COPPER 99 - COBRE 99

Pointe Hilton Resort

	Monday		Tuesday		Wednesday	
	AM	PM	AM	PM	AM	PM
Flagstaff/Gold-water/Indigo/ Jerome	Plenary Lectures: Session I		Plenary Lectures: Session II		Plenary Lectures: Session III	
Copper	Movement of Copper and Industrial Outlook: Economics-Finances	Movement of Copper and Industrial Outlook: Markets and Trends	Copper Applications and Fabrication: Fabrication	Copper Applications and Fabrication: Applications	Environment, Health & Safety: Session I	Environment, Health & Safety: Session II
Indigo	Electrorefining: Refinery Operations I	Electrorefining: Refinery Operations II	Electrorefining: Refinery Operations III	Electrorefining: Refinery Operations IV	Electrorefining: Refinery Anodes and Cathodes	Electrorefining: Reactions During Electrorefining
Goldwater	Smelting: Technology Development I	Smelting: Technology Development II	Smelting: Process Modeling and Control I	Smelting: Process Modeling and Control II/ Fundamental Studies	Smelting: Fundamental Studies and Technology Development I	Smelting: Fundamental Studies and Technology Development II
Flagstaff			Smelting: Process Modeling and Fundamentals: Gas Handling	Pyrometallurgy-Operations: Session V		
Jerome	Mineral Processing: Operations I	Mineral Processing: Metallurgy	Mineral Processing: Operations II			
Hopi	Hydrometallurgy: Ore Leaching	Hydrometallurgy: Design, Simulation and Control	Hydrometallurgy: Biohydro-metallurgy	Hydrometallurgy: Metal Extraction	Hydrometallurgy: Electrowinning I	Hydrometallurgy: Electrowinning II
Apache/Bisbee	Hydrometallurgy: Concentrate Leaching I	Hydrometallurgy: Concentrate Leaching II				
Estrella	Pyrometallurgy-Operations: Session I	Pyrometallurgy-Operations: Session II	Pyrometallurgy-Operations: Session III	Pyrometallurgy-Operations: Session IV	Pyrometallurgy-Operations: Session VI	Pyrometallurgy-Operations: Session VII

COPPER 99 - COBRE 99
Final Technical Program

Plenary Lectures: Session I

Monday AM — Room: Flagstaff/Goldwater/Indigo/Jerome
October 11, 1999 — Location: Pointe Hilton Resort

Session Chairs: G. A. Eltringham, BHP Copper, Inc., Special Projects, San Francisco, CA 94104-1020 USA; P. J. Mackey, Noranda Technology Centre, Point Claire, Québec, Canada

8:30 AM
Welcome Addresses by Co-Organizing Societies
G. A. Eltringham representing The Minerals, Metals and Materials Society
S. Demetrio representing the Chilean Institute of Mining Engineers
C. Diaz representing The Metallurgical Society of The Canadian Institute of Mining, Metallurgy and Petroleum

8:50 AM
Markets for Copper into the Millennium: A New Approach to Copper Market Forecasting: *Paul Dewison*[1]; [1]Metalica Limited, Forge Cottage, Ousden, Suffolk CB8 8TR England

For nine years, from mid-1987 to mid-1996, the copper market enjoyed what appeared to be an endless boom in which prices were much higher relative to production costs than for most other base metals. After the boom ended abruptly mid-1997 with Sumitomo affair, copper was burdened by an overhang of new projects that promised to swamp demand in what, with the Asian financial and economic crisis of 1997, had become a considerably worse consumption environment. Now, demand prospects do not look so bad. If, as we suspect, we will be dealing with a more rational market in the future, it becomes all the more important to forecast accurately the prospects for consumption. In this paper, we present a new methodology for copper demand forecasting. The methodology forms the backbone of the demand-side analysis for the multi-client study entitled "Long Term Outlook for Copper," co-authored by Metalica Ltd. and Bloomsbury Minerals Economics (BME). Key components of the methodology are as follows: relate demand to economic structure, focus on products rather than refined consumption, apply a consistent products/applications analysis to all countries and time series and incorporate scrap market dynamics within the analytical framework.

This Plenary Lecture will be preceeded by some observations by Paul Dewison on recent developments in the Copper Industry regarding consolidation and capacity changes.

10:00 AM Break

Electrorefining: Refinery Operations I

Monday AM — Room: Indigo
October 11, 1999 — Location: Pointe Hilton Resort

Session Chairs: J. E. Dutrizac, CANMET, Ottawa, Ontario, Canada K1A 0G1; V. Ramachandran, Asarco, Inc., Technical Service Center, Salt Lake City, UT 84119 USA

10:30 AM
Electrolytic Copper Refining - 1999 World Tankhouse Operating Data: W. G. Davenport[1]; J. Jenkins[2]; B. Kennedy[3]; *T. Robinson*[4]; [1]University of Arizona, Dept. of Mats. Sci. and Eng., Tuscon, AZ 85721 USA; [2]Cyprus Sierrita Corporation, 6200 W. Duval Mine Rd., P.O. Box 527, Green Valley, AZ 85622 USA; [3]Simons Engineering, Inc., 2700 N. 3rd St., Suite 2006, Phoenix, AZ 85004 USA; [4]CTI ANCOR, 2121 San Jacinta St., Suite 2500, Dallas, TX 75201 USA

A survey of world copper refining tankhouse practices has been carried out. This paper compiles the results and examines changes in operating practices since the similar 1987, 1991 and 1995 surveys. Continuing trends are the installation of ISA Process and Kidd Process stainless steel cathode technology, polymer concrete cells, anode preparation machines and automatic cranes. Instrumentation and automatic control are increasing, particularly for addition agent optimization; solvent extraction and ion exchange techniques are being increasingly applied for electrolyte purification. The overall consequences of these changes have been improved cathode purities and enhanced tankhouse productivities.

10:55 AM
La Caridad, the Newest Copper Refinery in the World: *M. E. Ramos Rada*[1]; J. M. Garcia R.[1]; I. Ramirez G.[1]; [1]Mexicana de Cobre S.A. de C.V., P.O. Box 20, Nacozari, Sonora CP 84330 México

Mexicana de Cobre, which is part of Grupo Mexico, carried out studies for the construction of a copper refinery in the La Caridad Metallurgical Complex located in Nacozari, in the state of Sonora, Mexico. After the studies were concluded, the decision was made to construct a 180,000 t/y refinery using the state of the art permanent cathode Kidd Process. The basic engineering was developed by Fluor Daniel and the detail engineering and the construction were carried out in record time by the Mexican company Bufete Industrial. During the construction phase, Grupo Mexico decided to expand the refinery, and actions were taken to increase its capacity by an additional 120,000 t/y; the final result was a refinery capable of producing 300,000 tonnes of grade A cathode per year. Construction began in

January 1996, and the operation of the first stage began on July 1, 1997. The operation of the second stage commenced on January 7, 1998. The capacity of the first stage was reached in November, 1997 and the total capacity of the refinery was achieved in May, 1998. This presentation describes the process and equipment installed in the refinery, the steps leading to the start-up, the operation and the results obtained during the first two years, the handling of anodes with high impurity contents, and the problems confronted and the way they have been solved. It also includes personnel productivity, the control parameters and the most relevant data on the operation of the process.

11:20 AM
Design and Operating Characteristics of the New Olen Tank House: C. Geenen[1]; J. Ramharter[1]; [1]Union Miniere Copper, Watertorenstraat 33, Olen B-2250 Belgium

At its Olen site, Union Minière Copper operates a new full-size deposit tank house. A first 200,000 t/y module was commissioned in October 1996, and an additional 130,000 t/y unit started in April 1998. The main objectives of the new tank house project were to produce grade A cathodes starting from anodes with a wide range of compositions and at a minimal operating cost. The tank house uses Isa Process technology. Based on the process parameters agreed upon with MIM, UM Copper developed the basic design and UM Engineering was the in-house contractor for the engineering. The new tank house is equipped with advanced technology polymer concrete cells, automated two-bale cranes and high-capacity machines. The first 200,000 t/y module treats anodes with a more conventional composition at 330 A/m˝; the second 130,000 t/y module treats anodes with a high slimes fall (12-13 kg/t) at current densities up to 285 A/m˝. After some teething problems, the new tank house is meeting all set targets. This paper illustrates and comments on the design characteristics and operational results.

11:45 AM
Design, Start-Up and Operation of the Cyprus Miami Copper Refinery: J. Garvey[1]; B. J. Ledeboer[2]; J. M. Lommen[3]; [1]Cyprus Miami Mining Corporation, P.O. Box 4444, Claypool, AZ 85532 USA; [2]Electrometallurgical Consultant, 3210 Melendy Dr., San Carlos, CA 94070 USA; [3]Fluor Daniel Mining and Minerals, 1527 Cole Blvd., Golden, CO 80401 USA

The new Cyprus Miami electrolytic copper refinery was commissioned in October 1994. The refinery has been operating at its design capacity of 190,000 short tons per year, and in recent months to 110% of design capacity, producing high-grade electrolytic copper cathodes. Basic and detailed engineering, performed by Fluor Daniel Mining and Minerals, Inc. state-of-the-art technology, including stainless steel cathodes, automated electrode handling, fine-filtering of the commercial electrolyte, autoclave leaching of the anode slimes and other techniques. The major design goals have been safety of operation and quality of the product. Relatively high cathode current densities of 30 amperes per square foot and greater have been applied since start-up. Cathode current efficiencies of over 94% have been achieved since the latter part of 1997. The cathodes were certified on the Comex and LME markets during 1996. ISO-9002 certification is in progress and should be completed during the first quarter of next year. This report discusses some of the studies that were performed to obtain an optimum layout for efficient materials handling and to create optimum conditions for producing high quality cathodes. A description of the design and operation of the anode slimes facility, including decopperizing with autoclave leaching, is provided. Finally, a description of the start-up experiences and present operation of the electrorefinery are presented.

