dept. of Metals & Matls. Engrg., M. H. Wong Bldg., 3610 Univ. St., Montreal, QC H3A 2B2 Canada; ²University of Saskatchewan, Canadian Light Source Inc., 101 Perimeter Rd., Saskatoon, SK S7N 0X4 Canada

Arsenic constitutes a major contaminant for the hydro-metallurgical industry. Its removal and immobilization from process effluents typically involve lime neutralization and co-precipitation with ferric iron (Fe(III)/As(V)>3). Alternatively, precipitation of scorodite (FeAsO₄·2H₂O(cr)) may be applied to arsenic fixation. The mechanism of arsenic fixation in the former process has been suggested to be surface adsorption. Unequivocal characterization of these products is difficult because of their amorphous nature hence a variety of methods need to be applied including particularly powerful method XAFS. In this study we have investigated the preparation of arsenate-adsorbed ferrihydrite with the purpose to compare its structure (by XAFS) to that of Fe(III)-As(V) co-precipitates and scorodite (both amorphous and crystalline). Furthermore the solubilities of these Fe(III)-As(V) solids are measured as a function of pH. Their structures are elucidated and correlated to their solubilities and thereby the application of these findings to the practice of arsenic removal and disposal is assessed.

9:45 AM

Adsorptive Removal of Arsenic and Fluoride by Using Orange Juice Residue: *Katsutoshi Inoue*¹; *Kedar Nath Ghimire*¹; *Kenjiro Makino*²; *Rabindra Prasad Dhakal*¹; ¹Saga University, Dept. of Appl. Chmst., Honjo 1, Saga 840-8502 Japan; ²Yamasoh Micron Inc., Kogawa, Wakayama 649-6561 Japan

Industrial application of low cost adsorbents is of immense importance for the treatment of environmental pollutants generated not only from various industrial sources but also from some geological sources such as ground and hot spring water. Two kinds of chemically modified orange juice residues were applied for the adsorptive removal of arsenic: phosphorylated orange juice residue (POJR) and saponificated orange juice residue (SOJR), respectively. Effect of metal ions immobilized on POJR gel were examined for the removal of fluoride and compared with the activated alumina, commercially available adsorbent for fluoride. Adsorption tests of arsenic on iron(III)-immobilized-SOJR with active carboxylic functional groups showed that it has nearly the same adsorption power with the POJR with active phosphoric group. The exchangeable cations of the SOJR were as high as 2.64 mol/kg. Adsorptive removal of fluoride on cerium(IV) and lanthanum(III)-immobilized POJR have shown better removal behavior as compared to activated alumina. Their loading capacities on such gels were almost the same, 1.7 and 1.8 mol/kg, respectively. Based on the fundamental adsorption tests, field test for the removal of arsenic was carried out for waste mine water from Harobetsu mine in Hokkaido, Japan, using SOJR. It was found that SOJR successfully achieved complete removal over wide pH range while some amount of arsenic was remained in the effluent treated by means of co-precipitation method together with iron(III) hydroxide by adding large amount of calcium or magnesium. In addition, some amount of co-precipitated arsenic was leaked from the precipitated iron sludge while no leakage of arsenic was observed from the SOJR adsorbent.

10:10 AM Break

10:30 AM

Removal of Arsenic by Red Mud from Contaminated Waste Water: Linda C. White¹; Eric Paling¹; *Pritam Singh*¹; Wensheng Zhang¹; ¹Murdoch University, Div. of Sci. & Eng., South St., Murdoch, Western Australia 6150 Australia

The use of red mud, which is a waste product of Bayer process for bauxite refining has been investigated for its effectiveness and efficiency of arsenic removal from aqueous solutions under various conditions. It is found that the red mud samples obtained from ALCOA, Western Australia can remove As(III) effectively in the pH range 7.6 to 9 and As(V) in the pH range 5.5 to 6. The pre-washing of the mud with seawater considerably improves its arsenic adsorption capabilities. Maximum arsenic removal efficiency was achieved at the $[\text{As}_{\text{initial}} (\text{mg/L})]:[\text{mud} (\text{g/L})] = 1:8$. With sufficient dosage of red mud, the residual arsenic in solution is decreased below the regulated acceptable arsenic limit (0.1 mg/L) from aqueous industrial wastes. The arsenic adsorption follows first-order rate kinetics. The experimental data fits the Langmuir isotherm model. The results suggest that red mud is potentially a useful adsorbent for removal of arsenic from contaminated water or industrial waste solutions.

10:55 AM

Biological Water Treatment for Dissolved Metals and Other Inorganics: *Brad Wahlquist*¹; Tim Pickett¹; D. Jack Adams¹; ¹Applied Biosciences Corporation, PO Box 520518, Salt Lake City, UT 84152 USA

Biological water treatment of selenium, arsenic, cyanide and nitrate has been successfully implemented at full-scale by Applied Biosciences Corporation at three plants in the US. Many other metals have been removed from various water streams at bench and pilot scale. The company's proprietary technologies use site-optimized microbial cultures and nutrient blends in a fixed-bed bio-reactor system to remove target parameters to below detection. Treatment costs are as low as \$0.12 US per 1000 gallons treated. Applied Biosciences has successfully tested waters from mining, oil refining, power generation, and other industries.

11:20 AM

Biosorption of Toxic Metals from Wastewater by *Streptomyces Viridosporus*: *Richard K. Amankwah*¹; W. T. Yen¹; ¹Queen's University, Mining Engrg., Goodwin Hall, Kingston, Ontario K7L 3N6 Canada

Currently, metal polluted effluents are mostly treated by chemical methods that tend to be expensive especially in the treatment of dilute solutions. The alternative use of biomass for metal removal has been investigated extensively in recent times. This paper looks at the use of the biomass of *Streptomyces viridosporus* in the removal of lead, copper, nickel, antimony and zinc from wastewater. Investigations revealed that over 90% of lead and copper ions were sorbed from wastewater at a concentration 10 ppm within 30 minutes. Sorption of antimony was 63% and that of nickel and zinc below 50%.

11:45 AM

Recovery of Chromium(VI) from Electroplating Rinse Water: The Development of a Hollow Fibre Solvent Extraction Process: P. J. Harrington¹; G. W. Stevens¹; ¹The University of Melbourne, Dept. of Chem. & Biomolecular Engrg., Victoria, 3010 Australia

Recovering and recycling of low concentration metal and other ions has traditionally been carried out using adsorption or ion exchange processes, these however become uneconomical at higher concentrations such as those that occur with many intermediate or waste streams. This paper describes the development of a process based on hollow fibre or non dispersive solvent extraction for the recovery of chromium(VI) from electroplating rinse water. During the chromium plating of steel the concentration of chromium(VI) in the rinse bath rises to approximately 100 ppm when it becomes unusable and is then disposed of. The aim of this project is to investigate processes for recovery and recycling of the chromium in the rinse bath. The recovered chromium is required to



be concentrated and purified before reuse. Tertiary amines have been shown capable of concentrating and purifying the chromium(VI) in solution. However, solvent extraction processes that have been applied to the recovery and reuse of metals from waste streams have had only limited success in the past, primarily because of the relatively high solvent losses when existing contracting equipment is used on low feed concentrations. Attempts to eliminate losses by immobilizing these complexing agents on substrates have not been successful. In order to control the losses and maintain specificity, a hollow fibre contained liquid membrane has recently been trailed in a pilot plant to recover chromium from chromium plating waste streams. Details of the trial are presented and show that the level of losses is significantly reduced. However, issues relating to fouling still need to be addressed. This type of equipment has many applications in the recovery and recycling of a range of materials in the manufacturing processes.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching I: Cyanide & Alternatives II

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Tuesday AM
August 26, 2003

8:30 AM

Surface-Enhanced Raman Spectroscopy of Gold Dissolution in Cyanide: Kym Marjorie Watling¹; Greg A. Hope¹; Ronald Woods¹; ¹Griffith University, Sch. of Sci., Kessels Rd., Nathan, Brisbane, Queensland 4111 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.

8:55 AM

The Link Between Hydrometallurgy and Gravity Recovery: A. R. Laplante¹; W. Staunton²; ¹A.J. Parker Cooperative Research Centre for Hydrometallurgy and McGill University, Dept. of Mining, Metals & Matls.; ²A.J. Parker Cooperative Research Centre for Hydrometallurgy

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 lixivants to treat gravity concentrates, and application of the gravity-leach approach to other systems such as PGEs.

9:20 AM

Hydrometallurgy of Gold without Cyanides: Alexander Gerasimovich Kholmogorov¹; Gennady Leonidovich Pashkov¹; Olga Nikolaevna Kononova²; Yuri Sergeevich Kononov¹; Nelya Viktorovna Danilenko²; Sergey Vasilyevich Kachin²; ¹Siberian Branch of Russian Academy of Science, Inst. of Chmst. & Chem. Tech., K. Marx St. 42, Krasnoyarsk 660049 Russia; ²Krasnoyarsk State University, Svobodny Pr. 79, Krasnoyarsk 660041 Russia

The traditional pyro- and hydrometallurgical processes applied for metallurgy of gold include its dissolution in cyanide solutions. It is known that sodium and potassium cyanide are dangerous for environment. That is why we have investigated and developed the processes for gold hydrometallurgy without cyanides. In our investigation, hard arsenopyrite concentrates were used as raw materials for production of gold. These concentrates contain up to 90-93% of gold in sulfides like FeS₂, FeAsS. The most widespread method for the recovery of gold from such concentrates is their pyrometallurgical breakdown (roasting at more than 1200°C).

The less common method for the same purpose is hydrometallurgical oxidation in nitric acid solutions with the subsequent cyanidation of gold from cakes or roasting residues. We have treated the gold-containing arsenopyrite hard concentrates by salt solutions [Fe(NO₃)₃;VHNO₃(H₂SO₄);VH₂O] at 45-70°C during 40-60 min. As a result, the complete decomposition of pyrite and arsenopyrite occurs, accompanied by the transition of iron, sulfur and arsenic into solution. Gold remains in an insoluble residue (the yield is about 23-27% to the initial mass of sulfide concentrate). We have used the following solutions for the dissolution of gold: Na₂S₂O₃ (0.5-1.0 mol/L) ;V NH₃ ;V H₂O (pH~7-9); NaSCN (0.8-1.5 mol/L) ;V H₂SO₄ (0.05 mol/L) ;V H₂O; (NH₂)₂CS (0.6-1.0 mol/L) ;V H₂SO₄ (0.1-0.3 mol/L) ;V H₂O. The principal advantage of the proposed method is that the application of cyanide solutions (NaCN, KCN) is not required when the dissolution of gold is done by acidic thiocarbamide, sodium thiocyanate or ammonia sodium thiosulfate solutions in a technological cycle of gold recovery from products of chemical preparation. The recovery of gold in this case is about 96-98%. It should be noted that the highest dissolution rate of gold from cakes is achieved in the presence of Fe³⁺ ions, which are already contained in aqueous phase of gold-containing cake (thus it is not necessary to specially add these ions into solutions). The reagent [Fe³⁺ ;V H₂SO₄ (HNO₃) ;V H₂O] can be completely regenerated. The proposed technological scheme can be used for the recovery of gold from gold-containing sulfide concentrates with different composition.

9:45 AM

The Leaching and Recovery of Gold with Alkaline Sulfide Hydrometallurgy: *Corby G. Anderson*¹; ¹CAMP - Montana Tech, 1300 W. Park St., Butte, MT 59701 USA

Globally, various alternatives for leaching and recovery of gold without the use of cyanide are again being considered. One economically viable and environmentally sound candidate is the alkaline sulfide hydrometallurgical system. This paper will outline the fundamentals of this technology. As well, pertinent applications and the associated, comparative economics will be illustrated.

10:10 AM Break

10:30 AM

Chloride Metallurgy as an Alternative to Cyanide for the Extraction of Gold - Going Full Circle?: *C. J. Ferron*¹; *C. A. Fleming*¹; *D. B. Dreisinger*²; *P. T. O'Kane*³; ¹Lakefield Research Limited, 185 Concession, Lakefield, Ontario KOL 2H0 Canada; ²University of British Columbia, Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1W5 Canada; ³O'Kane Consultants Inc., 502-455 Granville St., Vancouver, BC V6C 1V2 Canada

At the present time, cyanide is the most widely used reagent to extract gold from its ores and concentrates. However, its use in mining has become the focus of intense attack by various groups throughout the world; as a consequence, a renewed effort has been launched to

find suitable alternative lixiviants to recover gold. Chlorination was the most popular process to extract gold, before it was rendered obsolete with the advent of the cyanidation process at the turn of the last century, not least because it required the use of chlorine to oxidize/complex the gold. Furthermore the process was not suitable to treat sulphide ores, unless they were first roasted. The PLATSOL® process, originally designed to recover the platinum group metals (PGM's) from their ores and concentrates, also provides an alternative to cyanide leaching for gold ores. The process generates oxidizing conditions in the autoclave that are capable of forming - the Au^{III} ion, and gold chlorocomplexes result from the addition of small quantities (~5-10 g/L) of sodium chloride to the autoclave. The principles of the PLATSOL® process will be briefly described, and several applications of the process to gold concentrates will be presented. Various options available to recover gold from PLATSOL® leach solution will also be discussed.

10:55 AM

Using Thiocyanate as Lixiviant for Gold Recovery in Acidic Environment: *R.-Y. Wan*¹; *J. A. Brierley*²; *S. Acar*³; *K. M. LeVier*³; ¹Metallurgy Consultant, 9634 S. Kalamere Ct., Highlands Ranch, CO 80126-4904 USA; ²Brierley Consultancy LLC, PO Box 260012, Highlands Ranch, CO 80126-0012 USA; ³Newmont Mining Corporation, 10101 E. Dry Creek Rd., Englewood, CO 80112 USA

Thiocyanate was evaluated for gold recovery from low-grade refractory gold ores following biooxidation for an acidic heap leaching approach. One of the important features in using thiocyanate is that the leaching can be performed in acidic media, thus avoiding problems related to neutralization and material handling as leaching with alkaline cyanide. Also, the acidic leaching enables the use of ferric ion or bioleach solution as oxidants. In this study, Newmont-Nevada low-grade refractory sulfidic ore was biooxidized in columns at a particle size of minus 10.2 cm. Thiocyanate leach on the biooxidized ore sample was performed on both ground samples in pulps and coarse material in columns using ferric ion as an oxidant. The variables of thiocyanate and ferric ion concentrations were compared for effect on leaching. Thiocyanate leach results are encouraging and indicate potential for development of a practical process. Gold extractions by thiocyanate are comparable to cyanide leach. Thiocyanate consumption was higher than cyanide, but was in an acceptable level.



11:20 AM

A Comparison of Cyanide and Thiosulfate Leaching for the Recovery of Gold from a Copper Containing Ore:

*Xianwen Dai*¹; Chee Keng Chu¹; Matthew Ian Jeffrey¹; Paul L. Breuer¹; ¹Monash University, Dept. of Chem. Engrg., Clayton, Vic 3800 Australia

One of the biggest challenges for the gold industry in the 21st century is the presence of copper in gold containing ore bodies. This is because copper consumes large quantities of cyanide. In addition, copper cyanide species are more stable than free cyanide, and hence are problematic in events of tailings spillage. The present paper compares cyanide and thiosulfate leaching for the recovery of gold from a copper containing ore. For cyanide leaching, the extraction of gold using copper cyanide complexes instead of free cyanide was tested in the presence and absence of added ammonia. For the thiosulfate leaching, the effect of the minerals present in the ore on the solution potential and thiosulfate consumption are illustrated.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching II: Fundamentals I

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Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Tuesday AM
August 26, 2003

8:30 AM

Alloy Formation During the Cementation of Gold on Copper from Ammoniacal Thiosulfate Solutions:

*J. Brent Hiskey*¹; Jaecheon Lee¹; ¹University of Arizona, Dept. of Matls. Sci. & Engrg., Coll. of Engrg. & Mines, Tucson, AZ 85721 USA

Gold-copper alloys are shown to form during the cementation of gold on copper in a in an ammoniacal thiosulfate solution containing 0.25M [S₂O₃²⁻] at 25°C. The alloy composition is strongly dependent on the initial Cu:Au ratio in solution and ranges from Au₃Cu to AuCu₃. 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.

8:55 AM

Cyanide and Lead Effect on the Silver Cementation Reaction and Product Morphology onto Metallic Zinc in Cyanide Solutions:

*G. Viramontes Gamboa*²; *M. Medina Noyola*²; *M. A. Vidal Borbolla*³; *A. López Valdivieso*¹; ¹Universidad Autónoma de San Luis Potosí, Inst. de Metalurgia, Av. Sierra Leona 550, San Luis Potosí, S.L.P. 78210 Mexico; ²Universidad Autónoma de San Luis Potosí, Instituto de Física; ³Universidad de San Luis Potosí, Instituto de Investigaciones Ópticas

The cementation reaction and morphology of silver onto zinc in cyanide solutions, in the virtual absence of oxygen, were studied at several cyanide/silver molar ratios and lead concentrations, pH 10.5, in a stirred reactor at 25°C. At low cyanide concentration, in the absence of lead ions, cementation proceeded with a uniform silver deposit around zinc. The molar ratio of cemented silver to dissolved zinc was 2. At high cyanide concentration, cementation occurred with evolution of H₂ and growth of silver towards the aqueous solution as dendrites. The molar ratio of cemented silver to dissolved zinc was 1. Lead ions modified the cementation mechanism occurring at low cyanide concentrations to that taking place at high cyanide concentrations. Dendrites of finer silver crystals resulted from addition of lead in comparison to those deposited in the absence of lead ions. The evolution of H₂ was supported through mass spectroscopy studies.

9:20 AM

Fluosilicic Acid Leaching of Galena: *Patrick R. Taylor*¹; *Yeonuk Choi*¹; *Edgar E. Vidal*¹; ¹Colorado School of Mines, Dept. Metallurgl. & Mining Engrg., 1500 Illinois St., Golden, CO 80401-1887 USA

A kinetic study of the fluosilicic acid leaching of galena was performed under the presence of different oxidants. Fluosilicic acid concentration, agitation speed, concentration of solids and particle size, type and concentration of oxidant, and temperature were the variables studied. Hydrogen peroxide was found to be the most effective oxidant, its effectiveness being proportional to its concentration. As expected, an increase of leaching temperature increased the overall extraction and extraction rate. The same was found by decreasing the galena particle size. It is thought that leaching using hydrogen peroxide is controlled by fluid film mass transfer due to the calculated apparent activation energy. Reaction by-products such as sulfur and sulfur compounds retard the leaching rate. A mathematical model is proposed and compared to experimental results.

9:45 AM

Selective Bacterial Leaching of Cobalt from a Chalcopyrite Copper Concentrate: *Ralph P. Hackl*¹; Rikkert J. Vos²; ¹University of British Columbia, Dept. of Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada; ²British Columbia Research Inc., 3650 Wesbrook Mall, Vancouver, BC V6S 2L2 Canada

Bacterial leaching of the Doe Run Company's cobalt-containing copper concentrate at low pH (pH 1.0-1.2) and high redox potential (>750 mV vs. SHE) enabled the cobalt to be preferentially dissolved over copper due to the rapid passivation of the chalcopyrite component. Selective leaching of the cobalt was achieved with a mesophilic culture comprised mainly of *Leptospirillum ferrooxidans*. This finding led to the conception of a novel hydrometallurgical process for passivating chalcopyrite and recovering cobalt. The bacterial leaching process was tested extensively at the bench and pilot plant scales during 1997-1998. A pilot plant containing four leaching stages processed 30-40 kg/day of chalcopyrite concentrate continuously for 87 days. The cobalt extraction ranged from 75% to 86% during 6 and 8 day retention times respectively, whereas the copper extraction was limited to about 9%. An engineering study confirmed the economic viability of the process based on the prevailing metal prices at the time.