Hydrometallurgy: Ore Leaching

Monday AM Room: Hopi
October 11, 1999 Location: Pointe Hilton Resort

Session Chair: Henry Salomon-De-Friedberg, Compañia Minera Quebrada Blanca, Santiago, Chile S.A.

10:30 AM
Electrolytic Copper—Leach, Solvent Extraction and Electrowinning World Operating Data: *Jackson Jenkins*[1]; William G. Davenport[2]; Brian Kennedy[3]; Tim Robinson[4]; [1]Cyprus Sierrita Corporation, Tech. Svcs. Dept., Green Valley, AZ USA; [2]University of Arizona, Dept. of Mat. Sci. and Eng., Tucson, AZ USA; [3]Simons Engineering, Inc., Metallu. Eng. Phoenix, AZ USA; [4]International Business Development, Cti Anchor, Dallas, TX USA

The second survey of world copper SXEW plants has been completed. Solvent extraction and electrowinning data published in 1996 has been updated and leach data from seventeen plants is now included. The results of the thirty-two plants that responded to the survey are presented. Selected information is summarized in graphical form.

10:55 AM
Recent Changes to Operating Practices at Minera Quebrada Blanca: *Henry Salomon-De-Friedberg*[1]; [1]Compañia Minera Quebrada Blanca S.A., Apoquindo 3200, 4° Piso, Santiago, Chile

Quebrada Blanca has had to overcome numerous challenges in achieving design throughput. The paper reviews how actual practice has evolved from the original design. The major challenges that were encountered from heap leeching to solvent extraction, the tankfarrn and through to electrowinning are discussed. The eventual solutions to some of the key issues are presented.

11:20 AM
Enhanced Leaching of Copper Sulfide Leach Dumps: Application at Cananea, Mexico: *Jose Hector Figueroa P.*[1]; Jorge Enrique Ruiz H.[1]; Ramon Ayala F.[1]; [1]Mexicana de Cananea, S.A. de C.V., Av. Juarez No. 4, Cananea, Sonora 84620 Mexico

Mexicana de Cananea, S.A. de C.V. is a major copper producer mining a large deposit of the disseminated porphyry type considered one of the largest copper resources of the world with 2.7 billion tons

of 0.60% copper for the mill plus 4.1 billion tons of averaging 0.26% copper for leaching. Mining of low grade sulfide leach ore, has been an important part of the overall production of the open pit mine which started in 1944. Before this time all the mining in Cananea was by underground methods. The leaching process in Cananea began on the 1920's with in situ operations in the underground mine and small dumps up to the 1950's. Large scale leaching operations began in 1960 and the copper solutions produced were treated in precipitation plants until 1980 when the first SX/EW Plant was put in operation in Cananea. Leaching action is essentially ferric-bacterial, with no fresh acid added to the leaching solutions. Traditionally, 55-60% copper extraction is recovered from ROM, 70-120 meter high leach dumps in 80 months of leaching. Cananea has successfully improved copper recoveries by implementing several actions that include: stripping of old dumps, leaching of old dumps through slotted casing, and crushing conveying leach ore to minus 8 inch and stacking it in 30 meter lifts. As result of these actions, copper recovery has been increased to about 70% of total copper with actions 1 and 2 and up to 85% in half the time by crushing-conveying the leach ore, based on the same solubility index of the run-of-mine ore. This paper describes the above actions that were implemented to enhance the leaching recoveries from sulfide leach dumps and the economics of such actions.

11:45 AM

Design Modifications at Zaldivar to Reach Plant Capacity Production: *C. Garcia*[1]; H. Arias[1]; J. Campos[1]; S. Gonzalez[1]; J. Mallory[1]; G. Merino[1]; J. Roco[1]; O. San Martin[1]; J. Whittaker[1]; [1]Compañia Minera Zaldivar, Balmaceda 2536, 4° Piso, Antofagasta, Chile

Several modifications to Zaldivar's original design have been made in order to reach the design cathode production. This paper describes the modifications to the crushing, leaching, solvent extraction and electrowinning operations, which in turn have increased the production by 14.8% over the design capacity in 1999. The principal modifications were to (1) incorporate a dry prescreening plant between the secondary and tertiary crushers to increase the percentage of fines to the piles, (2) increase the retention time of the solutions inside of the piles, and (3) increase the efficiency of the tertiary crusher's to reduce the particle size of the product material. The leaching ratio was increased from 2.8 to 5.6 m^3/ton. The temperature of the pregnant leach solution (PLS) was increased, the amount of acid used was reduced, and a strain of native bacteria was adapted in highly contaminated solutions. The copper concentration in the PLS was increased by more than 50% and was stabilized at this level by commissioning a process of two-stage leaching. The current density in the tankhouse was increased from an average of 216 to 317 A/m^2.

12:10 PM

Heap Leaching Practices at San Manuel Oxide Operations: *Joel K. Witt*[1]; Phil E. Cantrell[1]; Manuel P. Neira[1]; [1]BHP Copper, San Manuel Oxide Operations, 28255 W. Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA

San Manuel Oxide operations of BHP Copper, located in Southeastern Arizona, operates a leach-solvent extraction/electrowinning (SXEW) facility that produces high quality cathode copper from low-grade oxide ores. Permanent heap leaching and in-situ leaching methods accomplish the dissolution of copper from the oxide ores. Open pit mining and heap leach construction took place from 1985 to 1995. Run-of-mine oxide ore from the pit was hauled to the heap dumps and leached by the soaking cure and continuous irrigation method. Solution application to the heaps still continues and acid soluble copper recovery has reached 86%. This paper presents and discusses the current operating practices and innovations applied to the leach facilities to maximize copper recovery from the heap leached residue. Factors such as irrigation methods, solution chemistry, sideslope treatment, post curing, lixiviant acid strength, and "rice paddies" irrigation, will be discussed. Heap leach solution control and sampling methodologies will be also presented.

Hydrometallurgy: Concentrate Leaching

Monday AM Room: Apache/Bisbee
October 11, 1999 Location: Pointe Hilton Resort

Session Chair: David Dreisinger, University of British Columbia, Vancouver, Canada BC V6T 1Z4

10:30 AM

Leaching of Copper Concentrate by a Chemical Catalytic Oxidation Method: *Burkhard Seeger*[1]; [1]Universidad de Concepción, P.O. Box 160-C, Concepción, Chile

The oxidation of copper sulfides can be highly accelerated in the presence of nitrous gases (NO_x) as reaction catalysts. Sulfur and sulfate are simultaneously produced in this highly exothermic reaction. This process, carried out in sulfuric acid medium, is performed at an approximately normal pressure and at a temperature of around 110ϒC, in a closed container, adding either oxygen or air. The oxidation is automatically controlled through a computer. The process covers the following steps: Catalytic oxidation, filtration and crystallisation of the hot concentrated liquid, electrowinning, mother liquor treatment through jarosite formation, recovery of dissolved copper and zinc and regeneration of industrial water, and non-soluble residue treatment with extraction of sulfur and recovery of silver and gold. No combustibles are needed. No air is contaminated, and no wastewater is produced. Solid residues are in a stable, non-toxic and non-corrosive state of equilibrium. Risk of accident is low. Investment costs are small compared to those of the comparable pyrometallurgical process, and production costs are competitive.

10:55 AM

The Treatment of Chalcopyrite Concentrates with Nitrogen Species Catalyzed Oxidative Pressure Leaching: *Corby G. Anderson*[1]; [1]Montana Tech, The Center for Adv. Min. & Metall. Process., Rm. 221 ELC Bldg., Butte, MT 59701 USA

Today, with a stringent economic and environmental climate prevailing in the copper business, there is

increased interest in evaluating new processing alternatives for production. Hydrometallurgical pressure oxidation of copper concentrates is one of the more viable approaches and several technological candidates have emerged. Of these, an overlooked but industrially proven methodology utilizing nitrogen species catalyzation in the oxidizing pressure leach system may prove to be a feasible process alternative for the future. In this paper, the history of the system and its application to chalcopyrite concentrates will be outlined. In particular, a methodology for effective treatment of precious metals bearing chalcopyrite concentrates via partial oxidation at low temperatures and pressures will be discussed. Finally, the perceived economics of this unique industrially proven process will be delineated.