10:10 AM Break

10:30 AM

Transition Metal and Platinum Group Metal Separations with Silica Polyamine Composites and Nitrogen Species Catalyzed Leaching: *Corby G. Anderson*¹; ¹CAMP - Montana Tech, 1300 W. Park St., Butte, MT 59701 USA

Nitrogen species catalyzed pressure leaching has successfully been applied to cobaltite, chalcopyrite and PGM concentrates. New hydrometallurgical protocols for the separation of cobalt from copper and arsenic in cobaltite concentrate leach solutions using a tandem fixed bed arrangement of two metal selective silica polyamine composites (CuWRAM and WP-2) at pH = 3 have been developed. Good rejection of arsenic and efficient separation and concentration of copper and cobalt were realized. A different resin, WP-1 was used to separate nickel from palladium at pH = 0. Here the separation of the transition metal from the precious metal was quantitative and excellent recovery of palladium was realized using acid-ammonium chloride strips at 50°C. The characteristics and synthesis of these novel technologies will be reviewed and the advantages of will be discussed.

10:55 AM

The Effect of Chloride Ions on the Oxidation of Pyrite under Pressure Oxidation Conditions: *Michael Nicol*¹; Jim Qing Liu¹; ¹Murdoch University, A J Parker Ctr. for Hydrometall., South St., Murdoch, Western Australia 6150 Australia

Pressure oxidation of refractory gold minerals such as pyrite has become one of the main pre-treatment routes prior to cyanidation for gold extraction. It has been reported from some operations that the presence of chlo-

ride is detrimental for both the oxidation of pyrite and the recovery of the gold. Electrochemical experiments have been conducted at high temperatures and pressures in order to confirm these reports and to establish possible mechanisms for the effects. Experiments on the anodic oxidation of pyrite and cathodic reduction of iron(III) were carried out using linear sweep voltammetry in sulphate solutions containing various concentrations of chloride ions in a nitrogen atmosphere at various temperatures up to 200°C and 2000 Kpa. Results indicate that an increase in temperature results in higher reactivity for both the anodic oxidation of pyrite and the cathodic reduction of iron(III). An increase in chloride concentration results in decreased reactivity for both reactions. A possible mechanism for the effect of chloride is presented.

11:20 AM

Use of Alternating Current for Leaching of Intermediate Products from Copper and Nickel Production: *A. V. Tarasov*¹; V. M. Paretsky¹; V. A. Bryukvin¹; ¹State Research Institute of Non-Ferrous Metals "GINTSVET-MET", 13 Acad. Korolyov St., Moscow 129515 Russia

In order to improve technical, economic and environmental performance of hydrometallurgical processing of intermediate products containing copper and nickel, the Gintsvetmet Institute and the IMET Institute of the Russian Academy of Sciences have conducted studies into the efficiency of the use of alternating current of industrial frequency on processes applied for hydrochemical leaching of various copper- and nickel-containing materials. It has been found that: 1. Imposition of alternating current over the process of leaching of softly reduced nickel oxide with recycled copper sulfate solutions resulted in an increase by 20 to 30% of the rate of the copper cementation process and reduced by 20% its activation energy. At the same time, the recoveries of nickel, cobalt and iron to the leach solution increased up to 82.2%, 78.5% and 57.1%, respectively, and that of copper to the cement precipitate up to 74%. Optimal process conditions have been identified with respect to the current density, electrode material, copper concentration in solutions and the process temperature. 2. In the process of hydroelectrochemical sulfuric acid leaching of nickel and copper sulfides, the grain size, the phase form of sulfides, the solution composition (H₂SO₄, Cl⁻, Cu²⁺, Fe³⁺) and the current amperage had an effect on the nickel recovery to the solution, which reached 90%, while the degree of copper transfer to solution did not exceed 20%. The process of hydroelectrochemical sulfuric acid leaching of nickel and copper sulfides with an addition of Cl⁻ made it possible to selectively recover nickel into the leach solution along with concentrating copper in the leach residue. 3. When subjecting samples of commercial-grade magnetic fractions of converter matte to sulfuric acid leaching, the



imposition of electric current, the concentrations of sulfuric acid and chloride ion in the solution and the duration of the reaction process had an effect on the process. The nickel recovery was 85% and that of cobalt and iron was 95% and the recoveries reached 97.5%, 98.3% and 99.8% as a result of repeated treatment of the primary residue under similar process conditions. Up to 75% of copper, 75% of sulfur and 99.0-99.5% of palladium was concentrated in the solid reach residues. The experimental data obtained indicates that the use of AC for hydroelectrochemical sulfuric acid leaching for separation of copper- and nickel-containing intermediate products has favorable prospects.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification I: Solvent Extraction II

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Tuesday PM
August 26, 2003

2:00 PM

Heat Balances in Copper SX/EW Operations: *Debra J. Burkhardt*¹; ¹Fluor Daniel, 1075 W. Georgia St., Vancouver, BC V6E 4M7 Canada

Newer copper SX/EW processes often incorporate hot water heating for the cell feed electrolyte to obtain the necessary plating temperatures of 40 to 50°C. Heating is most necessary in oxide heap leaching however it may also be required in bioleaching of secondary sulphides in colder climates or higher altitudes where most of the heat gain in the heap is lost to the environment. Given that the solution flows in the leach, organic circuit and electrolyte circuit are circular in nature, and the fact that the hot lean electrolyte is often exchanged with cooler rich electrolyte, it can be difficult to access the heating requirement for the cell feed. There are energy losses in piping, tankage, raffinate, and energy gains through the PLS and electrowinning process itself; some of these are significant and others are not. This paper discusses the overall heat balance, the relative significance of the various energy gains and losses, and describes a methodology

to develop a heat balance to assist the engineer in sizing the heating equipment.

2:25 PM

Extraction of Nickel and Calcium from Hypersaline Solutions Using Versatic 10: *D. Helm*¹; E. Paatero²; D. Ibane¹; ¹Curtin University of Technology, WASM-Parker Ctr. for Hydrometall., WA Sch. of Mines, Perth, WA Australia; ²Lappeenranta University of Technology, Dept. of Chem. Tech., Lappeenranta Finland

The solvent extraction of nickel using carboxylic acid based extractants such as Versatic 10 is well established but its recent application in the direct solvent extraction of nickel has highlighted the need to investigate its performance with hypersaline feed solutions. Direct solvent extraction (DSX) of nickel involves the separation of nickel and cobalt directly from the pregnant liquor stream (PLS) by solvent extraction, avoiding intermediate precipitation and re-leach stages. The result is a feed solution to the solvent extraction circuits containing high concentrations of soluble metal ions such as calcium and magnesium, resulting in some precipitations. The problem is exacerbated by the use of hypersaline process water such as those in Western Australia, which hosts many nickel laterite deposits. The effect of high calcium concentration is of particular interest because its presence in the PLS is unavoidable even in operations with access to good quality process water, as lime and limestone remain the preferred choices as neutralising agents. This paper discusses the results of an investigation on the extraction behaviour of nickel and calcium from hypersaline solutions - {both synthetic and actual plant solutions - {using Versatic 10. It includes studies on the kinetics of nickel and calcium extraction.

2:50 PM

Application of Solvent Extraction for the Separation of Molybdenum from Nano-Crystalline Cobalt Electrodeposition Effluents: *M. Olliazadeh*¹; R. Wu²; J. H. Haung²; *A. M. Alfantazi*²; ¹The University of Tehran, Dept. of Mining Engrg., Tehran Iran; ²University of British Columbia, Dept. of Metals & Matls. Eng., Vancouver, BC Canada

The present study was performed to develop a novel process for solvent extraction of molybdenum and cobalt from an acidic solution generated by a new electrodeposition process of nanocrystalline cobalt alloys. Solvent extraction is a common practice in hydrometallurgical and refining processes to produce metals, however its application for separation of molybdenum and cobalt from this specific solution is new, because molybdenum and cobalt are not commonly associated together in nature. Five commercial organic extractants were examined for extraction of cobalt and molybdenum from synthetic acidic solutions with pH ranged from 1 to 5. Preliminary results showed that at pH 2, any of the Cyanex 923, Alamine 336, Aliquat 336 and Hostarex A327 could be used to extract 99% of molybdenum

from solutions, while from pH 3 to 5, Aliquat was able to extract about 100% of Mo. Cobalt extraction, on the other hand, varied from 15% to 23% at pH 3 and 30% to 53% at pH 2 using different extractants. Comparison of results revealed that Aliquat 336 and Cyanex 923 could act more effectively than others, thus the effect of metal concentration was further considered with these two extractants. Based on results obtained, Aliquat 336 was applied on a mixed solutions of cobalt and molybdenum at various pHs. The results showed that molybdenum could be extracted as much as 99% from a mixture of Mo and Co at acidic pHs, while less than 1% of cobalt was separated at pH 2 to 4 simultaneously. The cobalt extraction was about 4.5% at pH 1.

3:15 PM Break

3:30 PM

Recovery of Phosphoric Acid in Waste Acid Mixture Discharged from the Liquid Crystal Industry by Solvent Extraction: *Junji Shibata*¹; Masataka Morikawa¹; Norio Yoshikawa¹; Norihiro Murayama¹; Hideki Yamamoto¹; ¹Kansai University, Dept. of Chem. Engrg., Fac. of Engrg., 3-3-35 Yamatecho, Suitashi, Osaka 564-8680 Japan

The waste acid mixture whose main component is phosphoric acid, is discharged from the etching process in liquid crystal production industry. In order to separate impurity acids from the phosphoric acid, trioctyl phosphate (TOP) is used as an extractant. TOP can extract acetic and nitric acids selectivity. The extraction and stripping operations are carried out for the acid mixture by beaker scale experiments and countercurrent multi-stages operations with a mixer-settler equipment. TOP selectively extracts the acetic and nitric acids in the acid mixture. From the results of McCabe-Thiele analysis obtained by beaker scale tests, the extractions for acetic and nitric acids are approximately 100%, respectively, by 6-stage extractions with the phase ratio (A/O) of 0.4. On the other hand, almost all of acetic and nitric acids are stripped with water from the organic phase by 4-stage strippings with the phase ratio (A/O) of 1.0. About 95% of acetic and 98% of nitric acids can be removed from the acid mixture without extracting phosphoric acid in case of the mixer-settler equipment operation.

3:55 PM

Phosphoric Acid Extraction from an Uranium-Phosphorous Liquor: *Jeaneth S. Benedetto*¹; Carlos A. Morais¹; ¹Cidade Universitária-Pampulha, Centro do Desenvolvimento da Tecnologia Nucl., CDTN/CNEN, CEP: 30 123-970, Belo Horizonte, MG Brasil

The physical and chemical upgrading process developed for the phosphoro-uraniferous ore body, located in the state of Ceará-Brazil, consists of three basic steps: Concentration of the phosphate bearing uranium by flotation, chemical dissolution of the concentrate by wet phosphoric acid route and extraction of uranium by solvent. In this process two products are obtained: uranium and phosphoric acid. The purpose of this work is to develop technological know-how by phosphoric acid purification

though an extraction of P₂O₅ by solvents, in order to supply the regional market with this product. It was investigated two lines of research. In one of that the uranium was extracted before the phosphoric acid purification. The second line the phosphoric acid was extracted before uranium recovery. The comparison of the two processes showed in this work. Experimental work has been developed in laboratory scale to select and optimize the process conditions and variables. Following that a complete research of extraction and stripping in pulsed perforated-plate columns made of glass, in pilot scale has been carried in order to investigate the main operational and process variables such as: phase relation, residence time and the hold up. The first experiments showed good results of phosphoric acid extraction using a raffinate sample obtained from the uranium extraction process. It was possible to obtain a high purity phosphoric acid that can be used in animal food or others applications.

4:20 PM

Indium Recovery from Sulfuric Solutions: A Comparative Study Involving Acidic Organophosphorus Extractants: Pedro Miguel Rosário¹; Paulo Jorge Martins¹; *Ana Paula Paiva*¹; ¹Faculdade de Ciências da Universidade de Lisboa, Dept. de Química e Bioquímica, Rua Ernesto de Vasconcelos, Bloco C8, Campo Grande, Lisboa 1749-016 Lisboa Portugal

Indium is industrially produced using leaching, cementation and electrorefining, and solvent extraction is often used to recover it from leach residues. The most common organophosphorus acids are widely applied to indium recovery from aqueous solutions, but the information available in the literature is often difficult to correlate. In this work it is aimed to compare the extraction performance exhibited by phosphoric (D2EHPA), phosphonic (Ionquest 801), phosphinic (Cyanex 272) and dithiophosphinic (Cyanex 301) acid derivatives towards In(III) recovery from a diluted sulfuric solution. Equilibrium extraction isotherms were obtained. Plots of %E vs. pH were established for D2EHPA, Ionquest 801 and Cyanex 301, denoting their behavior towards the extraction of similar concentrations of In(III), Fe(III), Fe(II) and Zn(II). Cyanex 301 is the least selective towards In(III), whereas D2EHPA and Ionquest 801, both for a pH=0.5, do not extract Zn(II) at all. Stripping of In(III) has also been studied using sulfuric and hydrochloric acid, showing that the metal ion can be efficiently stripped from Ionquest 801 and D2EHPA. In(III) from Cyanex 301 is very difficult to strip. The plots of log D vs. log [extractant] or vs. pH allowed the evaluation of the approximate stoichiometry of the In(III) extracted species by the four ligands.



4:45 PM

Extraction of Gd³⁺ by Bis (2,4,4-Trimethylpentyl)

Phosphinic: Muhammad Idris Saleh¹; Md Fazlul Bari¹; Bahruddin Saad¹; ¹Universiti Sains Malaysia, Sch. of Chem. Scis., 11800 Pulau, Pinang, Malaysia

The extraction of Gd³⁺ from nitrate-acetate medium using {bis (2,4,4-trimethylpentyl) phosphinic acid, H₂A₂, Cyanex 272} in toluene has been investigated as a function of Gd³⁺, H⁺, nitrate and acetate ion concentration in the aqueous phase, temperature, phase contact time and the extractant concentration in the organic phase. The equilibrium is reached within 2 minutes. The distribution ratio decreases with increasing Gd³⁺ concentration up to 3.82 mM Gd³⁺, after that increases up to 5.02 mM Gd³⁺ but decreases thereafter. The extraction slightly decreases with increasing nitrate ion concentration in the aqueous phase. Results at lower loadings suggest that extraction occurs via the following reaction: $[Gd(Ac)_2]^{++} + 3H_2A_2 \rightarrow [Gd(Ac)_2 \cdot 3HA] + Ac^- + 2H^+$. Loading studies suggest that variation of the extraction equilibrium reaction occurs during the course of loading and at high loading Gd³⁺, GdA₃ species is formed in the organic phase. The temperature dependence data give a DH value of 56 kJ mol⁻¹. The equilibrium constant, K_{ex} at lower loading is $10^{-1.35} \pm 0.095$. The loading capacity of Cyanex 272 for Gd³⁺ is 8.148 g Gd³⁺/100 g Cyanex 272.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification II: Precipitation III & Electrowinning I

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Tuesday PM
August 26, 2003

2:00 PM

Gibbsite Crystal Growth from Caustic Aluminate Solutions in Laminar, Turbulent and Cascading Flows, Laboratory Precipitators: Tian Li¹; Dianne Bedell¹; Iztok Livk¹; Dean Ilievski¹; ¹CSIRO Minerals, A J Parker CRC for Hydrometall., PO Box 90, Bentley, WA 6982 Australia

Molecular crystal growth during gibbsite precipitation from caustic aluminate solution was studied in this work. Three different types of laboratory precipitators were used, namely, Taylor-Couette precipitator (TCP), stirred tank precipitator (STP) and bottle roller precipitator (BRP). The laboratory precipitators were operated under completely different hydrodynamic conditions. The TCP and STP were operated under laminar and turbulent flows regimes, respectively, while the BRP was operated in a complex flow regime, where fluid flows was generated by the end-over-end rotation of the bottles. The precipitation experiments were conducted at the same temperature, initial liquor composition and seed type. Molecular crystal growth rate was extracted from the precipitation data using a differential parameter estimation technique. Gibbsite crystal growth estimates from the current work were tested against crystal growth theories and showed consistent results with previous gibbsite crystal growth studies, published in the literature.

2:25 PM

Reactions of Carbon Dioxide with Tri-Calcium Aluminate: Peter Smith¹; Russell Penniford¹; ¹CSIRO Minerals, AJ Parker CRC for Hydrometall., Waterford, WA Australia

Tri-calcium aluminate (TCA) is one of the most dominant alkaline components of the red mud residue from the Bayer process. Partial neutralisation of residue using CO₂ has been trialed at one of Alcoa's refineries in Australia. This paper outlines the chemistry of CO₂ neutralisation of TCA under Bayer conditions. CO₂ neutralisation of the liquor is fast. It results in the formation of amorphous aluminium hydroxide and dawsonite that agglomerate together. Neutralisation of solid TCA by carbonation is slower and leads to the formation of calcite, dawsonite and amorphous aluminium hydroxide. TCA dissolution in partially neutralised 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 optimises the neutralisation process.

2:50 PM

Electrolytic Copper Electrowinning - An Historical Perspective: Tim Robinson¹; ¹Phelps Dodge Mining Company, Process Tech. Ctr., 9780 E. Sanchez Rd., Safford, AZ 85546 USA

Commercial electrowinning of cathode copper from sulphate electrolytes and leach solutions has been practiced in the southwestern USA and South America since the early 1900's. This paper reports on the process technology developments in copper electrowinning from this latter time period to present day. These process technology components

include operating parameters, mist suppression methods and design of electrodes, cells and material handling. Over the past century these developments have resulted in improved cathode purity and tank house productivity.

3:15 PM Break

3:30 PM

Effect of Impurity Presence in Zinc Chloride Electro-winning: *C. Lupi*¹; D. Pilone¹; E. Beltowska-Lehman²; ¹Università di Roma, Dip. ICMMPM, Via Eudossiana 18, Roma 00184 Italy; ²Polish Academy of Sciences, Inst. of Metall. & Matl. Sci., 25 Reymonta Str., Krakow 30-059 Poland

Zinc chloride electro-winning present difficulties in obtaining smooth, compact and dendrites free deposits with a high current efficiency. Main reason for this is the presence in the electrolyte of undesirable metal ions, more electropositive than zinc. However, it is hard to define a level of impurities tolerable in zinc deposition and in spite of several works in this field, the undesired metal ion action mechanism is still not clearly understood. The influence of the above mentioned metal ions as well as their synergic effect on zinc deposition process from chloride electrolyte and on the obtained deposit morphology has been studied. The addition of organic additives that can reduce the harmful effect of such impurities on the zinc reduction has been investigated too.

3:55 PM

The Effects of Organic and Inorganic Impurities on the Physical Properties of Nickel Cathodes: Daniel Kittelty¹; Michael Nicol¹; ¹Murdoch University, A J Parker Ctr. for Hydrometall., South St., Murdoch, Western Australia 6150 Australia

A fully instrumented laboratory electro-winning cell has been used to produce nickel cathodes from synthetic solutions containing various impurities in order to evaluate the effects of both metallic ions and organic reagents (from prior solvent extraction processes) on the quality of the electrodeposited nickel. The conditions used were typical of those employed in industrial electro-winning operations. The impurities were found to alter crystal size and shape, the development of hydrogen pits on the deposit surface, the incorporation of metal hydroxides in the deposit, the internal stress and the current efficiency. In particular, an increasing concentration of aluminium ions resulted in an initial highly deleterious effect which was replaced by a positive influence at higher concentrations. A model which involves the buffering effect of the aluminium on the pH at the cathode surface has been proposed.

4:20 PM

Determination of Crystallite Size and Surface Roughness of Copper Deposits for Electro-winning in the Presence of Additives: *Cesimiro Fabian*¹; Sharon Ness²; Michael Ridd³; Thomas Lancaster⁴; Gregory Griffin¹; ¹James Cook University, Sch. of Engrg., Townsville, QLD Australia; ²James Cook University, Advd. Analytical Ctr., Townsville, QLD Australia; ³James Cook University, Sch. of Pharmacy & Molecular Scis., Townsville,

QLD Australia; ⁴Western Metals Copper Limited, Mount Gordon Ops., Gunpowder via Mount Isa, QLD Australia

The crystallite size of copper electrodeposits was determined using X-Ray powder diffraction analysis. Crystallite size was calculated for 4hours deposition thin films: these had been electrodeposited on a 316 stainless steel rotating cylinder electrode (RCE) in the presence and absence of additives. The profiles of crystallite size and surface roughness are related to the additive system. This technique forms part of electrochemical characterization techniques used to select/optimize an additive system for copper electro-winning and electrorefining to eliminate/reduce dendrite growth.

4:45 PM

Electrochemical Study and Control of Additives on the Process of Copper Electrorefining of the Sarcheshmeh Copper Complex: *Shahram Daneshpajoo*¹; A. Fadaeizadeh Bidari¹; B. Rezaei²; ¹Sarcheshmeh Copper Complex, R&D Div., Rafsanjan, Kerman Iran; ²Ispahan University of Technology, Coll. of Chem., Isfahan Iran

When copper electrorefined from acidic copper sulfate electrolyte without use of suitable additives, the cathodic deposit is rough and nodular. Such cathode roughness has detrimental effect in two ways. The nodular on dendrites growths can cause short circuits and thus reduced current efficiency for the electrorefining process. Also the rough cathode surface can cause entrapment of electrolyte and slimes resulting in contamination of the deposited copper. Organic compound such as glue and thiourea are normally added to electrolyte in small quantities to eliminate or control these damaging effects. These substances are usually codeposited at the cathode, and by various mechanisms they influence the morphological and kinetic aspects of electrolytic crystal growth. The surface active substance influence on the polarization potential of the cathode electrode. According to the results of copper refinery, for obtaining a homogeneous fine crystalline precipitation, glue and thiourea must be added to electrolyte. Concentration of glue and thiourea are very important on process of copper refinery. In this study, considered, the polarization potential of copper was varied with changing concentration of glue and thiourea. The relation between variation of potential and concentration of glue and thiourea was studied separately by using DVP (Differential Pulse Voltammetry) technique. The calibration curve were plotted. For this plot dynamic range obtained for thiourea and glue respectively is from 0.2 to 10 ppm and 0.2 to 8 ppm, and also relative standard deviation (%) for thiourea in 0.6 ppm is 1.95 and for glue is 1.94 in 4 ppm. This method was applied successfully in the real sample.



International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Technology Application: Environment

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Tuesday PM
August 26, 2003

2:00 PM

Metal Waste Prevention by SLM: I. Van De Voorde¹; J. Vander Linden¹; S. Vanderkerken¹; H. Dhanens¹; R. F. De Ketelaere¹; ¹Chemical and Biochemical Research Centre KaHo Sint-Lieven (CBOK), Group Environml. Tech. & Surface Treatment, Gebroeders Desmetstraat 1, Ghent B-9000 Belgium

In this paper, results are presented concerning the search to implement Supported Liquid Membranes (SLM) for the recovery of copper, nickel and zinc (ROPE, SERENI and SEREMET European projects) from effluents and also prevent metal waste. A study of the influence of the individual parameters and of their combined on mass transfer in small scale laboratory equipment has been performed, enabling to set forward the appropriate operating conditions for a pilot plant installation. For SLM the pilot plant has been tested extensively, including short and long term runs, with different real process solutions. It was demonstrated that the SLM technology is applicable for solutions containing 700 ppm of metal but also to the treatment of solutions with low metal content of origins other than plating shops.

2:25 PM

Separation of Cu-Co and Ni from Sulfuric Acid and Chloride Solutions by Solvent Extraction: *Yang Jiaoyong*¹; Li Junping²; Zhong Yonggong²; ¹Beijing Extract Metallurgy and Technology Development Company, Ltd. China; ²Chengdu Shuangliu Nonferrous Metal Smelter

A process including extraction of copper-Cobalt and nickel from smelting slags in nonferrous metal metallurgy, and then production of pure chemicals of corresponding metallic salts is presented in this paper. The slag is leached with sulfuric acid and chloride solutions, resulting in leach solutions with high contents of valuable metals and several

impurities. The purification and enrichment of the valuable metals are achieved by a series of processes, consisted of extraction copper from the leach solution with Acorga M5640, purification with D2RHPA and separating nickel and cobalt with PC88. The control of technological parameters and equipment arrangement in solvent extraction are emphasized in the paper. Finally, production of CuSO₄, and CoSO₄ and NiSO₄, and their quality are briefly described.

2:50 PM

The SO₂/O₂ System as a Novel Technology for the Remediation of Contaminated Sediments: *Maurizio Marezio Bertini*¹; Paul F. DUBY¹; ¹Columbia University, Henry Krumb Sch. of Mines, 500 W. 120 St., Mudd Bldg. #918, New York, NY 10027 USA

Successful treatment of contaminated sediments was achieved by sparging either 0.5 M NaOH solutions or distilled water with the SO₂/O₂ gas mixture. Metals such as Cu, Pb, Cr and Cd were successfully removed in a relatively short time. The effect of temperature and pH was investigated. Higher temperatures produced faster and higher recoveries, with Pb and Cr more affected to temperature increase than Cu and Cd. The removal of copper, up to 50%, was achieved in alkaline solutions through the formation of copper sulfite complexes. The complete removal of metals such as Cu, Pb, Cr and Cd required that part of the treatment be carried out in acidic solutions. A preliminary cost analysis was carried out.

3:15 PM Break

3:30 PM

Reclamation of Cobalt and Copper from Copper Converter Slags: *Tong Deng*¹; Yunhan Ling¹; ¹Chinese Academy of Sciences, Inst. of Proc. Engrg., PO Box 353, Beijing 100080 China

Clean processing of copper converter slags for reclaiming cobalt and copper could be a challenge. An innovative and environmentally benign approach for recovering metal values from such a slag was proposed in the present work. Curing the slag with sulfuric acid, without re-smelting or roasting as practiced currently in industry, made it amenable to leaching and more than 95% of cobalt and up to 90% of copper was extracted together with iron by water leaching, leaving silica behind in a residue. Copper in the leach liquor was recovered by cementation with iron and the dissolved iron crystallized as monohydrated ferrous sulfate. Cobalt in the pregnant solution rich in iron was recovered by either cementation or sulfide precipitation. Chemical and mineralogical characterizations of the slag and its processed products were examined and compared to ascertain the nature of changes during curing and leaching. Operation variables were also investigated and optimized.

3:55 PM

Use of Lead Isotopes to Determine Sources and Transport of Lead Contamination: *J. Brent Hiskey*¹; Orestes Morfin²; Martha H. Conklin²; Timothy L. Corley²; ¹University of Arizona, Dept. of Matls. Sci. & Engrg., Coll. of Engrg. & Mines, Tucson, AZ 85721 USA; ²University of Arizona, Dept. of Hydrology & Water Resources, Coll. of Engrg. & Mines, Tucson, AZ 85721 USA

There are numerous active, inactive, and abandoned metals extraction facilities in the Western US. Often located near readily-accessible surface water, such sites have contributed to pollution of an estimated 320 km of surface water in Arizona. Elevated levels of Pb, Cd, and As have been found in fish in the perennial reach of the Aravaipa Creek located near the Eastern entrance of the Aravaipa Wilderness Area of Arizona. Several abandoned mines, piles of mine waste, and tailings from lead/zinc processing plants have been implicated as potential sources of this contamination. This study emphasizes the application of controlled sample digestion, sequential metal extraction, and lead isotope ratios as a means of differentiating between these sources. Pb isotope ratios in samples, obtained by ICP-MS analysis, describe two distinct contributors. Locations with mixed oxide/sulfide mineralization generally have lower 208Pb/204Pb and 207Pb/204Pb signatures, whereas with predominantly primary mineralization (i.e. PbS) higher isotopic ratios are observed. Pb isotope ratios from perennial reach sediments are closely correlated with those obtained for the lead sulfide samples. The study concludes that Pb isotope data may successfully be reconciled to provide usefully constraints on Pb transport and its eventual fate. Importantly, this information will help identify specific targets requiring remediation and eliminate others.

4:20 PM

US Plants Operated Solely to Recycle Metal-Rich Wastes - An Update: *Paul B. Queneau*¹; ¹Paul B. Queneau, P.B. Queneau & Associates Inc./The Bear Group, 5906 McIntyre St., Bldg. 2, Golden, CO 80403 USA

Some twenty US plants solely devoted to recovering values from metal-rich wastes have established market niches based on one or more competitive advantages: superior process technology, access to key feedstocks, unique equipment, special knowledge of markets, and an appropriate exit for outfall water. Plant methodology, competitiveness, environmental, and changing economics are examined, with particular attention to feedstocks, technologies, products, and outputs.

4:45 PM

Recycling of ZnO Fly Dust to Produce Zinc by Hydrometallurgical Routes: *Jitka Jandová*¹; Vladimír Jirín²; Petr Dvořák¹; ¹Prague Institute of Chemical Technology, Technická 5, Prague 166 28 Czech Republic; ²Institute of Chemical Process Fundamentals Academy of Science, Rozvojová 135, Prague Czech Republic

ZnO fly dust arising during the zinc removal from galvanized low alloy steel sheets was investigated on a laboratory scale to obtain electrolytic zinc. The dust, which comprised ZnO in combination with ZnFe₂O₄ and SiO₂

was contaminated by Mn, Pb, Al, Mg, Pb, Cu and Ca. The dust was leached in 0.5 and 1.0 M H₂SO₄ and/or in 20 and 30% NaOH at various temperatures and liquid-to-solid ratios to determine optimum conditions leading to the highest possible selectivity of the leaching and the efficiency of Zn extraction in minimum time and to reach sufficient Zn concentration for the subsequent electrowinning of zinc. The electrolysis was performed with refined zinc sulphate leach liquors and/or with untreated zinc caustic solutions. Effects of operational variables on Zn electrowinning have been studied for sulphate and caustic electrolytes.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching I: Thiosulfate I

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Tuesday PM

August 26, 2003

2:00 PM

A Review of the Chemistry, Electrochemistry and Kinetics of the Gold Thiosulfate Leaching Process: *P. L. Breuer*¹; M. I. Jeffrey¹; ¹Monash University, Dept. of Chem. Engrg., Clayton, Vic 3800 Australia

Environmental and public concerns and the banned use of cyanide for the recovery of gold in some parts of the world have heightened the search for an alternative lixiviant to cyanide. Thiosulfate appears to be the most promising alternative to cyanide due to thiosulfate being non-toxic, relatively cheap compared to cyanide and generally gold recoveries are similar to those of cyanide. The most widely researched thiosulfate process is one where copper ions and ammonia are added to the solution. This paper reviews the leaching of gold in thiosulfate solutions and the contributions of the research at Monash University to the understanding of the gold oxidation reaction in thiosulfate solutions, the solution chemistry when copper ions, ammonia and oxygen are present, the influence of the changing solution chemistry on the gold leach kinet-



ics, and the application of thiosulfate in the leaching of gold from ores. It is clearly shown that the gold oxidation rate is hindered in thiosulfate solutions. In the presence of copper ions the gold oxidation rate though is significantly enhanced and thus is why copper(II) is more effective than other oxidants in the thiosulfate leach system. The copper-ammonia-thiosulfate leach solution chemistry is shown to be very complex, especially in the presence of oxygen as the rate of thiosulfate oxidation increases and the majority of the copper ions are not maintained in the copper(II) oxidation state. The thiosulfate oxidation rate must also be maintained low as an intermediate thiosulfate oxidation product hinders gold leaching. In optimising the recovery of gold from ores with copper-ammonia-thiosulfate leach solutions it is important to evaluate and minimise any negative effect an ore may have on the leach solution chemistry and hence gold leaching.

2:25 PM

Thermodynamics and Kinetics of the Dissolution of Gold in Ammoniacal Thiosulfate Solutions: *Gamini Senanayake*¹; XinMin Zhang¹; Michael Nicol¹; ¹Murdoch University, A J Parker Ctr. for Hydrometall., South St., Murdoch, Western Australia 6150 Australia

Despite the renewed interest in gold leaching with ammoniacal copper thiosulphate solutions, previous kinetic studies have suffered mainly due to a lack of detailed understanding of the nature of metal ion speciation and leaching chemistry. Although published Eh-pH diagrams indicate that the gold(I) diammine complex is more stable than the dithiosulfato complex at pH values greater than 9, recent results obtained in this laboratory have suggested that the reported stability of the diammine complex is overestimated by several orders of magnitude. Eh-pH diagrams based on the recently determined stability constants, showing the stability regions of relevant species are presented. The kinetics of dissolution of colloidal gold in ammoniacal copper thiosulfate show a reaction order of 0.4-0.6 with respect to copper(II), ammonia and thiosulphate. The data can be rationalized on the basis of a shrinking sphere kinetic model. It is shown that the comparison of results from the present study with reported data for the dissolution of gold metal can be used to suggest possible chemical reactions on the gold surface and an alternative reaction mechanism.

2:50 PM

Can a Thiosulfate Leaching Process be Developed which Does Not Require Copper and Ammonia?: *Irsan Chandra*¹; Matthew Ian Jeffrey¹; ¹Monash University, Dept. of Chem. Engrg., Clayton, Vic 3800 Australia

It is generally recognised that the gold thiosulfate leaching system requires the presence of copper and ammonia in order for acceptable leaching kinetics to be observed. However, the presence of copper and ammonia complicate the chemistry of the system as thiosulfate is rapidly oxidised

by oxygen under these conditions. In addition, the environmental impact of ammonia would need to be considered before the adoption of this system. This paper describes fundamental studies into the thiosulfate oxygen system. The two reagents for this system are thiosulfate and oxygen, and leaching is carried out at $\text{pH} < 7$. It will be shown using electrochemical techniques that both the reduction of oxygen and the oxidation of gold to gold thiosulfate are hindered. Thus, if leaching is to work under these conditions, then both half reactions need to be improved. The use of additives such as thiourea and lead have been shown to dramatically improve the oxidation of gold and the reduction of oxygen respectively. The leaching of gold in the presence of such additives is discussed.

3:15 PM Break

3:30 PM

Towards an Understanding of Copper(I) Speciation and Reactivity in the Copper-Ammonia-Thiosulfate Lixiviant System: *Jay Black*¹; Leone Spiccia¹; D. C. McPhail²; ¹Monash University, Sch. of Chem. & Ctr. for Green Chem., PO Box 23, Melbourne, Victoria 3800 Australia; ²The Australian National University, CRC LEME & Dept. of Geology, Canberra, ACT 0200 Australia

Research into alternative gold leaching agents to cyanide has identified thiosulfate, in combination with a Cu(II)-ammine catalyst, as a promising, more benign alternative.^{1,2} Studies of this process highlight the need to examine the chemistry controlling thiosulfate stability, high reagent consumption impacting on viability. A Cu(II)-tetrammine acts as an electrocatalytic oxidant, increasing gold dissolution rates.¹ Although the Cu(II)-NH₃ chemistry is well understood, the addition of thiosulfate produces radicals, Cu(I)/(II) complexes and other sulfur species, many of them poorly characterised.² Since the reduction of Cu(II) to Cu(I) accompanies thiosulfate oxidation and gold leaching, an understanding of Cu(I)-ammonia-thiosulfate speciation and the mechanism by which oxygen regenerates Cu(II)-tetraammine is needed. With this in mind, we have used UV-Vis. spectrophotometry to identify the complexes present in the Cu(I)-NH₃-S₂O₃²⁻-Cl system and to determine their thermodynamic properties. We are currently studying the kinetics of oxidation of Cu(I) complexes by oxygen to determine optimal conditions for regenerating the Cu(II) catalyst. ¹M.G. Aylmore, D.M. Muir Min. Eng., 2001, 14, 148. ²E. Molleman, D. Dreisinger, Hydrometall., 2002, 66, 1.

3:55 PM

The Role of Catalysts in the Thiosulfate Leaching of Gold: *Anita E. Lam*¹; David B. Dreisinger¹; ¹University of British Columbia, Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V4K 4K2 Canada

The thiosulfate leaching of gold generally requires the addition of "catalysts" such as soluble copper and ammonia in order to obtain reasonable leaching rates and gold extrac-

tions. Unfortunately, the same catalysts that accelerate gold leaching also tend to accelerate thiosulfate oxidation to tetrathionate and other species. It is therefore imperative that a detailed understanding of the role of the catalysts be obtained. It is equally important for plant application that a method of assessing the effectiveness of catalysts be developed. In this work the role of the copper and ammonia catalysts was studied using geochemical modeling for speciation prediction, thiosulfate leaching of gold ores and chemical analysis of resulting leach solutions. Results of these studies will be presented and discussed.

4:20 PM

Alternative Copper(II) Catalysts for Gold Leaching: Use of Multidentate Ligands to Control Thiosulfate Oxidation:

*Tiffany Brown*¹; Adam Fischmann¹; Leone Spiccia¹; D. C. McPhail²; ¹Monash University, Sch. of Chem. & Ctr. for Green Chem., PO Box 23, Melbourne, Victoria 3800 Australia; ²The Australian National University, CRC LEME & Dept. of Geology, Canberra, ACT 0200 Australia

In the thiosulfate gold leaching process, complexation of gold with thiosulfate follows electrocatalytic oxidation by Cu(II)-ammines.¹ Unfortunately, Cu(II) also catalyses the undesirable conversion of thiosulfate to polythionates. We have been seeking alternatives to ammonia, which fulfil the role of ammonia but minimise thiosulfate decomposition. These studies have involved the determination of the rate of thiosulfate oxidation by the Cu(II) complexes, from UV-Visible spectral changes, and redox potentials. They are to be followed by gold leaching trials. Various ligand classes, including pyridyls, polyamines, aminocarboxylates and picolinates, have been tested and the majority found to inhibit thiosulfate decomposition. Interesting variations in reactivity with the nature and denticity of the ligand and L/M ratio will be reported. A spectrophotometric study of the oxidation of thiosulfate by a Cu(II)-tren complex (tren = tris(2-aminoethyl)amine) has indicated that several processes are occurring, two of which involve the formation and decay of a tetrathionate radical. ¹M.G. Aylmore, D.M. Muir Min. Eng., 2001, 14, 148.