11:20 AM

New Atmospheric Leach Process for Copper Sulfide Ores and Concentrates: *C. J. Ferron*[1]; N. McKay[1]; L. Dymov[1]; D. Butcher[1]; [1]Lakefield Research Limited, 185 Concession St., Postal Bag 4300, Lakefield, Ontario, Canada KOL 2H0

Over the years, numerous hydrometallurgical processes have been proposed as an alternative or complement to smelters for the treatment of copper concentrates. Most of these initiatives met with limited success. Bioleaching is applied commercially for secondary copper minerals heaps and dumps, and bacterial leaching processes are being developed for copper concentrates, although industrial application is still years away. More recently developed processes usually include pressure leaching and/or ultrafine grinding. This paper proposes a new leach process to treat copper sulfide ores or concentrates: the process operates under atmospheric pressure and uses limited concentrations of ferric sulphate as oxidant; the key to the process is the regeneration of the ferric ion, which can be effected in-situ (direct process) or ex-situ (indirect process) using SO_2/O_2. Examples are presented for the treatment of copper concentrates by agitation leach and of copper ores by heap leaching. Application of the process to copper gold ores and chalcopyrite concentrates is also discussed.

11:45 AM

Pressure Leaching of Chalcopyrite Concentrates by Dynatec: Leslie A. Barta[1]; *Kelvin R. Buban*[1]; John Stiksma[1]; Michael J. Collins[1]; [1]Dynatec Corporation, Metall. Tech. Div., 8301-113 St., Ft. Saskatchewan, Alberta, Canada T8L 4K7

A new process for the leaching of chalcopyrite concentrates has been developed and tested in miniplant campaigns and locked cycle testwork carried out between 1996 and 1999. The process involves pressure leaching in a sulphuric acid solution, e.g. raffinate from copper solvent extraction. Iron in the feeds is precipitated predominantly as hematite in the autoclave, simultaneously with copper extraction. Gold and silver in the pressure leach residue are recoverable by conventional cyanidation, following flotation to remove elemental sulphur by-product. The results of recent miniplant tests and batch locked cycle tests are provided.

12:10 PM

The Total Pressure Oxidation of El Indio Ore and Concentrate: *David B. Dreisinger*[1]; Benjamin R. Saito[2]; [1]The University of British Columbia, Dept. of Metals and Mats. Eng., 6350 Stores Rd., Vancouver, Canada BC V6T 1Z4; [2]BHP Copper, San Manuel Refinery, 200 S., Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA

The total pressure oxidation treatment of arsenical copper ore and concentrate from the El Indio mine of Barrick Gold was tested in benchtop autoclave treatment. The concentrate oxidation typically achieved ~95% copper extraction. Copper extraction was limited by the reprecipitation of a complex precipitate containing arsenic. Gold extraction by cyanidation of the oxidation residue was around 95%. Silver extractions were less than 10% due to the formation of argentojarosite in the autoclave. The total pressure oxidation of the whole ore sample was more successful. Copper extractions of 98-99% were routine achieved. Gold extraction by cyanidation was +95%. Silver extraction could be increased to as high as 95% by using the lime boil treatment. A process flowsheet was proposed based on the results achieved. Copper recovery was proposed by direct solvent extraction and electrowinning of copper by treating the dilute solution from the autoclave discharge.

Mineral Processing: Operations I

Monday AM Room: Jerome
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: Mark O'Brien, Phelps Dodge; Eric Gutierrez

10:30 AM

Advances in Computer-Based, Multimedia Training Provide Significant Opportunities to Improve Results: *Stephen R. Brown*[1]; [1]Performance Associates International, Inc., 760 E. Pusch View Ln., Tucson, AZ USA

Current conditions in the copper market demand that mine and plant operators make budgeted production targets at the lowest possible unit costs. For those companies bringing new production capacity on-line, achieving budgeted production levels as quickly as possible after start-up is vitally important to minimize unit costs and to begin a positive cash flow. Whether the objective is to simply improve unit costs or successfully start-up a new, complex plant, success will be strongly influenced by the skill levels of the operators and supervisors. The only way to assure return on plant investment, and to survive during depressed metal prices, is to ensure that plant operators have the knowledge to effectively run the plant. Technology available in computer-based, multimedia training systems, including: interactive animation, videos, voice-overs, schematics, and text can now be used to train operators at their own pace using plant-specific information. Additionally, it has been shown

that learning through multimedia provides a higher degree of long term retention than more traditional learning methods.

10:55 AM

Copper Ore Preconcentration by Heavy Media Separation for Reduced Capital and Operating Costs: *Walter E. McCulloch*[1]; Roshan B. Bhappu[2]; John D. Hightower[2]; [1]Bateman Engineering, Inc., 305 S. Euclid Ave., Suite 111, Tucson, AZ 85719 USA; [2]Mountain States R and D International, P.O. Box 310, Vail, AZ 85641 USA

Recent laboratory bench scale and pilot plant metallurgical tests at Mountain States R and D International have demonstrated that some copper ores because of relatively coarse copper sulfide mineralization can be preconcentrated by heavy media separation (HMS). In tests with a copper ore from the AMT Copper Creek project near San Manuel, Arizona, HMS preconcentration rejected about 75 to 80 percent of the feed as a minus 13 mm gravel. The HMS concentrates copper recoveries were about 93 to 95 percent. With the incorporation of HMS preconcentration, significant capital and operating costs savings have been projected for the proposed AMT Copper Creek concentrator. An overview of the HMS preconcentration step development for the AMT Copper Creek project is presented. Also presented are other potential applications of HMS preconcentration for copper ore processing.

11:20 AM

Advances in Application Driven Design of Flotation Cells: *Jouko Kallionen*[1]; [1]Dorr-Oliver, Inc., 333 South Allison Pkwy., Suite 304, Denver, CO 80226 USA

Advanced Flotation Technology is the application driven design of flotation cells to achieve the optimum performance for each type and grind of flotation. This can be applied to roughers, scavengers, cleaners and specialty cells such as those to float hydrocyclone underflows in both primary and regrind circuits in order to reduce overgrinding. Standard, engineered, components are matched to provide mechanism design and cell dimensions for each case according to feed parameters and flotation type. Advances in process control have been achieved with high level controls and operator information data. This has gained a higher degree of understanding of cell operation and ore type being processed. Excellent results of this Advanced Flotation Technology in large scale porphyric copper ore have been achieved and designs through 7000 cu ft (200 $m^{3)}$ are currently available for high capacity concentrators. This paper will detail how flotation cells are more responsive to the exact requirements of the duty specified.

11:45 AM

Optimisation of the Phosphate Nokes Process at the El Teniente By-Product Molybdenite Plant: *S. H. Castro*[1]; C. Henriquez[2]; E. Beas[2]; [1]University of Concepción, Dept. of Metall. Eng.; [2]Codelco-Chile, El Teniente Division (MINCO)

The El Teniente molybdenite plant (Chile), with a nominal capacity of 3,200 tpd of bulk Cu-Mo concentrate, produced approximately 3,385 metric tonnes of Mo during 1998 by using the Phosphate Nokes Process (LR-744 reagent). This is the only Chilean moly plant which traditionally has depressed copper and iron sulfides with LR-744 reagent, which is a hydrolysis product of P_2S_5 NaOH. El Teniente's ore Mo grade is 0.02%Mo and is concentrated to 0.45%-0.50% Mo in bulk Cu-Mo flotation. Subsequently, molybdenite is floated by selective flotation to depress Cu and Fe sulfides, such as chalcopyrite, bornite, digenite and pyrite, to produce typically a 49%-50% Mo molybdenite concentrate. An optimisation program during the last two years was undertaken to improve molybdenite recoveries. Current molybdenite plant technology at El Teniente and the use of Phosphate Nokes in the process is reported. Use of phosphate Nokes reagent has increased average Mo recovery from 70.5% in 1977 to a mean of 74.7% for the first 4 months of 1999. The global Mo recovery, including bulk flotation, increased from 42.3% in 1997 to 46.8% in 1998, with a projection of 55.5% for 1999. Mo production per year has increased from 3,181 tons in 1997 to 3,385 tons in 1998 and a projected 4,000 tons for 1999.

12:10 PM

Plant-Wide Process Control for the Collahuasi Project: *Alex Del Castillo*[1]; Patricio Gomez[1]; [1]OCS, Industrial System Div., ABB, Chile

The mineral processing industry has followed the development of database control systems, and various systems have been installed in existing and new plants. The goal is to improve product quality, raise productivity and lower production costs. Improvements in different units for mineral processing have been applied. This has led to increasing information for the operators. To support the operators and for an easy overview of the process, a complete concept for an integrated process-control system is required. This paper describes the plant-wide process control system for the Collahuasi copper project located in northern Chile. The total investment for the project was $1,700,000,000 and included a port area and two copper processing plants, an oxide plant with a cathode production of 50 tons per year and a sulfide plant with a concentrate production of 330 kilotons per year. The main characteristics of the plant-wide process control system include a 200-kilometer long redundant control network and a 24-kilometer long redundant serial network providing coverage for the entire plant. The plants are located around 4,700 meters above sea level, serial communication links allow the integration of over 2,700 SCADA data units, and the system handles over 7,500 physical signals plus the SCADA data integration. The main equipment consists of 39 different sized controllers, 16 operator stations, 5 engineering stations, 2 information management systems and 4 X-terminals. The project management, control configuration, factory acceptance test, system integration test, training, commissioning and start-up were carried out in close cooperation with the customer. The result was completely satisfactory for the customer.