4:45 PM

Effect of Minerals on Thiosulfate Leaching of Gold:

*Mark G. Aylmore*¹; David M. Muir¹; Christine Rae¹; ¹CSIRO Minerals, AJ Parker Co-op. Rsch. Ctr. for Hydrometall., PO Box 90, Bentley, Perth, Western Australia 6982 Australia

The effect of some typical oxide and sulfide minerals, as well as activated carbon, on synthetic gold thiosulfate leach solutions has been studied. It is shown that the presence of pyrite and goethite in a synthetic gold ore slurry have a significant effect on the adsorption and stability of precious metals, copper and polythionates in ammoniacal thiosulfate solutions. Adsorption of tetrathionate in particular leads to significant gold and silver losses. The adsorption of copper on mineral surfaces inhibited gold and silver loss, even in the presence of tetrathionate. However goethite was found

to strongly adsorb copper(II). It is concluded that gold extraction from natural ores is lower than that obtained with cyanide as a result of sorption or precipitation reactions. Furthermore, the presence of silver in solution catalyses the precipitation of a mixed copper/silver/gold sulfide in ammoniacal thiosulfate solutions containing tetrathionate.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching II: Fundamentals II

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Tuesday PM

August 26, 2003

2:00 PM

The Mechanism of the Dissolution of Chalcopyrite - An Electrochemical Study:

*Isabel M. Lazaro-Baez*²; Michael J. Nicol¹; ¹A J Parker Ctr. for Hydrometall., South St., Murdoch, Western Australia 6150 Australia; ²Instituto de Metalurgia, Av Sierra Leona No 550, Col. Lomas 2a Seccion, San Luis Potosi SLP CP 78210 Mexico

A detailed study has been undertaken into the electrochemistry of the leaching of chalcopyrite in acidic solutions containing ferric ions. Mixed potential measurements have shown that the maximum potential achievable on a chalcopyrite disk in a ferric sulphate medium lies within the so-called passive or prewave region in the anodic behaviour of chalcopyrite. The formation of a copper sulphide-like species on the chalcopyrite surface in this potential region has generally been suggested as being responsible for the reduced reactivity of the mineral to leaching. A careful rotating ring-disk electrode (RRDE) study has enabled data to be obtained for the stoichiometry of the initial dissolution reaction to be obtained. Thus, in addition to the detection of soluble iron and copper as products in this potential region, a soluble sulphur species has also been detected. A comparison of the experimental with the expected collection efficiencies of the products



on the ring has revealed that this soluble sulphur species is likely to be thiosulfate. The ring-disk electrochemical results also suggest that the formation of a copper sulphide phase on the surface is unlikely. The characteristic transient anodic behaviour of chalcopyrite in this potential region has been interpreted in terms of a rate limiting solid-state diffusion process. Thus, extrapolated rates based on reported measured solid-state diffusion coefficients for the mineral at elevated temperatures have been shown to be consistent with the potentiostatic current-time transients. The results of this investigation have been combined with a parallel study of the non-oxidative behaviour of chalcopyrite in order to derive a model for the dissolution process which is consistent with other published studies of the electrochemistry and dissolution of the mineral.

2:25 PM

The Sonochemical Leaching of Chalcopyrite: *Nedam Abed¹*; David B. Dreisinger²; ¹Umicore Canada Inc., R&D Dept., 10110-114th St., Ft. Saskatchewan, Alberta T8L 4K2 Canada; ²University of British Columbia, Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada

A fundamental study of the sonochemical leaching of chalcopyrite in ferric ion media has been performed to understand and quantify the effects of sonication and other parameters on leaching reactions. The study covers sulfate and chloride media. The main leaching reaction was found to be dependent on temperature and initial particle size, but less dependent on ferric ion concentration. Leaching was performed under a variety of sonication, thermodynamic and physical parameters. The use of ultrasound activation showed a clear improvement in leaching kinetics and amount of copper extracted. Sonication has a catalytic-like effect on the leaching reaction. Compared to experiments without sonication, reaction rates were 2-3 times faster at the same temperature and can be faster by a factor of 20 for the same initial particle size. Regardless of initial particle size, the amount of copper extracted is comparable under sonication, and can be twice that under chemical leaching, implying the avoidance of fine particle grinding. Sonochemical leaching was found to be only temperature dependent, where the best copper extraction was at 75°C. Parabolic leaching kinetics were established and confirmed from the estimation of different thermodynamic parameters and dependence on other physical parameters.

2:50 PM

Leaching of Chalcopyrite in Ammoniacal Solutions Sparged with SO₂/O₂ Gas Mixture: *Maurizio Marezio Bertini¹*; Paul F. DUBY¹; ¹Columbia University, Henry Krumb Sch. of Mines, 500 W. 120 St., Mudd Bldg. #918, New York, NY 10027 USA

Ammonia-ammonium sulfate solutions were sparged in a glass reactor with a SO₂/O₂ gas mixture (2% SO₂ and 98% O₂) to leach copper from pure chalcopyrite and chalcopy-

rite concentrate. The SO₂/O₂ mixture produces higher and faster extractions than O₂ by itself. The effect of temperature, particle size and free ammonia concentration was investigated. The fastest and highest recoveries were obtained at 80°C from a chalcopyrite concentrate with a d80 equal to 13 mm, with about 83 gpl free ammonia, an average pH equal to 8.75 and a stirring speed of 500 rpm. The extraction process was controlled by diffusion through a product layer, according to the shrinking core model, with an activation energy of 41 kJ/mole.

3:15 PM Break

3:30 PM

Raman Investigation of Sulfide Leaching: *Gretel Kristen Parker¹*; Ronald Woods¹; *Greg A. Hope¹*; ¹Griffith University, Sch. of Sci., Kessels Rd., Nathan, Brisbane, Queensland 4111 Australia

In situ Raman spectroscopic investigations of copper sulfides in leach solutions have been undertaken. Coupling potentiodynamic techniques to Raman spectroscopy produces a powerful tool for studying mineral surface response to changing conditions, while ESEM and high-vacuum techniques provide complementary information on surface structure and composition ex situ. Ore samples and synthetic films oxidatively leached in acid developed regions of a covellite-like phase with bonded sulfur pairs. The potential of the appearance of S-S bonds indicates nonstoichiometric metastable phases exhibit this pairing. Leaching of chalcopyrite led to non-homogeneous product distribution. Raman spectroscopy was able to identify the products formed on the mineral surface in situ while leaching was occurring. Mapping and imaging demonstrated a surface distribution of the products which can be related to composition and structure changes of the mineral surface. The implications of these findings with respect to the feasibility of hydrometallurgical processing of copper sulfides are discussed.

3:55 PM

Studies on Kinetics of Sulfur Oxidation: Key Factor on the Copper Sulfide: *Eduardo Patiño¹*; Ricardo Sandoval¹; Jean Frenay²; ¹University Arturo Prat, Engrg. Dept., Iquique Chile; ²Universite de Liège, Service de Traitement des Minerais Belgium

Bioleaching is a robust metallurgical process with many advantages, including low capital expenditures and operating cost, suitability for processing low and complex grade ores, operational simplicity and environmental advantages to pressure oxidation and smelting. However, the complete leaching of copper bearing sulfide ore and waste is slow and incomplete and this is thought to be as a result of formation of a passivating layer. The nature of the passivating layer is still under considerable debate. The current theories on the nature of the passivating layer include the production of jarosite, ferric hydroxy sulfate, sulfur or an iron deficient polysulfide like covellite. On the other hand, the microbiological ox-

dition of iron and sulfur constitutes two key processes in mineral biooxidation, one each with quite separate aspects: 1) an anoxic, abiotic reaction (ferric iron attack) and 2) a biological reaction (regeneration of the oxidant) and chemical or biological sulfur oxidation. Optimum conditions for these reactions may be quite different. However, little work has been done on the kinetics of growth and sulfur oxidation. This paper investigates the comparative kinetics of sulfur chemical and biological oxidation and quantifies the effects of parameters as Eh, temperature and ferric concentration.

4:20 PM

The Reductive Dissolution of Manganese Dioxide with Iron(II) and Sulphur Dioxide: Kinetics and Mechanism: *Gamini Senanayake*¹; ¹Murdoch University, A J Parker Ctr. for Hydrometall., South St., Murdoch, Western Australia 6150 Australia

Iron(II) and sulphur dioxide are efficient reducing agents for manganese dioxide to produce Mn(II) solutions. The leaching of limonitic laterite and manganiferous ores with sulphur dioxide in acid media produces Fe(II) which in turn catalyses the leaching of manganese dioxide. Therefore, the kinetics of manganese dioxide dissolution plays an important role in the selective leaching of manganese from these materials. This paper presents a critical analysis of the reductive dissolution kinetics of synthetic manganese dioxide to compare and contrast the effect of sulphur dioxide and Fe(II) in acid media containing sulphate or perchlorate anions. Both one-electron and two-electron mechanisms are considered when sulphur dioxide is used as the reductant. The current knowledge on chemical speciation is used to modify the published Eh-pH diagrams to show the effect of anions. Heterogeneous and electrochemical reaction kinetic models are combined to propose reaction mechanisms which rationalise the dissolution kinetics.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification I: Solvent Extraction III

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday AM
August 27, 2003

8:30 AM

Gold Solvent Extraction from Alkaline Cyanide Solutions Using LIX 79 Extractant: *Jesús L. Valenzuela*¹; Salvador Aguayo¹; José R. Parga²; Roy G. Lewis³; ¹University of Sonora, Dept. of Chem. Engrg. & Metall., Hermosillo, Sonora 83000 México; ²Institute Technology of Saltillo, Dept. Metal-Mech., Saltillo, Coahuila 25280 México; ³Cognis Corporation, Tucson, AZ 85745 USA

The solvent extraction for gold from alkaline cyanide solutions has been investigated using LIX 79 guanidine extractant. Different variables that could affect the extraction system were evaluated: time, aqueous pH, extractant and modifier concentrations, amongst others. From the pH isotherms it was found that aurocyanide can be extracted in alkaline media. The extraction isotherms for the aurocyanide and other cyanoanions complexes were compared and the selectivity was in the order Au>Ag>Cu>Zn>>Fe. The best separation with respect to other cyanoanions was found in the pH range of 10.5 to 11.2. The highest selectivity was obtained at 10% vol LIX 79 and 5% vol tri-decanol. Stripping of gold from loaded organic phases was carried out at pH greater than 12, using NaOH and NaCN solutions. These results were evaluated in a continuous circuit using an actual cyanide pregnant solution showing that solvent extraction is a viable alternative procedure for recovering precious metals.

8:55 AM

Preparation of Ultrafine Silver Particles by Solvent Extraction Techniques: *María Guadalupe Sánchez-Loredo*¹; Marco Martín González-Chávez²; Julia López-Martínez³; ¹Universidad Autónoma de San Luis Potosí, Inst. de Metalurgia, Sierra Leona 550, Lomas, San Luis Potosí 78210 México; ²Universidad Autónoma de San Luis Potosí, Facultad de Ciencias Químicas, Manuel Nava 6, San Luis Potosí 78210 México; ³Universidad Autónoma de San Luis Potosí, Facultad de Ciencias Químicas, Manuel Nava 6, San Luis Potosí 78210 México

Research efforts are devoted toward synthesis of silver nanoparticles due to the role played by silver in catalysis, as substrate for surface-enhanced Raman spectroscopy (SERS) and photographic processes. Particles with small size, narrow size distribution, and highest purity are chemically produced by reduction of metal complexes in organic media. The use of reducing agents was proposed as an alternative to conventional stripping in solvent extraction technology. In this work, solvent extraction of silver by the commercial extractants TBP, Cyanex 471x, Cyanex 301 and Cyanex 302, was studied. After loading, several reagents were used to prepare silver powders by reductive stripping. Both Cyanex 471x and TBP could be stripped by aqueous solutions of ascorbic acid. Silver



was recovered as fine particles, which were characterised by means of SEM, X-ray diffraction and spectroscopical techniques. The powder size and morphology were affected by the composition of the applied organic and aqueous reducing phases.

9:20 AM

Equilibrium Modifiers in Copper Solvent Extraction Reagents - Friend or Foe?: *Gary A. Kordosky*¹; Michael J. Virnig¹; ¹Cognis Corporation, 2430 N. Huachuca Dr., Tucson, AZ 85745 USA

Equilibrium modifiers, first introduced into copper solvent extraction reagents in the late 1960's, are widely used. Equilibrium modifiers affect the following properties of a copper solvent extraction reagent: copper extraction and stripping, copper/iron selectivity, reagent stability, crud generation and entrainment. These properties are discussed and some conclusions are drawn relating the structure of the modifier to the resulting properties of the copper solvent extraction reagent. The properties of a new highly selective, low viscosity modifier are given and discussed.

9:45 AM

Third Phase Formation in TBP Solvent Extraction Systems as a Result of Interaction Between Reverse Micelles: *Renato Chiarizia*¹; P. Thiyagarajan¹; M. P. Jensen¹; M. Borkowski¹; K. C. Littrell¹; ¹Argonne National Laboratory, Chem. Div., 9700 S. Cass Ave., Argonne, IL 60439 USA

Third phase formation, i.e., the splitting of the organic phase in two layers, is a common feature observed, under conditions of high loading, for many solvent extraction systems of both analytical and industrial interest. Although this phenomenon has been investigated in a large number of works, its structural and physico-chemical description is still lacking. In this work, small-angle neutron scattering (SANS) data for the tri-n-butylphosphate (TBP)-n-octane, Th(NO₃)₄-HNO₃ solvent extraction system have been interpreted using the Baxter model for hard-spheres with surface adhesion. The increase in scattering intensity in the low Q range, observed when increasing amounts of HNO₃ and/or Th(NO₃)₄ are introduced into the organic phase, has been interpreted as arising from interactions between reverse micelles containing three TBP molecules plus solutes in their polar core. This intermicellar attraction, under suitable conditions, leads to third phase formation.

10:10 AM Break

10:30 AM

Room-Temperature Ionic Liquids as Diluents for the Liquid-Liquid Extraction of Metal Ions: Promise and Limitations: *Mark L. Dietz*¹; Mark P. Jensen¹; James V. Beitz¹; Julie A. Dzielawa¹; ¹Argonne National Laboratory, Chem. Div., 9700 S. Cass Ave., Argonne, IL 60439 USA

The unique physicochemical properties of room-temperature ionic liquids (RTILs) have led to intense interest in these materials as alternatives to conventional organic solvents in a range of synthetic, catalytic, and electrochemical applications. Recently, there has been growing interest in their potential use in various separation processes, among them the liquid-liquid extraction of metal ions. Although certain RTIL-extractant combinations (e.g., crown ethers in 1-alkyl-3-methylimidazolium bis[(trifluoromethylsulfonyl) imides] have been shown to provide extraction efficiencies far exceeding those observed with conventional solvents, recent work suggests that the utility of RTILs may be limited by solubilization losses and difficulties in recovering extracted metal ions. In this work, we demonstrate that these limitations arise from differences in the mechanism of metal ion partitioning in RTIL systems versus conventional organic diluents and consider approaches by which they might be overcome.

10:55 AM

Effect of the Nanostructure of Reversed Micelles on the Extractability and Selectivity in Hydrometallurgical Liquid-Liquid Extraction: *Ronald D. Neuman*¹; Taleb H. Ibrahim²; ¹Auburn University, Dept. of Chem. Engrg., Auburn, AL 36849-5127 USA; ²American University of Sharjah, Dept. of Chem. Engrg., Sharjah UAE

The physicochemical nature of the metal-extractant aggregates that exist in the nonpolar organic diluent of acidic organophosphorus extraction systems has been a matter of debate over the years. Our laboratory has presented evidence that short rodlike reversed micelles form in the liquid-liquid extraction of nickel (II) ions by bis(2-ethylhexyl) phosphoric acid (HDEHP). However, the conventional picture of reversed micelles is not consistent with what is known about the extent and selectivity of nickel extraction by HDEHP. Therefore, in a marked departure from traditional concepts, Neuman and co-workers proposed at ISEC '96 that solubilized water molecules can exist in "open" water channels which are in contact with the nonaqueous solvent rather than in an inner core (or "closed" water channel) of the reversed micelles. The "open water-channel" model of reversed micelles has recently been confirmed on the basis of ¹H-NMR spectroscopy and molecular modeling studies. In addition, molecular modeling has been used to examine the effect of extractant molecular structure, metal ions (Ni (II), Co (II)), solvent aromaticity and temperature on the nanostructure of the reversed micelles. One of the novel findings is that extractability and selectivity can be controlled by proper manipulation of the reversed micellar structure.

11:20 AM

Development of Extractants to Transport Metal Salts in Base Metal Recovery Processes: S. G. Galbraith¹; D. K. Henderson¹; H. A. Miller¹; P. G. Plieger¹; *Peter A. Tasker*¹; K. J. Smith¹; L. C. West¹; ¹University of Edinburgh, Dept. of Chmst., Edinburgh EH9 3JJ UK

We have used the principles of supramolecular chemistry to develop reagents to transport metal salts. These have separated charged “compartments” which recognise a metal cation and its attendant anions. They are potentially simple to manufacture because they contain phenolic-imine units that are structurally related to the commercial phenolic-oxime extractants for copper. The metal salt is transported in a zwitterionic form of the ligand, [M(L)X], leaving the pH of the aqueous feed solutions unchanged, thus removing the need for inter-stage neutralisation in metal recovery circuits. Stripping the loaded organic can be achieved by simple “pH-swing”, or other mechanisms. Incorporating the appropriate groups into the ligand superstructure allows the selectivity and strength to be tuned for particular metal cations or anions. In this paper we will focus on how these types of reagent can be used to recover base metals from sulfate and chloride media in flowsheets in which solvent extraction achieves separation and concentration, interfacing between conventional leach and electrowin/reduction processes. Work on the development of reagents that have high selectivity for metal chloride/sulfate transport, convenient stripping protocols and appropriate hydrolytic stability will be described.