Movement of Copper and Industrial Outlook: Economics-Finances

Monday AM Room: Copper
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: Peter Kettle, CRU International Ltd., Base Metal Business Unit, 31 Mount Pleasant, London WCIX OAD, England; Gary A. Campbell, Michigan Technical University, SBE, 1400 Townsend Dr., Houghton, MI 49931 USA

10:30 AM

Risk Management in the New Millennium: *John M. Rogers*[1]; Michael Chubb[1]; [1]SGS Mineral Services, 97, rue de Lyon, P.O. Box 2152, Geneva 1 CH-1211 Switzerland

Risk management has rapidly developed to become an integrated, holistic approach that now encompasses the main risk elements such as product quality control, occupational health and safety, security, environmental liability, social issues, and related management information systems. Given the obvious economic benefits, a seamless blend of risk management components has become essential to allowing organisations to sustain a competitive advantage, and is also looked upon as an important attribute in organisational growth. Juxtaposed with this management philosophy is the global trend towards outsourcing, which has seen the emergence of independent, and specialist risk management organisations. The New Millennium will undoubtedly see a shift away from "in-house" risk management practices, and consequently, the selection of a suitable risk management partner—a major vehicle for improving shareholder value—will become an important strategic management decision.

10:55 AM

Benefits of Private Mining in Chile: The Case of Minera Escondida: *Gustavo E. Lagos*[1]; Marcelo E. Andia[1]; Guillermo Donoso[2]; [1]Catholic University of Chile, Ctr. for Mining, Vicuña Mackenna 4860, Avda. Macul, Santiago, Chile; [2]Catholic University of Chile, Agronomy Dept., Avda. Vicuña Mackenna 4860, Macul, Santiago,Chile

Mining is one of the oldest and most important productive activities in Chile. In the latter half of the 80's and during the 1990's Chilean mining has experienced explosive growth fundamentally due to legislative changes which have encouraged an influx of foreign capital. Fine copper production has grown from 1.4 million tons in 1987 to 3.4 million tons in 1997. Gold production has increased from 17.03 tons in 1987 to 49.46 tons in 1997. In both cases private investment has driven this growth. The direct impact of mining on the Chilean economy has been considered one of the fundamental pillars of the growth of the country in the last years. The indirect impact that has generated on the other sectors of the Chilean economy and in particular the regional economies, has not been analyzed. This paper outlines a methodology for estimating the impact of mining investment and mining operations in different sectors of the Chilean economy at both regional and national levels. It applies this methodology to the case of Minera Escondida, the largest copper mine in the world, analyzing its economic impacts on the regional and national levels.

11:20 AM

Making Outsourcing Decisions with Incremental Analysis: *Bruce Cavender*[1]; [1]BHP Copper, Inc., P.O. Box M, San Manuel, AZ 85631 USA

Managers are frequently faced with the decision to perform a task or manufacture an object in-house or to hire an outside vendor to perform the function. Outsourcing decisions are usually driven by economics: work is outsourced if it can be completed at a lower cost or in a shorter time than it can in-house. A technique termed incremental analysis can be used to make this decision. Incremental analysis examines the financial impact of outsourcing decisions as a function of the firm's fixed and variable operating costs. To use this tool, individual components of production cost are identified as being either constant or varying with levels of production activity. The assignment of cost type can be made in several ways: through analysis of historical operating data, understanding of individual expense types, and so forth. Changes in fixed and variable costs resulting from each potential course of action are explicitly identified to project the financial outcome of each alternative. The alternative having the greatest positive impact on profit is selected for implementation. By using the fixed- and variable-cost framework, the analysis is conceptually straightforward and substantially simplified. Production managers can therefore use incremental analysis as a tool for fast and economically beneficial decisions on a real-time basis.

11:45 AM

Project Phasing and the Bottom Line: *C. Twigge-Molecey*[1]; D. Dawson[1]; [1]Hatch Associates, 2800 Speakman Dr., Mississauga, Ontario, Canada L5K ZR7

All projects that are implemented, have been given corporate go-ahead on the basis of a set of clearly defined targets. These are typically a production goal at a capital cost, operating cost and production schedule, that will yield an acceptable return on investment by the companies internal criteria. The challenge for the implementation team is two-fold, firstly to properly define the project criteria prior to board approval and secondly to deliver an operating facility that meets these objectives, in particular the R.O.I. The paper addresses the issues a project team and the company management must address for a successful project. Key questions that will be explored are: What is the status of key technologies?; Are they well proven in commercial practice, completely novel or in between?; Is the project schedule driven by market constraints or cash flow constraints?; Are the risks of fast tracking worth the potential rewards?; For a retrofit project, are all the technical and production interfaces and issues known at the time of approval to proceed?; How much should be invested in technological development and engineering and at which phase?; For owner-operator, how much responsibility is it wise or appropriate to push down to vendors? The answers to these questions for a specific project will define how you go about a project, the resources required, the contracting strategies, the

phasing and the appropriate level of investment in the definition and procurement phases, prior to starting major capital commitments and construction.

12:10 PM
The Price-Stock Relationship in the Copper Market: A Surprising Approach: *Pablo Pincheira Brown*[1]; [1]Comisión Chilena del Cobre, Div. of Policy Plannings, Agustinas 1161, 4° Piso, Santiago, Chile

The widely accepted inverse relationship between copper prices and stocks has been commonly used by analysts to explain the behaviour of the copper market and to forecast future copper prices. However, empirical data have not shown such a clear relationship between copper prices and stocks. Existing evidence only indicates a weak long-run relationship that vanishes in some periods. In this paper a simple comprehensive model is provided, which explains both parallel and opposite direction movements between prices and stocks. Former are explained mainly by stocks demand expansions-contractions while the latter are in essence due to increases in the supply curve. Furthermore, econometric estimations are provided, thus giving a powerful tool to forecast and explain price developments of the copper market.

Pyrometallurgy-Operations: Session I

Monday AM Room: Estrella
October 11, 1999 Location: Pointe Hilton Resort

Session Chair: David George; Kennecott Utah Copper, Salt Lake City, UT USA; Sergio Demetrio, ConOpti S.A., Cerro San Ramon 1491, Las Condes, Santiago, Chile

10:30 AM
Modernizaton of the Luanshya Smelter, Zambia: *Abhoy Mukherjee*[1]; Carlos L. Boetsch[2]; Antonio A. Luraschi[2]; [1]Roan Antelope Mining Corporation of Zambia PLC, P.O. Box 90456, Luanshya, Zambia, Central Africa; [2]INDEC, International Engineering Consulting Services, Avda. Providencia 2653, Of. 512, Santiago, Chile

The Luanshya Smelter is a traditional Reverbaratory Smelter which once worked with up to three coal-fired reverbs, and now operates one Reverb and one hot Peirce-Smith Converter, projected to produce approximately 42,000 tons per year of copper anodes. The aim of this study is to select a smelting technology which best fits the upgrading of the Smelter, such that low capital and operating costs are achieved for the projected design production capacity of 60,000 tpy, limited by the available supplies of concentrates. An equally important requisite is the compliance of present and future environment regulations, which determines the need to install and Acid Plant to treat the smelter primary gases. In the process selection study, the following technologies were analyzed, at a Conceptual Engineering level: the Oxy-fuel Burner Reverb, the Teniente Converter, the CONTOP Cyclone Smelting Reactor, and further, the Ausmelt Furnace, the engineering of which was provided by the proprietary firm. The engineering of the other processes was developed by INDEC, which also integrated the comparative analysis of the four options. The analysis of a comprehensive set of technical factors, including integrated smelter metallurgical models, together with the evaluations of economical features, led to the selection of the CONTOP Smelting Technology for the modernization of the Luanshya Smelter.

10:55 AM
Hernán Videla Lira Copper Smelter Modernization: Orlando C. Rojas[1]; *J. A. Sanhueza*[1]; [1]Empresa Nacional de Minería, Fundición Hernán Videla Lira, Copiaoó, Tercera Region, Chile

Improvements and modifications of layout and process, from 1997 until 1998, are presented. Based on an Teniente Converter, started up in 1993, a Strategic Development Plan was structured to increase the production efficiency and comply with the environmental regulations too. It considered the oxygen supplies to the Teniente Converter and Peirce Smith converters; reverberatory furnace shut down as a smelting unit; and the Teniente converter slag treatment through a combined process between a Slag Settler furnace and flotation. Also it included the off-gas handling and treatment.