11:45 AM

Application of Competitive Complexation/Solvation Theory in Metals Solvent Extraction New Opportunities in Process Development: Vladimir S. Kislik¹;

¹The Hebrew University of Jerusalem, Casali Inst. of Applied Chmst., Campus Givat Ram, Jerusalem 91904 Israel

Competitive complexation/solvation theory of solvent extraction constitutes a general framework for interpretation and quantification of ion-molecular interaction data in extraction systems. Depending on extracting metal — solvent affinity constant and metal concentration ratios, four possible stages of extraction behavior and interacting mechanisms, are considered. Affinity constant ratios are easily acceptable through the independent measurements of three-component systems. Once determined and tabulated, the affinity constant ratio data may be used in any system of interest. Mathematical descriptions of the results are introduced for different interactions. Active solvent (including water) concentrations in the organic phase and temperature are included to the quantitative consideration. The theory allows to compare directly the complexing/solvating power (competition order) of various extractants, active solvents and diluents. As a result, predictions for the extraction effectiveness and selectivity are possible. Some metal extraction systems are analyzed on the base of the theory. Analysis gives a key for preliminary quantitative prediction of suitable extraction systems.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification II: Electrowinning II

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday AM
August 27, 2003

8:30 AM

Effect of Some Polyols and Organic Acids on the Current Efficiency and the Cell Voltage During Zinc Electrowinning: *Shize Jin*¹; Edward Ghali¹; Guy St-Amant²; Georges Houlachi²; ¹Laval University, Dept. of Mining, Metall. & Matls. Engrg., Quebec, QC G1K 7P4 Canada; ²LTEE, Hydro-Quebec, 600 Avenue de la Montagne, C.P. 900, Shawinigan, QC G9N 7N5 Canada

Effect of four polyols, namely ethylene glycol (EGL), glycerol (GCL), propanediol (PDL), butanediol (BDL) and three organic acids, namely oxalic acid (OA), malonic acid (MA) and succinic acid (SA) on the current efficiency (CE) and the cell voltage during zinc electrowinning was studied. Galvanostatic polarization was conducted in a supporting electrolyte (SE) containing 180 g dm⁻³ H₂SO₄, 60 g dm⁻³ Zn²⁺ and 8 g dm⁻³ Mn²⁺ at 38°C with magnetic stirring. The imposed current density was 50 mA cm⁻². The anodes were made of a Pb-Ag alloy and the cathodes were made of an aluminum alloy. The results showed that all the polyols tested in this study decreased the current efficiency and the cell voltage, but the decrease of the cell voltage was not important. Oxalic and succinic acids decreased the current efficiency to a less extent than the polyols, but did not decrease the cell voltage much. The only compound that increased the current efficiency was malonic acid, and its capacity of decreasing the cell voltage was the highest within the seven tested organic compounds.



8:55 AM

Electrocrystallisation of Nickel: Effect of Certain Metal

Ions: *B. C. Tripathy*¹; U. S. Mohanty¹; T. Subbaiah¹; S. C. Das¹; V. N. Misra¹; ¹Regional Research Laboratory, Council of Scientific & Industl. Rsch., Bhubaneswar, Orissa 751 013 India

The effects of alkali metal ions Li⁺, Na⁺, K⁺ and transition metal ions Cr³⁺ and Mo⁶⁺ on the cathodic current efficiency, deposit quality, crystallographic orientations, deposit morphology and polarisation behaviour of the cathode during nickel electrocrystallisation on stainless steel substrate from aqueous sulphate solutions containing boric acid were investigated. The alkali metal ions had virtually no effect on the cathodic current efficiency, deposit quality, crystallographic orientations, deposit morphology and cathodic polarisation. On the other hand, there were significant variations in the current efficiency and deposit characteristics when Cr³⁺ or Mo⁶⁺ was present in the electrolyte. Current efficiency decreased by more than 10% even at lower concentrations. Similarly purity of the deposits was affected by the presence of either of the metal ions. In the presence of Cr³⁺ there was progressive shifting of the nucleation potential of nickel towards more -ve values, whereas, in the case of Mo⁶⁺ the nucleation potential shifted initially towards +ve values in the concentration range 2-40 mg/L but then towards -ve values when its concentration exceeded 40 mg/L.

9:20 AM

The Effect of Dissolved Manganese on Anode Activity in Electrowinning:

*Lauri Pajunen*¹; Jari Aromaa¹; Olof Forsén¹; ¹Helsinki University of Technology, Lab. of Corrosion & Matl. Chmst., PO Box 6200, FIN-02015 HUT, Helsinki Finland

DSA-anodes are widely used in metal electrowinning. In zinc electrowinning the electrolyte solution contains manganese ions and deposition of manganese dioxide happens on the anode. This manganese dioxide layer can not be removed without losing the active coating of the DSA-anode. Same problem can be found with hybrid anodes. In hybrid anodes mixed metal oxide coated titanium mesh is attached to lead base material. In this study the effect of dissolved manganese on anode behaviour is studied with three different anodes. These anodes are lead anode with 0.6% silver, hybrid anode and DSA-mesh. Study of anodes includes polarisation, galvanostatic and potential mapping experiments.

9:45 AM

Study of Anodic Slime from Chilean Copper Electrowinning Plants:

*Jorge Ipinza*¹; Juan Patricio Ibanez¹; Juan Aragon¹; ¹Arturo Prat University, Dept. of Metall., Av. Arturo Prat 2120, Iquique Chile

Impurities such as Mn²⁺, Fe²⁺ and Al³⁺ in the pregnant leaching solution are transferred to copper electrowinning plants causing a series of troubles, being the slime generation the less studied one. During electrowinning, in the cath-

ode the cupric ions are reduced and in the anode occurs a redox process: water oxidation and impurities reduction. These redox reactions are the basis for slime generation during electrowinning of copper. On the fresh Pb-Ca-Sn anode surface takes place the formation of PbSO₄ at first, then, it is transformed in the conducting PbO₂, which covers the anode surface. It has been experimentally established the formation of a manganese dioxide double layer at the anode; this double layer was always composed of a thick external layer of non-adhering and easily removable scales, and of a thin internal layer, which adheres relatively well to the surface of the electrode. It was found that manganese dioxides present in the slime were of different nature: a non-adhering layer produced by electrolysis (ϵ -MnO₂) on the PbO₂ surface and a pure chemical precipitation in the solution (γ -MnO₂). It was established that in the overall process of slime formation the ϵ -type manganese dioxide promote the detachment of the conducting combined layer of PbO₂-MnO₂(ϵ) due to a significant increase of the layer's weight. In industrial operations this detachment is favored by the frequent short-circuit in the cells. Due to the thermodynamic conditions of the process PbO₂ is spontaneously transformed in PbSO₄. Therefore, the slimes were found to consist mainly of manganese dioxides and lead sulphate. In addition, the chemical dynamic stability of the slime is discussed.

10:10 AM Break

10:30 AM

Zinc Electrowinning Using Novel Wrought Pb-Ag-Ca

Anodes: David Prengaman¹; *Andreas Siegmund*¹; ¹RSR Technologies, Inc., Dallas, TX 75207 USA

Cast or rolled lead anodes employed in zinc electrowinning typically contain between 0.5-1.0% silver to decrease the overall corrosion rate. The production of cast lead-silver or lead-silver-calcium anodes often results in the formation of numerous holes, voids or laps in the anode surface that can initiate internal corrosion in localized areas. In rolled anodes the presence of internal porosity is significantly reduce, thus resulting in extended service life. The obtained grain structure of rolled Pb-Ag anodes, however, requires a relatively long period of time to form a stable protective PbO₂/MnO₂ layer that can evolve oxygen without excessive lead contamination of the cathode. Therefore, these anodes are often mechanically, chemically or electrochemically conditioned prior to being placed in the electrowinning process. RSR Technologies developed an improved anode for zinc electrowinning. The anode consists of a rolled Pb-Ag-Ca-alloy with controlled surface grain structure. The preferred calcium and silver content of the alloy is 0.05-0.08% and 0.3-0.4%, respectively. Since May 2001 industrial scale tests are carried out at two zinc smelters in the USA in industrial electrowinning cells. The controlled grain structure of these anodes allows forming an adherent protective oxide coating within a short period of days when placed in an electro-

winning cell without the necessity of being preconditioned. Anode sludge growth is evenly distributed. The anodes stay dimensional stable and no short-circuits have been observed. Consequently, low corrosion rates and improved current efficiencies have been achieved.

10:55 AM

Electrodeposition of Nickel-Cobalt Alloys from Sulfate Acid Baths: *C. Lupi*¹; *D. Pilone*¹; ¹Università degli Studi di Roma, Dip. ICMMPM, Via Eudossiana 18, Roma 00184 Italy

Ni-Co alloys, having interesting properties such as hardness, magnetic properties and high strength, have found many technological applications. Aim of this work is to produce directly these binary alloys by electrowinning from sulphate baths coming from secondary battery dissolution. Nickel-cobalt alloys were electroplated from solutions containing about 40 g/L Ni and 2-8 g/L Co. Experimental tests have been carried out to investigate the effect of current density, temperature and electrolyte pH on current efficiency and specific energy consumption. The effect of the addition of two buffers such as H₃BO₃ and (NH₄)₂SO₄ has been also investigated. Experimental results show that the process parameters affect not only current efficiency and cell voltage, but also morphology and composition of the produced alloy.

11:20 AM

Extraction of Copper at High Feed Concentrations: *R. Molnar*¹; *N. Verbaan*¹; ¹SGS Lakefield Research Limited, 185 Concession St., PO Box 4300, Lakefield, Ontario K0L 2H0 Canada

A number of flowsheets have been designed and operated, or are currently being considered, to extract copper from leach solutions having much higher concentrations of copper than the 4 g/L levels typically found in heap leach liquors. Copper concentrations of 15 to 20 g/L are encountered. Dealing with these solutions has required that the envelope for "normal" copper solvent extraction be pushed beyond the usually considered limits. This paper discusses two pilot plant circuits that were operated at Lakefield Research to produce cathode copper from such solutions. Three different extractants were tested in these two campaigns. The roles of acidity and iron as well as some other key impurities, are discussed.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Technology Application: Recycling

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engi-

neering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday AM August 27, 2003

8:30 AM

Copper Recovery from Waste Printed Circuit Board: *Kazuya Koyama*¹; *Mikiya Tanaka*¹; *Jae-Chun Lee*²; ¹National Institute of Advanced Industrial Science and Technology (AIST), Rsch. Inst. for Green Tech., 16-1 Onogawa, Tsukuba, Ibaraki 305-8569 Japan; ²Korea Institute of Geoscience and Resources (KIGAM), Minls. & Matls. Procg. Div., 30 Gajeong-dong, Yuseong-ku, Daejeon 305-350 Korea

Leaching of copper from printed circuit board (PCB) and electrowinning of copper from cuprous solution in ammoniacal alkaline solutions were examined in order to develop an energy conservative hydrometallurgical process for copper recovery from electronic scraps. In the leaching experiments, copper in PCB was oxidized by Cu(II), and Cu(I)-ammine complex ions were formed. Copper(I)-ammine complex slightly depressed the leaching rate, while Cu(II)-ammine markedly enhanced it. In the electrowinning experiments, current efficiency of copper deposition was approximately 100% in the range of 200 to 1000 A m⁻² in current density. It decreased with increasing in Cu(II) concentration. Electrowinning of copper from Cu(I)-ammine complex solution favored the production of plates rather than powders.

8:55 AM

Selective Leaching of Platinum and Palladium by Chloride Solution: *Kejun Liu*¹; *Toyohisa Fujita*¹; *Wan Tai Yen*²; *Atsushi Shibayama*¹; ¹Akita University, Fac. of Resources & Engrg., 1-1 Tegata Gakuencho, SVBL, Akita 010-8502 Japan; ²Queen's University, Dept. of Mining Engineering, Kingston, Ontario K7L3N6 Canada

Platinum and palladium are usually dissolved together and followed by separation. In this study, the selective leaching of platinum and palladium from a secondary resource, such as dental waste, by using chloride solution (hypochlorite and chlorate) has been developed. Results indicated that about 100% of palladium could be initially extracted by the combination of 1.34 mol/l sodium hypochlorite (NaClO) and 0.068 mol/l sodium chloride (NaCl) at pH 1.2 and 298K in 1.5 hours or the combination of 0.005 mol/l sodium chlorate (NaClO₃) and 6.0 mol/l hydrochloric acid (HCl) at 298K in 0.5 hour. About 100% of platinum could be extracted from the residue by the combination of 0.47 mol/l sodium chlorate (NaClO₃) and 12 mol/l hydrochloric acid (HCl) at 298K in 2 hours.



9:20 AM

Metal Recovery from Electronic Scrap by Leaching and Electrowinning IV: *D. Pitone*¹; G. H. Kelsall²; ¹On leave from Università degli Studi di Roma, Dip. ICMMPM, Via Eudossiana 18, Roma 00184 Italy; ²Imperial College, Dept. of Chem. Engrg. & Chem. Tech., London SW7 2BY UK

A novel process is being developed for metal recovery from waste electrical and electronic equipment and involving a leach reactor coupled to an electrochemical reactor. Metals such as Ag, Au, Cu, Pb, Pd, Sn etc. are dissolved from shredded electronic scrap in an acidic aqueous chloride electrolyte by oxidising them with aqueous dissolved chlorine species. In the electrochemical reactor: (i) chlorine is generated at the anode for use as the oxidant in the leach reactor, and, simultaneously, (ii) at the cathode, the dissolved metals are electrodeposited from the leach solution. Results are described for the electrowinning of dissolved metals carried out at ambient temperature in a membrane divided cell using carbon felt as cathode. The experimental results are compared with the prediction obtained by a numerical model simulating the behaviour of flow-through porous electrode systems.

9:45 AM

Recovery of Zinc(II) from Spent Hydrochloric Acid Solutions from Zinc Hot Galvanizing Plants: Magdalena Regel-Rosocka¹; Ryszard Cierpiszewski¹; Ireneusz Miesiac¹; Krzysztof Alejski¹; Ana M. Sastre²; *Jan Szymanowski*¹; ¹Poznan University of Technology, Inst. of Chem. Tech. & Engrg., Pl. Skłodowskiej-Curie 2, Poznan 60-965 Poland; ²Universitat Politècnica de Catalunya E.T.S.E.I.B., Dept. d'Enginyeria Química, E-08028, Barcelona Spain

Extraction of zinc(II) from spent pickling hydrochloric acid solutions obtained in zinc hot dip galvanizing plants was studied. Tributyl phosphate and its mixtures with di(2-ethylhexyl)phosphoric acid (DEHPA), HOE F® 2562, ALIQUAT® 336, ALAMINE® 304, ALAMINE® 308, ALAMINE® 310, ALAMINE® 336 and CYANEX® 301 were used as extractants. The acidic extractants (CYANEX® 301 and DEHPA) did not extract both zinc(II) and iron(III) from 10% HCl. A precipitation occurred or stable emulsions were formed when ALAMINE® 304, ALAMINE® 308, ALAMINE® 310 were used. Each of other reagents co-extracted both zinc(II) and iron(III). The latter had to be reduced to iron(II) prior to extraction. However, iron(II) was also coextracted and transferred to the strip. The formation of reverse micelles and/or partial hydrolysis of TBP are probably responsible for that transfer. Tributyl phosphate and HOE F® 2562 showed the best extraction performance. ALAMINE® 336 and ALIQUAT® 336 induced the oxidation of iron(II) to iron(III) enhancing the co-extraction of iron. Zinc(II) could be effectively stripped from the loaded phases containing TBP and HOE F® 2562 with water. A higher efficiency of zinc(II) stripping was observed in the second stage. TBP was used for separations carried out in

laboratory mixer settlers. The dynamics of extraction and stripping was studied and successfully modeled.

10:10 AM Break

10:35 AM

Recovery of Cobalt and Tungsten from Scraped Carbide Pieces through a Hydrometallurgic Route: *S. N. Ashrafzadeh*¹; ¹Iran University of Science & Technology, Chem. Engrg., Tehran 16844 Iran

Nowadays, hard carbides have found various industrial applications in the manufacture of cutting tools, drilling and metal forming devices. About 60% of the world tungsten production is consumed in the manufacture of hard carbide pieces. Regarding the high values of hard carbide components such as Ni, Co, TaC, TiC, and WC, their recovery from scraped species is attracted many interests. In the current research, metallic cobalt and tungsten were recovered from scraped cemented carbide pieces through the application of high voltage electrolysis in nitric acid media. By the latter method cobalt and tungsten were initially recovered as cobalt nitrate and tungstenic acid, respectively. The tungstenic acid precipitate was calcinated at 800°C after being washed twice by distilled water. A pure tungsten oxide was obtained. The effect of current density, electrolyte concentration, speed of agitation, and the anode surface area on the efficiency of the electrolysis process were investigated. The optimum conditions including a current density of 1500 A/m², an acid concentration of 1.5 M, and a cell temperature of 80°C were obtained.

11:00 AM

Innovation: The Way Forward for Hydrometallurgical Processing: *V. I. Lakshmanan*¹; R. Sridhar¹; G. B. Harris¹; V. Ramachandran²; ¹Process Research ORTECH Inc., 2395 Speakman Dr., Mississauga, ON L5K 1B3 Canada; ²RAM Consultants, 9650 E. Peregrine Pl., Scottsdale, AZ 85262 USA

Whilst the prices of metals in nominal terms have largely remained static over the past thirty years, in real terms, the primary metals industry receives very much less today for its products than in the past. Yet, it has largely managed to remain competitive, despite the fact that ore reserves are not only diminishing, but are of lower grade and higher complexity, and that there are much greater pressures on companies to be good environmental stewards. This paper examines how hydrometallurgical processing has shown itself to be highly innovative in order to remain viable both economically and environmentally. Aspects of process chemistry are discussed, and the lessons to be learned from having a good understanding of this chemistry are highlighted with reference to a number of case histories such as HPAL for nickel laterites, the Avmin/Chambishi Cosac Project, use of chloride chemistry for titanium extraction, and plant effluent treatment and recycle.

11:25 AM

Feasibility Studies - Just How Good Are They?: *Mark Francis Vancas*¹; ¹BATEMAN Engineering, Solvent Extraction, 350 S. Williams Blvd., Ste. 230, Tucson, AZ 85711 USA

Virtually every new process plant project goes through the "Feasibility Study" phase before actually being built. The Feasibility Study is used by the owners and the bankers to evaluate the economics of the project and determine whether or not the proposed investment meets their respective investment guidelines. With a positive result, the project is approved and goes to construction and operation. Then, the actual costs are incurred and these actual costs may or may not agree with what the Feasibility Study predicted. Just how good have Feasibility Studies been? This paper looks at various projects and compares predicted to actual results and also gives information on how to spot a poor feasibility study.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching I: Thiosulfate II

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday AM
August 27, 2003

8:30 AM

A Novel Thiosulfate System for Leaching Gold without the Use of Copper and Ammonia: *Jinxing Ji*¹; *Chris A. Fleming*²; *Paul G. West-Sells*¹; *Ralph P. Hackl*³; ¹Placer Dome Inc., Rsch. Ctr., 323 Alexander St., Vancouver, BC V6A 1C4 Canada; ²SGS Lakefield Research, PO Box 4300, 185 Concession St., Lakefield, Ontario K0L 2H0 Canada; ³Placer Dome Inc., Tech. Grp., PO Box 49330 Bentall Sta., 1600-1055 Dunsmuir St., Vancouver, BC V7X 1P1 Canada

The thiosulfate lixiviant system that has been under extensive investigation for nearly two decades now consists of ammonium thiosulfate, copper and ammonia. There are several challenges with this system. The occurrence of ammonia must be taken into account from a health and hygiene aspect in the work place, and also from an environmental perspective with significant levels of ammonia and copper in the tailings. Copper accelerates the leaching rate but causes excessive thiosulfate degradation. The new lixiviant consists only of sodium

thiosulfate without copper and ammonia. Gold leaching is carried out in an enclosed reactor with slightly elevated oxygen overpressure and temperature. Extensive leaching experiments were carried out to minimize thiosulfate degradation while maximizing the gold extraction. For several preg-robbing carbonaceous ore samples tested, gold leaching was essentially complete within six hours and the thiosulfate consumption was lower than in the typical ammoniacal thiosulfate system. The gold thiosulfate complex in the pregnant leach solution was found to be quite stable under ambient conditions. This new leaching system has the advantages of being more environmentally friendly, has a shorter residence time, lower thiosulfate consumption, lower oxygen consumption, and is easier to control.