11:20 AM
Recent Operation and Environmental Control in the Kennecott Smelter: C. J. Newman[1]; *D. N. Collins*[1]; A. J. Weddick[1]; [1]Kennecott Utah Copper Corporation, 8315 West 3595 South, P.O. Box 6001, Magna, UT 84044-6001 USA

The new Kennecott Utah Copper smelter, started in 1995, was designed to be the most clean smelter environmentally in the world. The plant is operating at production rates above the original design capacity. Copper concentrate is smelted in an Outokumpu flash smelting furnace. Matte is granulated and processed using Kennecott-Outokumpu flash converting. Copper anodes are processed in a modernized copper refinery using the Kidd Process while anode slimes are processed for precious metals recovery using a unique hydro-metallurgical process. To allow the production of high quality cathode, using modem smelting and converting technology to minimize emissions, impurity control had to be carefully addressed. All process bleed streams from the smelter and refinery are treated in a hydro-metallurgical plant to fix impurities in a stable form, allow for the rejection of impurities as required and recover valuable metals. Special technology was developed for the copper refinery to ensure production of high quality cathode from anodes containing high levels of impurities. The smelter routinely achieves a sulfur capture in excess of 99.9% which is equal to less than 2 kg of S02 per tonne of copper produced. This paper describes the design of the smelter and refinery and includes recent production and emission data and modifications carried out to allow operation at above the original design rates. It emphasizes the unique features required to achieve environmental and quality goals and compares environmental performance data to that published on other smelting operations. The processing of intermediate streams, the management of recycled materials and the impurity control strategy will be covered in detail.

11:45 AM
New Strategic Scope of the Caletones Smelter Development: *Ruben Alvarado*[1]; Jorge Godoy[1]; [1]Codelco-Chile, El Teniente Div., Caletones Smelter, Caletones, Rancagua, Chile

The need to increase business competitiveness while complying with environmental requirements represent the great challenge that the Caletones smelter has decided to face in a new development project with a compromising and willing alliance with its workers. To date, the project is at the feasibility stage, with start up scheduled for the middle of the year 2002. The processing capacity of the Teniente Converters will be increased to levels up to 2400 tpd of chalcopyrite-based concentrates containing 30% Cu, by means of more intensive use of oxygen and improved stabilization of the overall operation. Productivity increases in the converting of white metal and the pyrometallurgical treatment of slag are also planned. As a result of related strategies, the productivity of the supporting facilities, included the capacity of the sulfuric acid plants, will be increased. An intensive and well-designed labor-upgrading scheme will allow the transformation of every worker into an expert in his working areas, thus becoming an active driving force in technology development. Mechanization, appropriate infrastructure, and complete process control and instrumentation will give to the skilled and motivated personnel the necessary tools in order to attain the highest potential ever reached with the Teniente technology. The necessary investment for this project based on the adding facilities to the existing plant is only a third of that required to reach the same objective for a greenfield plant, thus yielding a very high return on investment.

12:10 PM
Copper Smelting and Refining in Indonesia: *Shunichi Ajima*[1]; Koichi Konda[2]; Kiyoshi Kanamori[2]; Toshihiko Igarashi[2]; Tatsuya Muto[2]; Shosaku Hayashi[2]; [1]PT Smelting Company, Plaza 89, 6th Floor, S-602, HR Rasuna Said Kav. X-7, No. 6, Jakarta 12940 Indonesia; [2]PT Smelting Company, Gresik Smelter & Refinery, Desa Roomo, Kecamatan Manyar, P.O. Box 555, Gresik, Jawa Timur 61151 Indonesia

PT Smelting Company was established in February, 1996 to construct and operate the Gresik Smelter and Refinery. The construction work of the first Copper Smelter and Refinery in Indonesia was completed in the end of August, 1998 and it was put into the integrated test operation in December, 1998. Gresik Smelter and Refinery is designed to produce 200,000 tpy of copper cathode from copper concentrate supplied from Grasberg Mine of PT. Freeport Indonesia Company in Irian Jaya, Indonesia. As by product 592,000 tpy of sulfuric acid, 382,000 tpy of slag, 31,000 tpy of gypsum and 480 tpy of slime will be produced in the full operation. Major processes applied at Gresik Smelter and Refinery are: Smelter: Mitsubishi Continuous Copper Smelting and Converting Process (Mitsubishi Process); Anode Casting: Continuous Casting of Copper Anodes with the Hazelett Twin Belt Caster; Refinery: ISA Process; Acid Plant: Lurgi Mitsubishi Double Contact Process.

12:35 PM
Technical Improvement and Modification of Guixi Smelter in Recent Ten Years: *Yuan Zeping*[1]; Bai Meng[2]; [1]Guixi Smelter of Jiangxi Copper Corporation, Changsha China; [2]Center South University of Technology (CSUT), Changsha, China

The Guixi smelter is the first Outokumpu flash smelter in China. It was commissioned on December 31, 1985. Originally, the smelter was designed to produce 90,000 tonnes of copper annually. After the implementation of oxygen enrichment and other modifications, the smelter will reach its anticipated annual capacity of 200,000 tonnes of copper in December, 1999. This paper describes the performance of the smelter, the first phase modification project and the second phase expansion project which have made Guixi one of the best copper smelters in the word through the use of existing and innovative technologies.

Smelting: Technology Development, Process Modeling and Fundamentals: Technology Development I

Monday AM — Room: Goldwater
October 11, 1999 — Location: Pointe Hilton Resort

Session Chairs: C. M. Diaz, University of Toronto, c/o Dept. of Metallurgy and Matls. Sci., Toronto, Ontario, Canada; A. J. Weddick, Kennecott Utah Copper Smelter, 12000 West 2100 South, Magna, UT 84011 USA

10:30 AM
Copper Smelting in the 21st Century: *Nickolas J. Themelis*[1]; [1]Columbia University, Earth Engr. Ctr., 500 West 120th St., New York, NY 10027 USA

The role of copper in the economy will not diminish in the 21st century. Following the tenets of industrial ecology, production and use of copper must take into account both human needs and also how to minimize "collateral" effects on the environment. Dispersive uses will be phased out and post-use recovery of copper will increase. This will result into an advantage for smelting processes that can accommodate mixed metal scrap and waste streams. The bath smelting processes of Noranda and Mitsubishi will continue to make progress but the dominance of the Outokurnpu flash smelting will not be challenged until the Noranda reactor overcomes the obstacles to the direct production of copper, thus eliminating the need for a converter.

10:55 AM
Single Stage Copper Making-Flowsheet Development: *M. Somerville*[1]; T. Norgate[1]; P. Jefferies[1]; A. Vecchio-Sadus[1]; S. Jahanshahi[1]; [1]GK Williams CRC for Extractive Metallurgy, CSIRO Minerals, P.O. Box 312, Clayton South, Victoria 3169 Australia

In 1989 CSIRO Minerals initiated investigations into continuous converting of copper matte into low sulphur blister in Sirosmelt type reactors. Following the successful piloting of this processing route, some effort was directed towards a single stage copper making process where copper metal is made in one step from concentrate. The aim of the project is to develop a continuous process, which offers consider-

able environmental and economic benefits over conventional copper making processes, which use Pierce-Smith converters. In the selection of the optimum flowsheet a number of slag treatment operations have been considered and tested. These unit operations include: leaching and electrowinning, floatation-leaching-electrowinning and floatation with recycling of recovered copper through the smelting vessel. In this paper the suitability of these process options are evaluated using the available information and recently measured copper recoveries from our testwork at CISRO. The operating and capital costs of the various options have been estimated using Aspen Plus simulation procedures. The most attractive flowsheet in terms of capital and operating costs is the treatment of slag using mineral processing techniques and the recycle of a copper slag concentrate to the smelting vessel. It has been found that the chemistry of the slag being treated has a large bearing on the recovery of copper in flotation and hence on the economics of the process.

11:20 AM

One Step Forward, Two Steps Back: Crackpots, Charlatans and Metallurgical Absurdities in the Development of Smelting Technology: *Larry M. Southwick*[1]; [1]L. M. Southwick & Associates, 992 Marion Ave., Suite 306, Cincinnati, OH 45229 USA

The smelting of copper and other non-ferrous metals have made considerable advances over the last 125 years. Many of the ideas and processes currently in use were attempted early in the history of smelting and were unsuccessful. Often the cause was incomplete understanding of the metallurgy involved, inadequate refractories, poor materials of equipment fabrication or trying too many new ideas at once. With time, these problems get solved and the technologies become commercialized. These were processes whose time had not come when originally proposed, but did eventually. On the other hand, there have been some concepts whose time will never come. They were impossible then and they are impossible now. The people that dream these up were either crackpots (they didn't know what they were doing, but thought they did), or charlatans (they knew they didn't know what they were doing, but didn't care). Both rely on bad science to propose metallurgical absurdities. These too have their place in the development of technology, though mostly negative, and several examples will be discussed in this paper. Three from around the turn of the century will be covered, as well as one from this decade. The last demonstrates that the art of creating absurdities has not withered, even after ninety years of scientific sophistication, and some can even be patented. The first three reached field trials due to the gullibility of company management. The last arose from a fortuitous mis-operation of a plant which solved a problem, but the explanation and patent which arose are metallurgically impossible.