8:55 AM

A Process for Counteracting the Detrimental Effect of Tetrathionate on Resin Gold Adsorption from Thiosulfate Leachates: *Paul G. West-Sells*¹; *Jinxing Ji*¹; *Ralph P. Hackl*¹; ¹Placer Dome Technical Services Limited, 323 Alexander St., Vancouver, BC V6A 1C4 Canada

Recovery of gold from thiosulfate leachates is typically accomplished by adsorption of the gold thiosulfate complex by a strong base resin. Two of the most significant impurities that can decrease this gold adsorption are tetrathionate and trithionate, which are produced as oxidation products of thiosulfate during gold leaching. This paper investigates gold adsorption on a strong base resin (Puro-lite A500C) as a function of the concentration of these impurities. It is shown that concentrations of tetrathionate and trithionate as low as 150 mg/L can decrease gold loading by an order of magnitude, and that of the two ions, tetrathionate has a stronger detrimental effect. The resin and solution gold concentration profiles were successfully fit using a Freundlich isotherm, which further shows the strong effect of tetrathionate. To counteract the decrease in gold adsorption by tetrathionate, a novel process was proposed. Sulfite was added to the solution to oxidize tetrathionate to trithionate, and a nitrogen blanket was added to ensure that no further oxidation of thiosulfate could take place. It is shown that by incorporating this process, gold adsorption was doubled from both synthetic and real gold thiosulfate leachates.

9:20 AM

The Simultaneous Oxidation of Sulfide Minerals and the Dissolution of Gold: *Suchun Zhang*¹; *Michael J. Nicol*¹; ¹Murdoch University, A J Parker Ctr. for Hydrometall., South St., Murdoch, Western Australia 6150 Australia

The alkaline oxidation of refractory gold concentrates containing arsenopyrite and pyrite at ambient temperatures and pressures has been found to be accompanied by the simultaneous dissolution of gold without the addition



of cyanide. A detailed study has been made of the kinetics of the oxidation of the pure minerals and of several concentrates. The reaction products of the oxidation of arsenic and sulphur have been monitored using chromatographic techniques. In the case of arsenopyrite, thiosulfate, monothioarsenate, arsenate and sulfite are the principal products while thiosulfate has been confirmed to be the dominant product of pyrite oxidation. Gold, either as added powder or as a constituent of the concentrates has been found to dissolve simultaneously during the alkaline oxidation of both arsenopyrite and pyrite, and this appears to be associated with the formation of thiosulfate. The effects of temperature, stirring speed, oxygen partial pressure, alkalinity and pulp density on the oxidation of arsenopyrite and the dissolution of gold have also been investigated.

9:45 AM

Ammonium Thiosulfate Heap Leaching: *Pragna N.H. Bhakta*¹; ¹Newmont Mining Corporation, PO Box 669, Carlin, NV 89822 USA

Newmont has investigated potential treatment options for low-grade refractory gold ores since 1988. After extensive R&D at Newmont's laboratories, biooxidation pretreatment followed by ammonium thiosulfate leaching was selected for application to sulfidic preg robbing ores. A heap biooxidation and ammonium thiosulfate leaching demonstration facility was constructed in 1995 to conduct large-scale pilot tests at Newmont's Carlin Operations. This paper presents Newmont's experience with the recovery of gold from preg robbing ores using ammonium thiosulfate.

10:10 AM Break

10:30 AM

The Use of Biohydrometallurgy for Tails Retreatment in Mining and Smelting Enterprises of the Republic of Uzbekistan: *M. Sagdieva*¹; *S. Borminskii*¹; *K. Sanakulov*²; ¹Institute of Microbiology, AS of Uzbekistan, 7b. A. Kadiry St, 700128, Tashkent Uzbekistan; ²Almalyk Mining and Metallurgical Company, 58, A. Timur Av., 702400, Almalyk Uzbekistan

The modern deficiency in source of raw materials of non-ferrous, rear and noble metals raise a question of the possibility for searching new reserves of mineral raw-materials that the wastes of hydrometallurgical enterprises. In this connection we carried out investigations dealing with the use of biotechnological methods for flotation tails retreatment in Almalyk Mining and metallurgical company. On the basis of conducted experiments, the flotation tails were found to be used for retreatment by means of bacterial leaching approach that was used for copper leaching and gold stripping out of sulphide minerals containing copper and iron. It was determined the main parameters of Bioleaching and, on the basis of data obtained, the developed technology was used and tested in laboratory, pilot and semi-industrial experiments. The results of conducted tests have shown that copper extrac-

tion amounted to 68-75%, sulphide mineral destruction of 78-82%, gold extraction with the use of thiosulphate leaching from bacterially digested material of 85-90% and silver of 58-60%. Thus, the technology under investigation is of great perspectives for retreatment of the wastes in hydrometallurgical enterprises and will allow extending the source of raw materials in Uzbekistan.

10:55 AM

Measurement and Application of Biooxidation Kinetics for Heaps: *Pragna N.H. Bhakta*¹; ¹Newmont Mining Corporation, PO Box 669, Carlin, NV 89822 USA

The use of microbes for sulfide oxidation was investigated as a potential treatment option for low-grade refractory gold ores at Newmont Mining Corporation. The patented technology of heap biooxidation relied on maximizing the oxidation rate through even distribution of microbes on the ore before placement on the heap. This paper presents data on global oxidation rates based on oxygen uptake in a 50 kg column for two ore types. The oxygen uptake data was converted to a global oxidation rate. The calculated global oxidation rate was used to determine heap cycling times for Newmont's commercial heap biooxidation facility.

11:20 AM

Mathematical Modeling of Pyritic Refractory Gold Ore Heap Biooxidation: Model Development and Isothermal Column Simulations: *S. C. Bouffard*¹; *D. G. Dixon*¹; ¹The University of British Columbia, Dept. of Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada

Poor understanding of the heap biooxidation pretreatment of pyritic refractory gold ores prompted us to develop a mathematical model, which includes experimentally-measured and fundamentally-derived subroutines. Lateral stagnant pores, connected to vertical plug flow channels, and in contact with uniformly-distributed gas streams, constitute the model hydrodynamic structure. Results from potentiostatic stirred-tank and packed-bed tests provide the particle kinetic model. Growth of attached and planktonic iron- and sulfur-oxidizing cells is modeled over three specific temperature ranges with a dual, limiting-substrate Monod expression. Heat conduction, generation, and advection complete this unsteady-state system of non-linear partial differential equations. Isothermal column tests validate the model simulations. Excellent fits of several leaching indicators (potential, extent of sulfide oxidation, iron concentration, cell numbers) reveal the rate-limiting step to shift from particle kinetics to oxygen gas/liq uid mass transfer with increasing temperatures. The model demonstrates how faster particle kinetics, higher head grade, and lower mass transfer coefficient prolong the oxygen transfer-limited phase. According to the model simulations, large pellets, comprised of rapidly-oxidizable pyrite, leach zone-wise due to the rapid consumption of dissolved oxygen within the pellet pores. This modeling

tool may assist engineers in the design and operation of heaps, hopefully resulting in complete gold liberation and shorter biooxidation time.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching II: Chloride Leaching

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday AM
August 27, 2003

8:30 AM

Chloride Hydrometallurgy: Application of Fundamentals: *Gamini Senanayake*¹; David M. Muir²; ¹Murdoch University, A J Parker Ctr. for Hydrometall., South St., Murdoch, Perth, Western Australia 6150 Australia; ²CSIRO Minerals, A J Parker Ctr. for Hydrometall., PO Box 90, Bentley, Perth, Western Australia 6982 Australia

A good understanding of fundamentals is beneficial for the rationalisation of complex chemistry in hydrometallurgical processes. Water activity decreases and proton and chloride ion activity increases with ionic strength. Thus acidic concentrated chloride solutions provide faster kinetics and selectivity in the leaching of sulphides and oxides. Activity of the metal ion in the form of the hydrated chloro complex species plays an important role in determining the redox potential and solubility of metal chloride at high ionic strengths. Whilst the hydration theory can be used to predict and/or rationalise the changes in proton and uncomplexed or complexed metal ion activity, Pourbaix diagrams along with the measured redox potentials can be used to predict the nature of the complex ion. This paper outlines the successful outcomes and limitations of translating the fundamental knowledge of the physico-chemical behaviour of base metal ions to practical applications in chloride hydrometallurgy.

8:55 AM

Minimizing Fuel Costs During Thermal Regeneration of the Hydrochloric Acid Lixiviant: *Kamal Adham*¹; Cassandra Lee¹; ¹Hatch Associates, Ltd., 2800 Speakman Dr., Mississauga, ON L5K 2R7 Canada

Hydrochloric acid is used as lixiviant in such hydrometallurgy flow sheets as synthetic rutile and nickel pro-

duction. Intermediary metal chloride is roasted to release gaseous HCl and a solid metal oxide. A large amount of fuel is required for this regeneration, mainly to vaporize the water content. Some energy recovery from the off-gas is currently achieved, but fuel consumption can further be reduced by process optimization and energy recovery from the roaster products. Here, first the existing limitations to fuel efficiency in the industrial scale HCl roasters are described. Then, for the case of a dilute feed solution, options for pre-evaporation and fuel minimization are modeled and compared. Energy recovery technologies including heat pumps, acid heat exchangers and solid waste heat boilers are described, and their potential as heat source for the pre-evaporation process is evaluated. Finally, for a representative example, the possible fuel saving from each option is quantified.

9:20 AM

Solution Purification in the Outokumpu HydroCopper™ Process: *Matti Hämäläinen*¹; Marika Jyrälä¹; Olli Hyvärinen¹; ¹Outokumpu Research Oy, PO Box 60, 28101 Pori Finland

Outokumpu has developed a new chloride leaching process, HydroCopper™, for copper concentrates. The process utilizes cupric ion as oxidant, which is able to dissolve chalcopyrite. After solution purification monovalent copper is precipitated as cuprous oxide, Cu₂O, with sodium hydroxide. Copper product is produced from Cu₂O by reduction, melting and casting. An essential part of the new process is chlor-alkali electrolysis, which regenerates the reagents used. All impurity metals are removed before Cu₂O precipitation, because otherwise they report to the copper product, impairing its quality. A multistage solution purification scheme has been developed consisting of firstly, chemical precipitation of impurity metals by pH increase, secondly, cementation of silver and thirdly, removal of trace multivalent ions by ion exchange. This paper describes the characteristics of the HydroCopper™ process solution purification based on the laboratory tests and pilot runs made by Outokumpu Research Oy.

9:45 AM

Direct Hydrochloric Acid Leaching of an Egyptian Ilmenite Ore for Production of Synthetic Rutile: *I. A. Ibrahim*¹; M. H.H. Mahmoud¹; A. A.I. Afifi¹; B. A. El-Sayed²; ¹Central Metallurgical R&D Institute, PO Box 87, Helwan, Cairo Egypt; ²Azhar University, Chmst. Dept., Fac. of Sci., Cairo Egypt

Ilmenite in its natural form is inactive mineral from which the selective removal of iron is rather difficult. The reactivity of ilmenite so that it can be leached with dilute hydrochloric acid can be enhanced by chemical reduction in solution using a suitable metal as a reducing agent. The present paper aims at evaluation of an Egyptian ilmenite



for the production of synthetic rutile by direct leaching with hydrochloric acid in presence of iron powder. In this process, the titanium and iron contents are dissolved, meanwhile the dissolved titanium is hydrolyzed and re-precipitated leaving mainly iron in solution. Leaching conditions were optimized to obtain less iron in the final solid product. Addition of sufficient amount of iron powder during leaching reduces the dissolved Fe³⁺ to Fe²⁺ and reduces the dissolved Ti⁴⁺ to Ti³⁺. The creation of Ti³⁺ in solution is assumed to have a role in dissolving the ferric iron and hence increase the reactivity of ilmenite ore. Synthetic rutile of about 90% TiO₂ and 0.77% Fe₂O₃ was obtained from ilmenite ore of grain size 100% -200 mesh using 20% HCl at boiling temperature (110 °C), with addition of 0.11 g iron powder/g ore for 5 hours.

10:10 AM Break

10:30 AM

The Altair Hydrochloride TiO₂ Pigment Process: *D. Verhulst*¹; B. Sabacky¹; T. Spitler¹; ¹Altair Nanomaterials Inc., 204 Edison Way, Reno, NV 89502 USA

The Altair process involves digesting ilmenite ore in concentrated hydrochloric acid, cooling and crystallizing to separate iron chloride, solvent extraction to concentrate Ti in a purified stream and spray hydrolysis to produce a TiO₂ hydrate, followed by final calcining and milling. HCl gas is regenerated by pressure-swing distillation and reinjected in the leaching solution. Chromium compounds generally remain in the residue. Solvent extraction provides flexibility for the removal of radioactive elements (NORMs). The process was previously tested at a 5 t/day feed scale. Recent work at pilot scale (30 liter reactor) led to further improvements. Digestion time is now less than 3 h, crystallization at lower temperature lowers the amount of Fe in solution to about 5 g/l and improves solvent extraction, which is now conducted in columns. Higher Ti and lower Fe concentrations in the SX eluate improve the economics. A new formula for pigment production via spray hydrolysis looks very promising.

10:55 AM

Electrochemical Mechanism Investigation of Manganese Dioxide Dissolution in Acidic Chloride Solution in Presence of Ferrous/Ferric Ions: *Guo Xueyi*¹; ¹Central South University, Coll. of Metallurg. Sci. & Eng., Yuelu Dist., Changsha, Hunan 410083 China

Hydrometallurgical method is a prospective choice to extract Mn and co-existed metal values from low grade manganese ore in land and manganese nodule in deep sea bed. By this process, the manganese dioxide dissolves with presence of reductants, implying leaching is essentially an electrochemical process. In this study, electrochemical kinetic equation of manganese dioxide reduction dissolution in acidic chloride solution in presence of ferrous/ferric ions was deduced in term of Butler-Volmer equations and chemical kinetics theory, thereafter a series of experiments were

conducted and the results obtained were found in consistent with the theoretical deduction. This achievements are useful to offer the guide for the actual leaching of manganese dioxide minerals.

11:20 AM

Use of Pressure Hydrometallurgy in Direct Processing of Base Metal/PGM Concentrates: *Joe C. Milbourne*¹; Lynton S. Gormely¹; ¹AMEC E&C Services, Mining & Metals, 400-111 Dunsmuir St., Vancouver, BC V6B 5W3 Canada

Available processing technology for use in treating copper-nickel-cobalt-platinum group metal concentrates will be surveyed. Block flowsheets will be provided and the technical characteristics will be compared. The probable economic impact of the technical features will be assessed qualitatively. The current state of development for each process will be summarized. Perceived risks and rewards associated with each technical concept will be provided in the conclusions.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification I: Solvent Extraction IV

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday PM

August 27, 2003

2:00 PM

Solvent Extraction System Modeling Using the Program SXFIT: *Laetitia H. Delmau*¹; Charles F. Baes¹; Debbie A. Bostick¹; Tamara J. Haverlock¹; Bruce A. Moyer¹; ¹Oak Ridge National Laboratory, CSD/CSG, 1 Bethel Valley Rd., PO Box 2008, MS 6119, Oak Ridge, TN 37831-6119 USA

SXFIT is the latest in a series of programs developed in our group designed to model solvent extraction systems of increasing complexity. SXFIT permits the user complete freedom to define the constituents from which the composition of each phase is to be specified in the data and from which all species of a model for a system are assumed to be formed. Activity coefficients in the nonaqueous and aqueous phases, water activity, apparent molar volumes of aqueous species, and solution density needed for the conversion of

concentration from the molarity to the molality scale are all taken into account by the program. Several extraction systems relevant to nuclear-waste treatment were modeled successfully using this program. As an example, the cesium extraction efficiency of the CSSX process chosen by the USDOE for cesium removal from high-level waste stored at the Savannah River Site can be predicted correctly for varying feed composition.

2:25 PM

Mass Transfer Rates for Up-Pumping Impeller Systems: Dan Adams¹; Bernd Gigas¹; *Michael Giralico*¹; ¹LIGHTNIN, 135 Mount Read Blvd., Rochester, NY 14611-1921 USA

A number of gas-liquid processes require high intensity agitation systems to provide uniform blending and dispersion of reactants in order to achieve desired end products. Processes such as hydrogenation, fermentation, and minerals processing have used conventional down pumping or radial agitation systems with some success. In 1996, LIGHTNIN introduced the concept of Up-Pumping to the industrial marketplace as an improved mixing technology for these applications. For processes requiring gas-liquid mass transfer, such as those listed above, conventional mixing technology requires the use of gas introduction devices (spargers) below impellers. These devices can be a maintenance concern due to plugging and erosion in the presence of solids. Up-Pumping impeller systems are able to draw in a significant amount of gas from the head space, much more so than conventional vortexing impellers designed for head space gas incorporation. This paper will demonstrate the effectiveness of Up-Pumping impeller systems that have the potential to eliminate need for sparge devices entirely. It demonstrates the ability of Up-Pumpers to re-entrain gas for higher utilization compared with conventional impeller technology. This is significant in applications using costly gases such as enriched oxygen or hydrogen, reducing overall operating costs of production.

2:50 PM

Development of On-Line Analysis in Nickel and Copper Solvent Extraction: *David Victor Hughes*¹; Matti Kongas¹; Eero Rauma¹; ¹Outokumpu Technology Group, Automation, PO Box 84, Riihitontuntie 7 C, Espoo FIN-02201 Finland

The paper covers the utilization of on-line analysis in process control of solvent extraction in nickel leach solvent extraction processes in Finland and Australia and in copper heap-leach and solvent extraction in Chile. The goals of and requirements for controlling the solvent extraction stages of the processes are reviewed. The applications at three plants are compared. The development of the technology used is reviewed and design considerations are discussed. Requirements for on-line control and analyzer performance are compared. A new generation of analyzers and its effect on the set-up process of a project is introduced.

3:15 PM Break

3:30 PM

Biological Degradation of Solvent Extraction Circuit Plant Organic: *Nelson I. Collao*²; Gary E. Jenneman³; Kerry L. Sublette⁵; *Marshall D. Bishop*¹; Sharon K. Young⁴; Alison G. Morrison⁶; ¹Chevron Phillips Chemical Company LP, Mining Chem., 1768 Hwy. 123, Bartlesville, OK 74004 USA; ²Compania Minera Quebrada Blanca S.A., Vivar 493, 2 Piso, Iquique Chile; ³Conoco Phillips Petroleum Company, Rsch., 224 GB, Bartlesville, OK 74004 USA; ⁴Versitech Inc., 1438 W. San Lucas Dr., Tucson, AZ 85704 USA; ⁵The University of Tulsa, Environml. Engrg., 600 S. College Ave., Tulsa, OK 74104-3189 USA; ⁶Teck Cominco Metals Ltd., Rsch., PO Box 2000, Trail, British Columbia V1R 4S4 Canada

Loss of the organic phase from solvent extraction circuits is a major cost factor for SXEW operations. Recognized sources of loss include evaporation, entrainment, and biological degradation. The mechanisms for both entrainment and evaporative losses are well recognized. Biological degradation of the organic has not been as extensively evaluated as the other mechanisms but is a major source of loss. This paper discusses the impact of biological degradation on an operating plant, potential mechanisms for degradation, conditions under which biodegradation of plant organic can occur and plant conditions that may assist in promoting biodegradation.

3:55 PM

FRP (Fiberglass Reinforced Plastic) as a Material of Construction for Solvent Extraction Equipment: *David Goodman*¹; Rein Aaslepp²; Rafic Moubarac³; Matthew T. Belford⁴; ¹Nemato Composites Inc., 1725 Oakdell Dr., Menlo Park, CA 94025 USA; ²Nemato Composites Inc., 1605 McEwen Dr., Whitby, ON L1N 7L4 Canada; ³Experco Composites Inc., 4946 Ste. Suzanne St., Pierrefonds, QC H8Y 1Z9 Canada; ⁴The Dow Chemical Company, 2301 N. Brazosport Blvd. B-1603, Freeport, TX TX 77541 USA

The typical operating conditions in Solvent Extraction plants will be presented, various materials of construction reviewed and the use of FRP (Fiberglass Reinforced Plastic) as a material of construction described with world wide examples of this application.

4:20 PM

Scale-Up of Pumper-Mixers for Solvent Extraction: *Thomas Post*¹; ¹ConsultDrPost, 7 Tippet Way, Pittsford, NY 14534-4520 USA

The methodology of determining the optimum SX pumper-mixer system based on bench top, pilot, or small scale solvent extraction systems is demonstrated. The design of small scale SX-plants is different than a full scale plant. The difference is shown. The use of dimen-



sionless parameters N_h , N_q , and N_p that describe the head, flow and power of the pumper is shown and how to use them for the scale-up. Comparisons will be made with well known currently operating SX plants. The emphasis on the optimization of hydraulic efficiency will be shown on examples, including how the hydraulic efficiency is affected when the through put of the system goes beyond the design. Designs of all sizes of equipment will be shown which optimize the hydraulic efficiency.

4:45 PM

Characterization and Optimization of Auxiliary Mixers for Solvent Extraction: *Mike Giralico*¹; Thomas Post²; ¹LIGHTNIN, 135 Mount Read Blvd., Rochester, NY 14611-1921 USA; ²ConsultDrPost, 7 Tippet Way, Pittsford, NY 14534-4520 USA

The newest design in auxiliary mixers for solvent extraction allows for variable tip chord angles (TCA). These angles allow for the optimization of up-pumping impellers on the basis of flow and shear. Previously, only hydrofoils with a single TCA were used. In order to obtain the optimum flow, shear, flow pattern and impeller diameter, the TCA is an ideal parameter to change in the range of 10 to 35°. The optimum auxiliary impeller(s) is designed to maintain the dispersion from the pumper at the lowest possible power consumption. To achieve this, the auxiliary mix tank may have 1 to 3 impellers on a shaft to obtain flow and dispersion uniformity. The spiral impeller design has been claimed to achieve this. A comparison of up-pumping hydrofoils will be made with a spiral design to show that the spiral design does require more power and delivers more shear than the hydrofoils. The comparison will be made with laser-grams and CFD. Lastly, the optimum design of the mix tank will be discussed which compliments the use of these hydrofoils.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Solution Purification II: Electrowinning III

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday PM

August 27, 2003

2:00 PM

Successful Industrial Use of Quillaja Saponins (Quillaja saponaria Mol.) for Acid Mist Suppression in Copper Electrowinning Processes: *A. F. Otero*¹; R. M. San Martin²; A. Cruz³; ¹Catholic University, Mining Ctr., Fac. of Engrg., Ave. Vicuña Mackenna 4860, Santiago Chile; ²Catholic University, Dept. of Chem. & Biochem. Engrg., Fac. of Engrg., Ave. Vicuña Mackenna 4860, Santiago Chile; ³Radomiro Tomic, Hidrometallurgical Plant, Div. CODELCO-Norte, Calama Chile

Electrolytic Processes produce significant quantities of highly toxic vapor due to the liberation of gases (oxygen and hydrogen) at cathodes and/or anodes. For example, in the electrowinning of metals (e.g. Zinc, Copper), bubbles of gas produced at the anodes rupture when they reach the surface producing an aerosol of sulfuric acid called acid mist. Acid mist affects the health of operators, the environment and plant infrastructure, for which reason strict environmental regulations exist concerning acid mist generation and control. Saponin-rich extracts derived from the Chilean endemic tree Quillaja Saponaria Molina, have been successfully used for the suppression of acid mist in copper electrowinning at an industrial scale, 950 tpd cathode copper production plant (Radomiro Tomic, CODELCO-Chile). Chemically, Quillaja Saponins are triterpenoids, with two sugars chains linked to carbons 2 and 23. Historically they have been used as foaming agents in beverages, photographic film emulsions, etc. They are approved for human consumption by the FDA (U.S.), European Union, WHO Food Codex, and the Ministry of Health, Japan. In summary this work establish and determine technical parameters which enable the use of Quillaja Extracts in electrolytic industrial application, such as, Copper Electrowinning Process, through the application of a Natural Base Reagent, named Mistop®, product destined for both domestic consumption and overseas export.

2:25 PM

Hydrogen Inhibitors Applications in Fuel Cells and Base Metal Electrowinning: *Bruce W. Downing*¹; Elod Gyenge²; Jianming Lu²; David Dreisinger²; Joey Jung³; ¹MagPower Systems Inc., Vancouver, BC Canada; ²University of British Columbia, Vancouver, BC Canada; ³BC Research Inc., Vancouver, BC Canada

MagPower has developed methods to control the detrimental formation of hydrogen that occurs in electrochemical reactions in numerous commercial applications such as the Magnesium-Air Fuel Cell, electrowinning, zinc alkaline batteries, hydrogen embrittlement, waste water/ metal recycling and coolants. The company's approach to an alternative energy source is the development of an environmentally friendly non-toxic alternative power source that generates electricity through a combination of magnesium, oxygen and

a saltwater electrolyte with MagPower's patent pending hydrogen inhibitors. The magnesium-air technology has never reached the commercial stage due to its limiting power output caused by hydrogen generation. MagPower has solved this problem and has patents pending on its intellectual property; the Hydrogen Inhibitors and has developed several consumer power units for a variety of applications through licensing agreements. The company has also shown that the inhibitors have an impact on zinc electrowinning through laboratory test work where current efficiency was improved. This will significantly reduce power consumption and increase the efficiency of the electrowinning process, as well as reduce the potential acid mist hazards associated with electrowinning.

2:50 PM

Direct Electrowinning of Silver from Dilute Leach Liquors: *Sunil Jayasekera*¹; ¹Lakefield Orestest Ltd., 12 Aitken Way, Kewdale, Perth, Western Australia 6105 Australia

This paper describes the results of a study carried out to examine the feasibility of electrolytic recovery of silver from cyanide leach liquor generated from a Western Australian silver mine tailings using a novel high mass transfer electrowinning cell. The proposed circuit involves heap leaching and electrowinning in a closed loop. The filter-press-like closed electrode arrangement of the cell allowed much improved mass transfer of metal ions to the cathode surface, making direct electrowinning of metals from dilute solutions feasible. The tests were conducted both in the laboratory and at large scale using a prototype with 1.0 m² cathode area. The results showed that the recovery of silver from as low as 250 mg/L tenor was feasible. The silver deposit produced with the prototype cell was non-adherent and powdery and could be readily removed from the closed cell. A system was designed such that the silver powder was discharged continuously without having to open up the cell for regular cathode stripping.

3:15 PM Break

3:30 PM

The EMEW® Technology, Case Studies: *Tony Treasure*¹; ¹Electrometals Technologies Ltd., 28 Commercial Dr., Ashmore, Queensland 4214 Australia

Electrometals Technologies Limited has now brought from concept to commercial availability a new electrowinning technology which successfully overcomes many of the process and cost limitations which plague conventional EW plants. Progress in its development over the period between 1996 and 2002 has been characterised by continual improvements in engineering of the technology, growing acceptance of its unique capabilities, and (most importantly) a growing number of installed facilities in a variety of process settings. The EMEW® cell is not a new process technology. It represents simply a modification of the hardware used in the process, which achieves 'factorially' higher efficiency in mass transport of metal ions than a conventional EW cell. It is simple, modular and of relatively low unit cost. Across most

applications that have been examined, tested and installed, capital and operating costs are lower than in an equivalent conventional tankhouse. Furthermore, improvement in operating efficiency and the versatility of the technology has expanded the breadth of applications over which electrowinning can be applied. Extensive work has now been carried out on application of the unique characteristics of the EMEW® cell to electrowinning of a number of metals in a variety of mining and industrial settings, including Copper, Nickel, Cobalt, Zinc, Gold, Silver, and Cadmium. The established usages for the technology range from profitable extraction of low grade metals from mine and industrial waste solutions, through treatment of metal refinery bleed streams, to primary metal production at large mining operations. The Company's development efforts over the past years has firmly established that the EMEW technology offers "generic" improvements to the process of electrowinning. This paper briefly presents a series of case studies comparing EMEW with conventional techniques in a variety of applications.

3:55 PM

Performance of Intercell Bars for Electrolytic Applications: A Critical Evaluation: *Guillermo A. Vidal*¹; Eduardo P. Wiechmann¹; Alberto J. Gonzalez²; ¹University of Concepcion, Barrio Universitario s/n, Concepcion, Bio Bio Chile; ²Teck Cominco Metals Ltd., Teck Cominco Rsch., PO Box 2000, Trail, BC V1R 4S4 Canada

Recently designed facilities have substantially improved on plant layout, automated cathode processing and copper harvesting. Despite these advancements only limited progress has been accomplished on the electric current distribution of the process. Lately a number of proposals focused on preventing short circuits and balancing cathode currents have emerged. Among these are the AZSA intercell, the Outokumpu double contact, and the segmented Optibar. Although these intercell bars are clearly superior to the conventional bar, little or conflicting data is available about their merits. A critical evaluation of the performance of the aforementioned bars on the basis of the application is provided.

4:20 PM

Commercial Development of a Descending Packed Bed Electrowinning Cell: *Douglas J. Robinson*¹; Stacey A. MacDonald¹; ¹Dremco, Inc., via bistolfi 35, Milano 20132 Italy

This paper describes technical work done to develop a Spouted Bed Electrode Cell into a commercially viable Electrowinning Cell. The studies have included hydrodynamic tests to understand the criteria for the circulating flow of metallic beads in the cell, particularly in the region at the entrance to the draft tube, and electrochemical tests to find a suitable diaphragm for extended time electrolysis. Various patent pending features were devel-



oped including a double nozzle to allow for automatic stopping and restarting of the bed, an arrowhead shaped draft tube to control the flow of beads into the entrance to the draft tube, a roof-top shaped device to control the flow of beads out of the top of the draft tube, an overflow weir to allow the continuous recovery of beads from the cell, and a family of diaphragm fabrics for extended operation. Prior to the identification of the diaphragm material, short circuits would develop within a few hours. A pilot scale cell was operated for three days, with continuous operator attention, and then for ten days coverage only on day shift. The cell is currently advancing to the next stage of development which will involve continuous testing in a commercial copper electrowinning facility.

4:45 PM

Investigations of Spouted Bed Electrowinning for the Zinc Industry: *O. M.G. (Mike) Newman*¹; Peter A. Adcock¹; Paul Freeman¹; Matthew J. Meere¹; James W. Evans²; Juan C. Salas²; Stanley Siu²; Asit Roy²; ¹Pasminco Smelter Technical Support, PO Box 175, Boolaroo, NSW 2284 Australia; ²University of California-Berkeley, Dept. of Matls. Sci. & Eng., Berkeley, CA 94720 USA

Research into potential applications of spouted bed electrowinning (SBE) in the zinc industry was conducted, in a collaboration between our two organizations. The main system investigated was zinc from acidic sulfate electrolytes. However, SBE can be extended to other electrolytes, or recovery of other elements. Electrolytic tests were carried out at the 0.01 to 0.1 m² scale. Spouting behavior has been studied at a larger scale, approaching a size suitable for an industrial unit cell. Much of our work was carried out using a micro-porous separator (Daramic®). However, we have also shown that ion exchange properties can have a controlling effect on the process chemistry, electrochemical efficiency, and plant flow-sheet. In 0.1 m² scale electrolytic tests, problems which appeared minor at smaller scale were magnified. We review the major achievements, promising areas for application in the zinc industry, current status, and remaining barriers to development of SBE technology. We gratefully acknowledge funding from AusIndustry, formerly Department of Industry, Technology and Regional Development (Commonwealth Grant AGR 05495), as well as the support of ILZRO (for research on alkaline SBE).

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Technology Application: Operations

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday PM August 27, 2003

2:00 PM

Financing Hydrometallurgical Processes: *Amy E. James*¹; ¹Stone & Webster Consultants, 8310 S. Valley Hwy., Ste. 250, Englewood, CO 80112 USA

Throughout the past decade, the worldwide mining and metals industries have seen numerous changes. Some of these changes have included consolidation, stricter environmental regulations, declining metals prices, rising inventories and weak demand outlooks, fluctuating and unpredictable power costs and lower ore grades. Because of these factors, mining and metals companies are continuously investigating new and innovative processes that can be used to create a competitive advantage. Hydrometallurgy can and has played a critical role in this movement. It can be said that the two most critical stages in taking a new hydrometallurgical process from imagination to commercial operation are 1) establishing the technical viability of the process and 2) procuring sufficient financing. Determining which of these stages is more important is equivalent to asking which came first, the chicken or the egg. The issues and questions faced by a developer when approaching investors and bankers are explored in this paper. Additionally, this paper looks at how research programs and feasibility studies can help or hinder the financing process. Several case studies are presented.

2:25 PM

Copper Concentrate Leaching Developments by Phelps Dodge: *John Marsden*¹; ¹Phelps Dodge Corporation, 1 N. Central Ave., Phoenix, AZ 85004-4415 USA

In early 1998, Phelps Dodge embarked upon program to investigate alternative technologies for the extraction and recovery of copper, and other metal values, from copper concentrates. A review of all of the available process alternatives indicated that many were unsuitable for large-scale com-

mercial application and others were clearly targeted at niche applications where contaminants (and consequently smelter penalties) were driving the decision-making. A result of this effort is the world's first commercial application of high temperature pressure leaching of chalcopyrite concentrates which is under construction at Bagdad, Arizona, and start up is scheduled for early 2003. Other processes are in various stages of development. In addition to the obvious technical considerations, the economic aspects of this technology have been considered in detail at each step in the development of the program. The technology developments in this area are reviewed with emphasis on the economic viability and commercial application.

2:50 PM

Hydrometallurgical Applications of Rheology Testing: *A. Mezei*¹; ¹Lakefield Research Limited, 185 Concession St., Lakefield, ON K0L 2H0 Canada

Experimental rheology data are needed to produce design criteria for mass and energy transfer processes. Large throughput plants operate under continuous flow mode. The capital cost is determined by the accuracy of the rheology data used for design. The operating cost is dictated by the energy required to sustain the flowing conditions of various process slurries. Typically, rheology investigations are carried out during the final stages of metallurgical test work, which is too late to set the design criteria for the pilot plant. This leads to increased testwork cost, and sometimes lowers confidence in the quality of the data produced. In addition, the engineering and feasibility studies are often delayed because of the lack of pertinent rheology data. The object of this paper is to emphasize the importance of timely planning and execution of the rheology study, which is shown to be a critical component of the overall testwork program. The application examples presented include slurry transport, separation processes and high temperature rheology, pertaining to precious and base metal metallurgy.

3:15 PM Break

3:30 PM

The Development and Piloting of an Industrial Hydrometallurgical Gallium Plant: *Corby G. Anderson*¹; ¹CAMP - Montana Tech, 1300 W. Park St., Butte, MT 59701 USA

Gallium is sometimes found in conjunction with zinc ores. In one existing North American hydrometallurgical facility, gallium will now be recovered as a value added by-product. This paper will outline the process development, lab testing and pilot scale confirmation undertaken to implement the technology. Pertinent economics will be discussed.

3:55 PM

The Sepon Copper Project: Development of a Flowsheet: *Graham Pratt*²; Ken Baxter¹; David B. Dreisinger³; ¹Bateman Metals Pty Ltd, 47 Burswood Rd., Victoria Park 6100, Perth, Western Australia 6100 Australia; ²Oxiana Resources NL, Level 9, 31 Queen St., Melbourne, Victoria Australia; ³University of British

Columbia, Metals & Mats. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada

The Sepon Copper Project is located in Laos and has a mineable reserve of approximately 16Mt of ore grading 5% copper with minor gold and silver values. The deposit is a clay hosted secondary copper mineral suite predominantly chalcocitic in nature with minor pyrite. The current project design is based on the production of 60,000t/a of LME Grade A cathode by an acid leaching process followed by solvent extraction and electrowinning. Significant metallurgical testwork was conducted as part of the Definitive Study (DFS) with process challenges identified and overcome at each phase of testing. Flowsheet configuration is geared to autogenously generating sufficient acid and ferric iron to leach the copper and is strongly influenced by the proportion of pyrite in the ore presented to the process facility. This paper will outline flowsheet development from preliminary variability testing to pilot plant and DFS design. The Sepon process solution provides a balance between operability and capital/operating costs and provides insights to the basic mechanisms influencing flowsheet selection for these ore types.

4:20 PM

The Teck Cominco HydroZinc™ Process: *Hector M. Lizama*¹; Juris R. Harlamovs¹; Suzanne Belanger¹; Stephanie H.R. Brienne¹; ¹Teck Cominco Metals Ltd., Teck Cominco Rsch., PO Box 2000, Trail, BC V1R 4S4 Canada

A new integrated process, known as HydroZinc™, is described for the recovery of zinc from sulfide ores that includes heap leaching, neutralization, solvent extraction, and electrowinning. Unit operations were scaled up from bench scale to a 1 t/d zinc cathode demonstration plant. Studies defined the process chemistry and a process flowsheet. Column tests were used to design full-scale heaps for zinc bioleaching and a mini-pilot rig was used to design a solvent extraction circuit. The characteristics of the process required development of a novel bleed circuit for water and impurities. The complete integrated process was tested on a demonstration plant scale for two years, with about 10,000 t of zinc sulfide ore being bioleached in two 6-m tall test heaps. In addition to 1 t/d of zinc cathode, iron hydroxide and gypsum residues were also made as well as a small effluent bleed. Over the course of the two-year demonstration test, a number of technical hurdles were overcome and a number of improvements were made. Some of the more significant ones are presented along with process descriptions and experimental and pilot plant data. Some engineering aspects and economic evaluations of the new process are also discussed.