11:45 AM

Computerized Fluid Dynamic (CFD) Modeling, an Important New Engineering Tool for Design of Smelting Furnaces: Jonathan M. Berkoe[1]; D. M. (Mike) Lane[1]; *Brigette M. Rosendall*[1]; [1]Bechtel Corporation, Min. & Metls. Tech., P.O. Box 193965, San Francisco, CA 94119-3965 USA

Design engineers and metallurgists have long recognized the need for better methods to calculate a wide range of fluid dynamic effects in smelters and hydrometallurgical facilities. Examples can range from the capture of fume in the secondary hoods of a copper converter, to controlling the thermal effects of heat transfer resulting from metal and slag flows within a furnace. With the advent of relatively low-cost, high-speed computers and user-friendly, commercially available computerized fluid dynamic (CFD) programs, these calculations can now be made. Use of CFD increased the understanding of both hot gas and molten flows in smelter facilities and has already led to design improvements in converter fume control hoods as well as improved management of heat transfer in electric furnaces. This paper will present two representative CFD applications to metals industry facilities. To date, Bechtel has implemented CFD results on four continents.

12:10 PM

Application of Composite Furnace Module Cooling Systems in a Flash Furnace Reaction Shaft: *Andrew K. Kyllo*[1]; Neil B. Gray[1]; Diamond Papazoglou[2]; B. J. Elliot[2]; [1]The University of Melbourne, GK Williams Cooperative Rsch. Ctr. for Extract. Metallu., Dept. of Chem. Eng., Parkville, Victoria 3052 Australia; [2]WMC Resources Ltd., Kalgoorlie Nickel Smelter, P.O. Box 448, Kalgoorlie, WA 6430 Australia

The use of Composite Furnace Module cooling systems has been shown to give improved refractory performance in a number of above bath locations in WMC flash furnaces. To test the behaviour of modules in contact with a melt, a set of instrumented modules have been installed in the reaction shaft of a nickel flash furnace. The location was chosen to provide a suitably harsh environment to ensure rigorous testing, while still allowing relatively easy access for module installation. The modules were continuously monitored to provide information on the module performance, as well as the temperature in the shaft itself. The shaft temperature showed significant transient behaviour, which resulted in heat fluxes through the modules ranging from 10 to 92 kW m-2. The modules were capable of handling the highest heat flux with no risk of the coolant boiling. This paper details the design and operation of the modules over a period of seven weeks.

12:35 PM

The SKS Copper Smelting Process in China: *Li Cheng*[1]; Wang Jianming[1]; Wang Zhongshi[1]; Jiang Jimu[1]; Huang Qixing[1]; [1]Beijing Central Engineering and Research Institute, ENFI, 12 Fuxing Ave., Beijing 100038 China

The SKS copper smelting process was jointly developed by Shuikoushan Mining Corporation and ENFI (Beijing Central Engineering and Research Institute for Non-ferrous Metallurgical Industries) in China. It is a new bath copper concentrate smelting process with oxygen enriched air. The pilot plant testwork was completed successfully in 1993. SKS has demonstrated to be an advanced bottom blown smelting process. This technology got the First Class Prize of Scientific and Technological Progress awarded by CNNC (China National Non-ferrous Metal Industry Corporation) in 1994. The SKS process has significant capital and operating cost advantages. Its environmental and industrial safety and hygiene performance represents

a substantial improvement when compared to conventional technologies. The technology has generated great interest in the Chinese metallurgical industry. Feasibility studies and basic designs have been carried out to incorporate in retrofit and green field smelter projects in China and abroad. This paper describes the history of the pilot plant operating data (50 tonnes dry feed/day), and discusses the features of the SKS technology, its application and possible future trends.

Electrorefining: Refinery Operations II

Monday PM Room: Indigo
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: J. W. Holzenthaler, Phelps Dodge, El Paso Works, El Paso, TX 79998 USA; P. E. Donaldson, Falconbridge, Kidd Creek Metallurgical Division, Timmins, Canada P4N 7K1

2:00 PM
The Red Metal of Amarillo: R. M. Donovan[1]; *W. D. Read*[1]; G. A. Herring[1]; H. E. Tallert[1]; [1]ASARCO, Inc., Amarillo Copper Refinery, P.O. Box 30200, Amarillo, TX 79120 USA

This paper documents the efforts to improve quality and production at the Amarillo Copper Refinery. It summarizes the change in attitudes, work procedures, equipment maintenance, instrumentation and the ever changing market. The Amarillo Copper Refinery is dedicated to the ASARCO Management System, ISO-9002 and continuous improvement.

2:25 PM
Recent Experiences at the Ventanas Electrolytic Refinery: *R. Abel F.*[1]; N. Cornejo R.[1]; E. Correa C.[1]; [1]Fundición y Refinería Ventanas - ENAMI, Carretera F-30, N° 58270 Ventanas, Comuna Puchuncavi, V Región, Chile

In 1997, Ventanas electrolytic refinery expanded its production capacity from 215,000 to 325,000 metric tons per year. This increase in capacity has involved the treatment of anodes with different impurity contents, changing the operational strategy of the plant. On the other hand, the increasing necessity to accomplish environment conservation rules and quality assuring requirements, has led the plant operation and administration to compete in an advantageous way. The present work describes the results obtained in the startup and in the operation of the ENAMI Ventanas electrolytic refinery expansion, and shows the difficulties which have been faced in the processing of anodes of increasing complexity, in a competitive market and with environment and quality restrictions.

2:50 PM
Modernization of the CCR Refinery: J. Y. Aubut[1]; C. Bélanger[1]; R. Duhamel[1]; Y. Fiset[1]; M. Guilbert[1]; N. Leclerc[1]; *O. Pogacnik*[1]; [1]Noranda, Inc., CCR Refinery, 220 Ave. Durocher, Montreal-East, Québec, Canada H1B 5H6

The modernization of the CCR Refinery to permanent cathode technology is presently underway. The 360,000 mt/y refinery is being retrofitted to accept the Kidd process. Part of this modernization includes the installation of Kidd stripping machines, and the total replacement of the materials handling equipment. It also involves the reinforcement of building structures to accept the new equipment and the ability to operate in different modes. The future equipment will interface with some existing apparatus, which is being retained for future operations. The whole operation will be automated and will allow product traceability for quality purposes. This retrofit poses important challenges given the size and scope of the modernization project and because it is being undertaken concurrently with normal plant operations.

3:15 PM
Copper Refinery Modernization: Project Organization Coping with a Multi-Constraints Context: P. C. Guillaume[1]; *F. Michaud*[1]; [1]UM Engineering, 4, rue du Bosquet, Louvain-la-Neuve 1348 Belgium

Global plant modernization or expansions cannot be considered in the same light as any other industrial investment project. Relationship between the partners, relationships and communications with the client, structure and organisation of the teamwork, schedule of the work, and a lot of other tasks and missions devoted to external contractors, have to be defined considering one fundamental input: an operating plant. For an engineering company, expert in processing, like UM Engineering, such a context requires a specific approach as well as specific procedures able to efficiently challenge the generated constraints. First of all, even if a detailed audit had been conducted at the beginning of the conceptual engineering phase, new elements will be discovered during the preparation and realization of the project, and must be continuously integrated. Consequently, a close proximity to the site is necessary. This is one reason why UM Engineering, most often, works in partnership with a local engineering company. The second important point for the client is that the operation must not be interrupted during the realization. In order to make that possible, UM Engineering has defined a specific project structure and organisation, integrating on a permanent basis, the operators (the "users") in the project teams. This paper presents the way UM Engineering copes with this type of "multi-constraints" context with reference to the recent copper cellhouse modernization under realization for CCR Refinery of Noranda, Inc. in Canada.

3:40 PM Break

4:10 PM
Improvements in the Tankhouse of the Tamano Smelter: *M. Hashiuchi*[1]; K. Noda[1]; M. Furuta[1]; K. Haiki[1]; [1]Hibi Kyodo Smelting Company, Ltd., Tamano Smelter, No. 6-1-1 Hibi, Tamano City, Okayama Prefecture, Japan

In 1972, the tankhouse of the Tamano Smelter adopted a high current density electrolysis operation applying the PRC (Periodic Reverse Current) method. In 1994, the phase four production expansion project, which incorporated significant re-structuring of the organization, was completed and we have achieved an annual production capacity of 191,000 tons. The target of this project, the production capacity, was increased by 18% and labor productivity by 25%. Af-

ter the expansion, some improvements in the starting sheet section and the verticality of the electrodes were carried out, and the efficiency of the operation was greatly enhanced, including the improvement of the quality of the electrolytic copper.

4:35 PM

Tankhouse Expansion and Modernization of Copper Refineries, Ltd., Townsville, Australia: *B. O'Rourke*[1]; [1]Copper Refineries Pty, Ltd., P.O. Box 5484, Townsville, Queensland 4810 Australia

Copper Refineries Ltd. (CRL), Townsville is Australia's largest producer and exporter of refined copper cathode. This status has been maintained by the implementation of a significant capital works program that increased the production capacity to 270,000 t/y by June, 1999. In 1979, CRL was the first in the world to commission the ISA Process Technology which has now been marketed to 47 licensees worldwide. The new tankhouse design has focused particular attention on customer requirements, operational improvements, materials handling and equipment modernisation. Equipment which has been upgraded includes cranes, anode preparation, cathode stripping and scrap washing machines along with the total replacement of the electrolyte and electrical reticulation systems. Side stream electrolyte filtration has been introduced. Improvements to electrode alignment afforded by the conversion to polymer concrete cells, precise electrode location, and the upgrade of the electrode handling machines will ensure that CRL continues to be one of the world's major quality copper cathode producers.