4:45 PM

Removal of Phosphorus from Lisakovsky Iron Ore by a Roast-Leach Process: *Harold R. Kokal*¹; Mahendra P. Singh²; Vladimir A. Naydyonov³; ¹Ispat Inland, Inc., Proc. Rsch., Ispat Inland Rsch. Labs., 3001 E. Columbus Dr., E. Chicago, IN 46312 USA; ²Orken LLP, Iron Ore Div., 13 "40 Years of Kazakhstan" St., Karaganda, Karaganda 470051 Kazakhstan; ³Orken LLP, Lisakovsky GOK, 18 Microregion 1, Lisakovsk, Kostani 459335 Kazakhstan

Lisakovsky is a 3-billion ton oolitic iron ore deposit in north-central Kazakhstan operated by Orken LLP, a subsidiary of Ispat Karmet and the LNM Group. The iron oxide minerals are goethite and limonite. The gangue occurs as discrete quartz grains and an unidentified form of colloidal silica-alumina. The concentrate produced contains about 49.5% iron (Fe) and 0.7-0.8% phosphorus (P) or 10-20 times the acceptable phosphorus level. The phosphorus is intimately associated with the iron oxide and colloidal gangue, no discrete phosphorus minerals are found, and beneficiation is not possible. Therefore, to reduce the phosphorus, a hydrometallurgical process that includes roasting followed by leaching in dilute sulfuric acid has been developed. Phosphorus extraction is 70-90%, with only a minor loss of iron. The process has been tested in the laboratory and in a pilot plant at 50-300 kg/h. Planning for a 900,000 t/y demonstration plant is underway.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching I: Heap Leaching

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

Wednesday PM
August 27, 2003

2:00 PM

Heap Leach Modeling: The Current State of the Art: *David G. Dixon*¹; ¹University of British Columbia, Dept. of Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada

Since the early 1970's and its first implementation for the recovery of gold from low-grade ores by cyanidation,

heap leaching has developed into a key hydrometallurgical technology, in conjunction with solvent extraction and electrowinning, for the recovery of base metals, including most notably copper from both oxides and secondary sulfides, and more recently, nickel and zinc. And given recent advances in bioleaching with thermophilic microbes, the successful application of heap leaching technology to low-grade primary copper ores seems only a matter of time. However, with each new development, it becomes increasingly apparent that the successful application of heap leaching technology will ultimately depend on our having an ever more complete understanding of the fundamental processes underlying the process. Much work has been done toward the development of this understanding, on many different fronts. In this paper, a critical overview of the most important work of the last ten years is presented, and potential directions for future work are discussed.

2:25 PM

Improvements in Bioleaching Process at ZALDIVAR: *C. García*¹; J. Cruz¹; J. Campos¹; G. Rodríguez¹; D. García²; J. D. Miller³; ¹Compañía Minera Zaldivar, Av Grecia 750, Antofagasta Chile; ²Universidad de Santiago, Dept. de Metalurgia, Santiago Chile; ³University of Utah, Dept. of Metall. Engrg., Salt Lake City, UT USA

Compañía Minera Zaldivar has recognized that many improvements could be done in heap Bioleaching of copper sulphide minerals in order to increase copper recovery. Several research projects were carried out to study the effect of different parameters that control bioleaching process. This paper presents the results of these projects and the effects in copper recovery of drip emitters placement, solution application rates, drip emitters blocking, heap aeration systems, temperature, particle size effects, particle liberation, heap height and re-mining.

2:50 PM

A Comprehensive Copper Stockpile Leach Model: Part I. Background and Model Formulation: *C. R. Bennett*²; M. Cross²; T. N. Croft²; J. L. Uhrig³; J. E. Gebhardt¹; ¹Process Engineering Resources, Inc., 1945 S. 1100 E., Ste. 100, Salt Lake City, UT 84106 USA; ²University of Greenwich, Ctr. for Numerl. Modlg. & Process Analy., Park Row, Greenwich, London SE10 9LS UK; ³Phelps Dodge Mining Company, Process Tech. Ctr., 9780 E. Sanchez Rd., Safford, AZ 85546 USA

The first phase in the design, development and implementation of a comprehensive computational model of a copper stockpile leach process is presented. The model accounts for transport phenomena through the stockpile, reaction kinetics for the important mineral species, bacterial effects on the leach reactions, and heat, energy and acid balances for the overall leach process. The paper describes the formulation of the leach process model and the implementation of the model in PHYSICA+, a computational fluid dynamic (CFD) model-

ing software environment. The model draws on a number of phenomena to represent the competing physical and chemical features active in the process model. The phenomena are essentially represented by a three phase (solid-liquid-gas) multi-component transport system; novel algorithms and procedures are required to solve the model equations and these are described, including a methodology for dealing with multiple chemical species with different reaction rates in ore divided into multiple particle size fractions.

3:15 PM Break

3:30 PM

Ore Geotechnical Effects on Copper Heap Leach Kinetics: *Graeme Miller*¹; ¹University of Queensland, Sinclair Knight Merz Australia, A J Parker CRC for Hydrometall., Div. of Mining & Minls. Process Engrg., Brisbane, QLD 4072 Australia

The ore geotechnical characteristics are important in understanding the kinetics of copper heap leaching. They can indicate potential problems and be used to determine the semi-quantitative changes in field kinetics as compared with column kinetics. The application of this approach allows a more rigorous basis for scale-up than previously. The shrinking core model is a poor predictor of leach kinetics based on crushed ore size distribution. However the model itself is a useful tool to analyse leach data. Geotechnical parameters such as: bulk density-stress characteristic, limit moisture capacity and particle density are used to determine the effect of changes on the diffusion controlled leach rate. By considering the geotechnical reaction of the ore mass the leach rate changes are related to changes in these variables. Analysis of leach data has indicated effective diffusion lengths of up to ten times the largest particle size.

3:55 PM

The Dynamics of Chalcocite Heap Bio-Leaching: *Jochen Petersen*¹; David G. Dixon¹; ¹University of British Columbia, Metals & Mats. Engrg., 6350 Stores Rd., Vancouver, BC V6T 1Z4 Canada; ¹University of Cape Town, Chem. Engrg., Private Bag, Rondebosch 7700 S. Africa

Chalcocite, the most common secondary copper sulfide, leaches by a two-stage mechanism. The first stage is rapid, whereas the second stage proceeds slowly at ambient temperatures. Nonetheless, this rate is still considerably faster than what is commonly realised in a full-scale chalcocite heap leach operations. Column leach tests of a chalcocite ore have shown that the mineral leaches in a zone-wise fashion corresponding to the two stages. The rate of migration of the zones is directly related to the rate of acid supply in the column feed, and acid supply rather than mineral kinetics controls the overall rate of leaching. In full scale heaps, there is evidence to suggest that solution distribution favours channelling between relatively large clusters of material exposed to stagnant solution. The rate of mineral oxidation is therefore governed by the rate of acid diffusion through long stagnant pores. Column experimental results have been reproduced with a comprehensive heap modelling tool. The

model predicts that by simply changing the length of the average diffusion channel from column conditions (a few cm) to heap conditions (tens of cm), extraction times can change from weeks to years under otherwise identical conditions.

4:20 PM

The Life Cycle of a Chalcocite Heap Bioleach System: *David John Readett*¹; Linus Sylwestrzak¹; ¹Straits Resources Limited, PO Box 1641, West Perth, Western Australia 6872 Australia

Bioleaching of chalcocite ores in heaps has been practiced for many years. Recently Straits Resources Limited successfully implemented heap bioleaching of chalcocite at its Nifty Copper Operation, transferring its operational experience from its previous successful Girilambone Copper Operation. In order to obtain a greater fundamental understanding of the heap bioleach system Straits has been working closely with CSIRO. A 85,000t chalcocite test heap was established at Nifty to allow for detailed study. On an ongoing basis the physical, chemical and biological components of the system were monitored. Due to implementation of a heap management strategy and the specific mineralogy of the heap it was possible to maintain operating conditions within the heap of 40 to 70 C. There was a significant change in the chemistry and bacterial biota over the life of the heap. Initially only mesophilic bacteria were detected. However, within two months of the commencement of leaching, the presence of moderate thermophiles was detected. As leaching progressed the moderate thermophile species stabilised as did the mesophiles. This has been the first time that moderate thermophiles have been detected at a Straits operation. It was achieved without the external inoculation of moderate thermophiles. The elevated temperature and controlled physical and chemical heap environment resulted in a significant increase in copper extraction kinetics, with +45% recovery in 50 days and +70% recovery in 180 days. Ultimate target extraction of 85% was achieved in 300 days. Previous data from GCC gave optimum recoveries of 85% in 480 to 600 days. The paper covers in detail findings from the 85,000t test heap.

4:45 PM

Process Improvements at Mantoverde Heap Leach Operation: *Gabriel E. Zárate*¹; Luis O. Trincado²; Ulises I. Troncoso²; Carlos A. Vargas²; ¹Empresa Minera de Mantos Blancos, Tech. Mgmt., Pedro de Valdivia 295, Providencia, Santiago Chile; ²Empresa Minera de Mantos Blancos, Mantoverde Div., Pedro de Valdivia 295, Providencia, Santiago Chile

Mantoverde is a heap leach-solvent extraction-electrowinning plant that was commissioned in December 1995 at a production rate of 42,130 tpy of copper and an ore treatment rate of 5.4 millions tpy. Copper pro-



duction has steadily increased from 40,539 tonnes in 1996 to 56,311 tonnes in 2001. Forecast copper production for 2003 is 60,000 tonnes for an ore treatment rate of 8.5 million tonnes. Several improvements in the heap leach process, in order to reach the actual level of production have been implemented. The main process improvements are related to the optimization of operating conditions such as heap height, particle size, irrigation rate and leach cycle, in addition to a better heap drainage design and a better solution management system. A first dump leach operation was started in 1999 at an initial production rate of 1,922 tonnes of copper. A second dump leach operation was started in early 2002 at an initial production rate of 2,805 tonnes of copper. Dump leach copper production will increase over time to as much as 24,000 tonnes of copper. The main heap leach process improvements, as compared to the original plant design, as well as the main dump leach operating conditions are discussed in this paper.

International Symposium on Hydrometallurgy in Honor of Professor Ian Ritchie: Leaching II: Pressure and Autoclave

Sponsored by: Extraction & Processing Division, The Minerals, Metals & Materials Society (TMS)

Program Organizers: Courtney A. Young, Montana Tech of the University of Montana, Metallurgical Engineering, Butte, MT 59701 USA; Akram M. Alfantazi, University of British Columbia, Dept of Met & Mat Eng, Vancouver, BC V6T 1Z4 Canada; Corby G. Anderson, Montana Tech of the University of Montana, Center for Advanced Mineral & Metallurgical Processing, Butte, MT 59701-8997 USA; David Bruce Dreisinger, University of British Columbia, Department of Metals & Materials Engineering, Vancouver, BC V6T 1Z4 Canada; Bryn Harris, Consultant, Montreal, Quebec H2X 2L4 Canada; Amy James, Stone & Webster Management Consultants Inc, Denver, CO USA

**Wednesday PM
August 27, 2003**

2:00 PM

The Use of Ortho-Phenylene-Diamine (OPD) as a Surfactant in the Pressure Oxidation of Pyrite: *David B. Dreisinger¹; Zhimin Zheng¹; Nancy J. Dunlap²; ¹University of British Columbia, Metals & Matls. Engrg., 309-6350 Stores Rd., Vancouver, BC V4K 4K2 Canada; ²Dupont Company, Barley Mill Plaza 23-2284, 4417 Lancaster Pike, Wilmington, DE 19805 USA*

The pressure oxidation of pyrite is an important hydro-metallurgical technology, especially in the total oxidation of refractory gold ores and concentrates (gold is locked in the pyrite structure). It has been noticed in some commercial applications and bench-scale studies that the leaching of pyrite may be slow and can be inhibited by the presence of

molten elemental sulfur in the leach pulp. The purpose of this study was to determine whether Ortho-Phenylene-Diamine (OPD) could be used as a surfactant or dispersant for sulfur in the pressure oxidation of pyrite. OPD has previously been shown to be useful for pressure leaching of zinc and copper sulfides at 150°C. In this work, the interfacial chemistry of sulfur was studied at temperatures of up to 200°C in acidic solutions in the presence of OPD and other surfactants. The contact angle between molten sulfur and pyrite was also measured and the work of adhesion calculated. Finally, the impact of OPD on the kinetics of pyrite oxidation was measured in bench-scale pressure oxidation experiments. OPD was found to be effective as a surfactant and fully degraded at high temperature in the leach tests.

2:25 PM

Development and Implementation of a Novel Pressure Leach Process for the Recovery of Cobalt and Copper at Chambishi, Zambia: *Ed Munnik³; Hira Singh³; Thys Uys⁴; Mark Bellino¹; Bryn Harris⁵; Kevin Fraser²; John du Plessis¹; ¹HATCH Africa (Pty), Ltd., Non-Ferrous, PB X20, Gallo Manor 2052 S. Africa; ²HATCH Associates, Ltd., Non-Ferrous, 2800 Speakman Dr., Mississauga, Ontario L5K 2R7 Canada; ³Chambishi Metals P.L.C., Chambishi Zambia; ⁴Anglovaal Mining, Ltd., PO Box 62379, Marshalltown 2107 S. Africa; ⁵Process Research Ortech, Mississauga Canada*

The Chambishi Metals Cobalt Plant in Zambia has recently installed a novel oxidation/precipitation pressure leach process as part of the COSAC (Cobalt from Slag and Copper as by-product) Project. An iron-cobalt-copper alloy, produced by the carbothermic reduction of slag, is atomized and pumped to the COSAC Leach Plant, where cobalt and copper are recovered as dissolved sulphate salts, and iron is rejected primarily as hematite. Cobalt and copper are subsequently recovered as cathode metal in the existing Chambishi operation by conventional electrowinning. This paper examines the challenges faced during the design and subsequent successful commissioning of the COSAC Leach Plant. The challenges discussed include alloy handling, autoclave design, autoclave cooler design, residue liquor recovery and the water balance design.

2:50 PM

pH Measurements in High-Temperature Hydrometallurgical Systems: *V. G. Papangelakis¹; D. S. Seneviratne¹; X. Y. Zhou²; S. N. Lvov²; ¹University of Toronto, Dept. of Chem. Engrg. & Appl. Chmst., 200 College St., Toronto, ON M5S 3E5 Canada; ²The Pennsylvania State University, The Energy Inst. & Dept. of Energy & Geo-Environml. Engrg., University Park, PA 16802 USA*

The implementation of a flow-through yttria-stabilized zirconia (YSZ) sensor for pH measurements in high temperature and concentrated electrolyte systems relevant to hydrometallurgical processing of nickeliferous laterites is discussed. Instrumentation involved the use of a custom made flow-through titanium electrochemical cell. Accuracy and validity

of the pH measurements at temperatures up to 250C were assessed using concentrated sulphate process solutions ranging from synthetic binary sulphuric acid-water solutions to progressively multicomponent metal-sulphate solutions simulating laterite Pressure Acid Leach conditions. The measurements were also compared with theoretical models using recently obtained thermodynamic data. An average difference of ± 0.15 pH units was observed between measured and calculated pH over a wide range of temperatures. This is an acceptable difference given that these are the first direct high temperature pH measurements ever on the concentrated acidic sulphate solutions. This result is encouraging more research for the development of industrial electrochemical systems for direct pH measurements in autoclaves.

3:15 PM Break

3:30 PM

Design of Horizontal Autoclaves a Pilot Plant Evaluation of Solids Suspension, Blending and Residence Time Distribution: *Peter Forschner*¹; *David Houlton*¹; *Ronald Klepper*²; *Volker Kasser*³; ¹EKATO Rühr- und Mischtechnik GmbH; ²EKATO Corporation; ³CF Consultants

Mixing theory is based on applying many fundamental correlations to symmetrical vertical cylindrical vessels with dished or flat bottoms. Horizontal autoclaves have been used for more than two decades to rapidly complete chemical reactions at elevated temperatures. All compartments and especially the first and last compartments are asymmetrical. To date no comparison of the effects of the asymmetric geometry on mixing system design and scale-up has been published. The results of investigating solids suspension, mixing time, momentum of impeller to feed slurry and feed location in the first autoclave compartment are presented as influences on residence time distribution and presented using CFD modeling that was verified with test apparatus.

3:55 PM

CFD in Autoclave Vessel Design: *Lanre Oshinowo*¹; *Lowy Gunnewiek*¹; *Kevin Fraser*¹; ¹Hatch Associates, Ltd., 2800 Speakman Dr., Mississauga, Ontario L5K 2R7 Canada

The trend in process engineering is to design compact, more efficient processes that utilize expensive materials of construction. There is the paramount requirement to get the job done right the first time going from the drawing board to full-scale commercial operation. There is the need for tools beyond the traditional engineering toolkit to evaluate designs through virtual prototyping thereby reducing the risks associated with making design decisions. One of the most important tools that has recently come to the forefront of process design and development is Computational Fluid Dynamics (CFD). CFD has been used to address the key process parameters that drive the design of the hydrometallurgical unit operation. This paper will detail the role of CFD in achieving a superior level of confidence in the process design of autoclave technology. Specifically, the optimum application of multiphase modelling including hydrodynamic, heat and

mass transfer and chemical reaction to hydrometallurgy operations, the impact of non-Newtonian slurry rheology on autoclave performance, and the challenges of optimizing the mixing of key reactants into slurries in autoclave reactors, is discussed. In addition, model verification and validation is presented.

4:20 PM

Autoclave Technology for Mineral Processing: *A. V. Tarasov*¹; *E. M. Timoshenko*¹; ¹State Research Institute of Non-Ferrous Metals "GINTSVETMET", 13 Acad. Korolyov St., Moscow 129515 Russia

The high efficiency of autoclave processes is attributed to the fact that they are suitable for processing of refractory raw materials, have low capital costs and high productivity, ensure integrated utilization of the feed materials, produce innovative saleable products, completely eliminate any air emissions, provide low-waste or waste-less technology, as well as mechanization and automation of production processes. In the immediate future, it might be expected that autoclave processes will find use on commercial scale for production of heavy non-ferrous metals in combination with other processes (hydrometallurgical, upgrading, sorption and solvent extraction, electrolytic, etc.) to ensure: - Integrated processing of refractory ores and concentrates (pyrrhotite, zinc, copper-zinc, lead-zinc, nickel-cobalt, copper, pyrite); - Production of metallic powders of base metals as commercial products (copper, cobalt, nickel, etc.), composites on their bases, final products and saleable salts. Processing technologies incorporating autoclave processes, especially, at the stage of liberation (chemical upgrading) of minerals, are characterized generally by high overall recoveries of valuable constituents significantly exceeding recoveries common for conventional pyrometallurgical processes (for some elements by several tens of percent).

4:45 PM

On-Line Analyzers in Hydrometallurgical Applications: *Richard Krentz*¹; ¹Sherritt International Corporation, 10101 114 St., Box 3388, Ft. Saskatchewan, Alberta T8L 2T3 Canada

Two separate on-line analysers have been commissioned at the Corefco metals refinery. The first application is an on-line refractometer which measures the ammonium sulphate concentration in the primary feed slurry tank. The second application is a multi-stream X-Ray fluorescence analyser which measures the metals and sulphur concentrations in eight key refinery streams. Specific applications of the on-line analysers with advanced control systems for improved process control will be discussed.



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