5:00 PM

Outokumpu Moves Forward Towards Full Control and Automation of All Aspects of Copper Refining: H. Virtanen[1]; T. Marttila[2]; *R. Pariani*[3]; [1]Outokumpu Harjavalta Metals Oy, Kuparitie 5, Pori 28100 Finland; [2]Outokumpu Wenmec Oy, Riihitontuntie 7 E, Espoo 02200 Finland; [3]Outokumpu Technology, Inc., 351 Thornton Rd., Lithia Springs, GA 30122 USA

Outokumpu copper refining operations have a long history of expansions and application of new technologies. Outokumpu is a name known around the world for technological excellence in the field of base metals, and part of the policy of operations is continuous investment and investigation in new technologies. The results of this hard work sometimes are immediate and sometimes take years. The work done during the last years at the Outokumpu Harjavalta Metals copper refinery, together with a sister technology group Outokumpu Wenmec, has started to bear fruit in terms of the following radical developments and advances that are and will be applied to assure Outokumpu's position as the technology leader and a low cost and safe producer. Some of the developments discussed include the new anode and cathode design, mechanised electrode handling, cell design incorporating features facilitating full automation, automated short circuit detection and removal, automated on line anode slime removal, and high efficiency and intensity refining.

Hydrometallurgy: Design, Simulation and Control

Monday PM Room: Hopi
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: Jackson Jenkins, Cyprus Sierrita Corporation, Green Valley, AZ 85622-0527 USA; Mark F. Vancas, Bateman Engineering, Inc., Tuscon, AZ 85719 USA

2:00 PM

NICO, A Dynamic Simulator for Leach-SX-EW Plants: *Cristián Araya L.*[1]; [1]Kvaerner E&C, Dept. of Tech., Nueva Tajamar, Las Condes 481 P19, Santiago, Chile

A dynamic agglomeration, heap leaching, solvent extraction and electrowinning software, called NICO, has been developed in order to either design or simulate copper ore recovery plants. NICO contains a library of routines, each representing a unit operation or piece of equipment, which are assembled like a meccano to match almost any wet plant configuration. Routines include agglomeration or curing either in drams or belts, belt conveyors, heap stacking and reclaiming, heap leaching of oxide, sulfide or mixed copper ores, heap irrigation, drainage, ponds, mixer-settlers, filters, columns, coalescers, tanks, electrowinning cells, pumps, and all connections and related piping. All models are semi-phenomenological, i.e., they include all physical-chemical, mass, thermal, transport equations, which are required to represent as closely as possible the equipment or unit operation. However, operating experience has been incorporated into the model in order to make it simpler, faster and reliable. This experience has been tested in several plants in Chile since 1992. Site meteorological data is simulated also; in this way the model is responsive to weather conditions (temperature, solar radiation, ambient humidity, atmospheric pressure, wind velocity, etc). NICO has been used recently for design and optimization studies in copper plants in Chile like Radomiro Tomic, Collahuasi and Zaldivar. A user-friendly interface allows fast and comprehensive simulations. The entire plant is shown in a single graphic screen, so the user can see all the relevant information, and soft-keys are provided in order to change parameters on-line and watch their effect in final copper production in cathodes. Model also calculates and reports operating parameters, as well as estimated investments and operating costs.

2:25 PM

Modeling the Speciation of Sulfuric Acid - Cupric Sulfate Solutions: *J. M. Casas*[1]; F. Alvarez[1]; G. Crisostomo[2]; G. Cifuentes[3]; L. Cifuentes[2]; [1]Universidad de Chile, Depto. Ingenieria Quimica, Beauchef 861, Santiago, Chile; [2]Univesidad de Chile, Dept. Ingenieria de Minas, Av. Tupper 2069, Santiago, Chile; [3]Universidad de Santiago, Depto Intenieria Metalúrgica, Av.B. O'Higgins 3363, Santiago, Chile

This work presents the development of an ionic equilibrium model and its use to simulate the distribution and concentration of the species (speciation) in

sulfuric acid-cupric sulfate solutions in the 0-2 pH range, 0.1-10 gpl copper concentration range and 15-45ϒC temperature range. The model consists of a set of equations which represent the equilibrium relationships for the ionic reactions and the mass balances for the components present in the system. The effect of ionic strength was taken into account by correcting the equilibrium constant in concentrated solutions. Several species can be formed at different pH and temperature values, the principal being: HSO_4^-, SO_4^{2-}, $CuSO_4(aq)$, Cu^{2+}, and H^+ in order of increasing solution acidity. Simulations show that species concentrations are highly dependent on pH. The sulfuric acid speciates mainly as bisulfate ion (HSO_4^-) and hydrogen ion (H^+) at pH values lower than 1. The model presented in this work can be applied to evaluate and to analyze the solution composition in electrolytic copper processes such as electrowinning, electroreflnning, electrodialysis, and in the purification of various industrial solutions.

2:50 PM

The Use of a Mineralogical Data Base for Production Forecasting and Troubleshooting in Copper Leach Operations: *Wolfgang Baum*[1]; [1]Pittsburgh Mineral & Environmental Technology, Inc., 700 Fifth Ave., New Brighton, PA 15066-1837 USA

Copper and gangue mineralogy constitute the most critical parameters for the hydrometallurgical processing and cost-efficient extraction of copper. Minor changes in copper, rock, or alteration mineralogy can severely impact the comminution efficiency, curing, agglomeration, acid consumption, copper extraction and PLS impurity loading. Further, copper leach operations, particularly in the southwestern United States, are increasingly challenged by a combination of low grades and semi-refractory copper. This paper discusses the metallurgical and economical benefits of continuous mineralogical analyses in order to establish and operate a mineralogical data base in copper leach operations. Troubleshooting for copper extraction, integration of process mineralogy into production forecasting, and process optimization will be illustrated with operational experiences from Chile and the United States.

3:15 PM

A Framework for Improving the Ability to Understand and Predict the Performance of Heap Leach Piles: *M. O' Kane*[1]; S. L. Barbour[2]; M. D. Haug[3]; [1]O'Kane Consultants, Inc., 232-111 Research Dr., Saskatoon, Saskatchewan, Canada S7N 3R2; [2]University of Saskatchewan, Dept. of Civil Eng., 57 Campus Dr., Saskatoon, Saskatchewan, Canada S7N 5A9; [3]M. D. Haug and Associates Limited, 232-111 Research Dr., Saskatoon, Saskatchewan, Canada S7N 3R2

Operators and designers require a comprehensive model to predict performance of heap leach piles and provide input of reliable and defensible data for economic modeling. A conceptual, theoretical, or numerical predictive model addressing the required metallurgical, geological, biological, and operational considerations should be developed within the framework of the hydraulic performance of the heap leach pile. It is generally agreed that segregation, compaction, and consolidation are physical aspects which significantly affect recovery and in general hydraulic performance. Hydraulic performance of heap leach piles can be described through the application of unsaturated zone hydrology. Unsaturated zone hydrology describes the flow and storage of moisture and oxygen in a porous medium under conditions where the pore water pressure is less than atmospheric. The porous material is "unsaturated" if an air phase, in addition to the water phase and solid material phase, is present. These conditions describe the operation of a copper heap leach pile. This paper will focus on developing an understanding of hydraulic performance in segregated heap leach material and demonstrating that unsaturated zone hydrology can be used as the framework to improve understanding and prediction of heap leach performance.

3:40 PM Break

4:10 PM

Large Scale Hydrometallurgical Test Facilities of Phelps Dodge Mining Company: *Kevin L. Purdy*[1]; Robert E. Johnson[1]; [1]Phelps Dodge Mining Company, Process Tech. Ctr., 9780 E. Sanchez Rd., Safford, AZ 85546 USA

The Process Technology Center of Phelps Dodge Mining Company (PDMC) operates several test facilities in support of PDMC's hydrometallurgical operations. Installations for small leach columns, 15 cm. to 60 cm. (6 in. to 24 in.) in diameter, and large leach columns, 1.8 m. (6 ft.) in diameter, are complemented by a test facility for SX/EW operations. The history of and reasons for the development of these facilities are described and original standard equipment is discussed. A primary goal in constructing these facilities was achieving a high degree of flexibility to allow for testing of new equipment and new leaching and SX/EW technologies as they are developed. Along with this challenge, construction of a fully integrated SX/EW test facility on a small scale brought its own set of challenges.

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Designing the Leach System for Cerro Negro Ore: A. F. Kaczmarek[1]; Joe Campbell[3]; *W. J. Schlitt*[2]; Joseph M. Keane[4]; [1]Cyprus Amax Engineering & Project Development Company, P.O. Box 4444, Claypool, AZ USA; [2]Kvaerner Metals, Metals E & C Div., 12657 Alcosta Blvd., Suite 200, San Ramon, CA 94583 USA; [3]Sociedad Minera Cerro Verde S.A., Asiento Minera Cerro Verde-Uchumayo, Casilla, Arequipa 299 Peru; [4]KD Engineering Company, Inc., 7701 N. Business Park Dr., Tuscon, AZ 85743 USA

Cerro Negro is an undeveloped ore body located at the Cerro Verde mine near Arequipa, Peru. The minable reserve contains 70 Mt of oxide ore grading 0.532% copper. Mineralization is hosted in three distinct rock types: tourmaline breccia, crackle breccia and granodiorite. Rock type effects copper recovery and acid consumption. The paper describes Cyprus' testwork philosophy and the resulting four-phase metallurgical program used to define the commercial leaching parameters. Copper recovery and acid consumption were monitored as functions of crush size, heap height, irrigation rate and acidulation conditions. Single lift, on-off and permanent multi-lift heaps were considered. Leach cycle times were based on incremental copper extraction and acid consumption rates, with added constraints imposed by operational requirements. The optimum leach system in-

volves an on-off pad using tertiary crushed ore acidulated with 20 kg/t acid and stacked to a height of 6.5 m. The active leach cycle is 82 days at an irrigation rate of 0.26 l/min/m^2. Under these conditions copper recovery is expected to average 81% over the life of the mine.

5:00 PM

Interpretation of the Recovery/Time Curve and Scale-Up from Column Leach Tests on a Mixed Oxide/Sulfide Copper Ore: *Ronald J. Román*[1]; Jose Hector Figueroa P.[2]; Jorge Enrique Ruiz H.[2]; Jorge Helleon G.[3]; Efrén Pérez S.[4]; [1]Leach, Inc., 4741 N. Placita del Sol, Tucson, AZ 85749 USA; [2]Mexicana de Cananea S.A. de C.V., Av. Juarez S/N, Cananea, Sonora 84620 Mexico; [3]Mexicana de Cobre, S.A. de C.V., Aptdo 20, Nacozari, Sonora 84340 Mexico; [4]University of Sonora, Dept. of Geology, Hermosillo, Sonora 83000 Mexico

The shrinking core model for coarse particle leaching has been generally accepted as describing the leaching of a copper oxide or sulfide ore. However, when a mixed oxide/sulfide ore is leached this model can not be used in its simple form because at least two and possibly three separate leaching processes are occurring simultaneously (dissolution of oxide copper minerals, secondary copper minerals and primarily copper minerals). It has been impossible to isolate their individual leaching curves from the recovery/time curve generated by the column leach test. This paper describes a test program carried out at the Groupo Mexico, Mexicana de Cobre's La Caridad operation in which the individual recovery/time curves for the leaching of copper oxide mineral, secondary copper mineral and primary copper minerals were developed from standard column leach tests. Once the individual recovery/time curves were developed scale-up of the column leach test results to the commercial heap leaching operation is possible by using the shrinking core model.

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Simulation of Oxidized Copper Ores Heap Leaching: *Luiz R. P. De Andrade Lima*[1]; [1]Federal University of Bahia, Polytechnic School, Rua Aristides Novis, 2, Salvador, Bahia 40210-630 Brazil

This paper presents a mathematical model for the oxide copper ore heap leaching process. The data used in the model include physical-chemical, geometrical and operational data, as: leachable metals ore contents, flow rate and acid concentration, parameters of passivity, ore size distribution, the average residence time of the solution in the heap, height, irrigated area and weight of ore in the heap. In this model the heap is divided into horizontal and plane layers of constant area. The flow of the liquid in the heap is considered unidirectional and the solid-fluid reaction model is considered under diffusive control. The average residence time of the solution into the heap and the apparent effective diffusivity of the acid through the ore particles have a significant influence on the rate of the copper extraction and its concentration in the pregnant solution; therefore these parameters are used in the model calibration. When this algorithm was applied to a laboratory test, the results showed that the model is adequate to predict the process performance.

5:50 PM

Pyrite as a Stockpile Leach-Aid: *John L. Uhrie*[1]; [1]Phelps Dodge Mining Company, Process Tech. Ctr., 9780 E. Sanchez Rd., Safford, AZ 85546 USA

Oxide stockpile leaching operations can realize increased copper recovery and decreased acid consumption from in-situ generated acid resulting from the oxidation of intentionally introduced pyrite recovered from mill tailings or other sources. While all oxide leach ores can benefit from pyrite addition, low acid consuming ores can show remarkably increased recovery and net acid generation; however, more highly acid consuming ores will show benefit more exclusively through increased copper recovery. Additional work shows that the value of highly acid consuming ores can be optimized by balancing copper recovery against acid consumption.

Hydrometallurgy: Concentrate Leaching

Monday PM Room: Apache/Bisbee
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: V. I. Lakshmanan, Ortech Corporation, Mississauga, Ontario, Canada L5K 1B3K; Brent Hiskey, University of Arizona, Tucson, AZ 85721 USA

2:00 PM

Ammonia Leaching of Copper Sulfide Concentrates: *Nathaniel Arbiter*[1]; Terry McNulty[2]; [1]Columbia University, Emeritus Professor, Henry Krumb School of Mines, 6300 S. High Valley Rd., Vail, AZ 85641 USA; [2]T.P. McNulty and Associates, Inc., 4550 N. Territory Place, Tucson, AZ 85750 USA

The first ammonia leaching plants, applied to copper carbonate and native copper tailings in 1915, were followed more recently by research and development of flowsheets for ammonia leaching of sulfide concentrates. These were applied to two commercial plants. Anaconda's Arbiter Plant started up in 1974 with a design capacity of 36,000 tons/year of cathodes, to be produced by ammonia leaching with oxygen, followed by solvent extraction and electrowinning. The plant shutdown in late 1977 as a result of high maintenance and operating costs, partly due to harsh winters; to complications associated with sulfate disposal; and to changes in mineralogy. BHP's Coloso plant in Chile was designed to produce 80,000 tons/year of cathodes by leaching part of Escondida's concentrate production. Using a similar flowsheet but with air and low temperatures to avoid sulfate production, it started up in late 1994 and shutdown in mid 1998 after failing to reach cathode design capacity, and experiencing problems with its technology. The paper reviews the technologies and also alternative methods for overcoming the problems.

2:25 PM

An Electrochemical and Chemical Study of the Leaching of Copper Sulfides in Acidified Ferrous Sulfate Solutions Sparged with an O_2-SO_2 Mixture: *Michael James Perpich*[1]; Paul Duby[1]; [1]ECI Technology, 1 Madison St., East Rutherford, NJ 07073 USA

Electrochemical and chemical leaching tests were carried out on chalcocite, covellite and chalcopyrite in acidified iron sulfate solutions sparged with a mixture of O_2 - SO_2. The gas mixture catalyzed the ferrous to ferric oxidation reaction in situ and, therefore, increased the redox potential and oxidizing strength of the solution. Anodic polarization curves in dilute sulfuric acid on copper sulfide electrodes showed that chalcopyrite passivates and dissolves at current densities orders of magnitude less than chalcocite and covellite. The addition of a depassivating agent (Ag^+) increased the passive current density of chalcopyrite and caused breakdown near 0.625 V (SCE). The depassivating effect was also observed during the leaching of chalcopyrite particulate samples as small amounts of Ag^+ added to acidified iron sulfate solutions in the presence of O_2 - SO_2 mixtures greatly increased the leaching rate and the total amount of Cu oxidized (>90%). Passivation was prevented in the absence of Ag^+ by decreasing the initial oxidizing power of the solution and by pretreating the sample in a reductive leach. Both of these methods resulted in transformation of the chalcopyrite surface from its characteristic greenish-gold into deep black. Increased concentrations of Fe^{+++} due to O_2 - SO_2 sparging were then able to oxidize the transformation product.

2:50 PM
Ferrous Promoted Chalcopyrite Leaching: *Naoki Hiroyoshi*[1]; Hajime Miki[1]; Tsuyoshi Hirajima[1]; Masami Tsunekawa[1]; [1]Hokkaido University, Grad. Schl. of Engr., Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido 060-8628 Japan

It is generally accepted that ferric ions are effective for leaching chalcopyrite as an oxidant and ferrous ions contribute to the leaching only as a source of the oxidant ferric ions. However, this paper shows that ferrous ions are more useful for leaching chalcopyrite than oxidant ferric ions in sulfuric acid solutions in air at ambient temperatures. Leaching experiments and dissolved oxygen consumption measurements were carried out with a very pure chalcopyrite and 0.001 - 1 mol dm^{-3} sulfuric acid solutions containing 0 - 0.1 mol dm^{-3} ferric or ferrous ions at 303 K. Chalcopyrite oxidation with dissolved oxygen was promoted by ferrous ions but suppressed by ferric ions. As a result, the amount of extracted copper was larger with ferrous ions than with ferric ions. Effects of Thiobacillus ferrooxidans on the ferrous promoted chalcopyrite leaching were also investigated and discussed based on the experimental data.

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Open

3:40 PM Break

4:10 PM
Engineered Membrane Separation (EMS|) Systems for Acid Hydrometallurgical Solution Concentration, Separation, and Treatment: *Ron Bernard*[1]; Dennis H. Green[1]; Jeffrey J. Mueller[1]; [1]HW Process Technologies, Inc., 1208 Quail St., Lakewood, CO 80215 USA

HW Process Technologies has successfully developed and commercialized various applications utilizing Engineered Membrane Separation (EMS|) systems for the processing of acidic copper hydrometallurgical solutions and wastewaters. Copper hydrometallurgical EMS| applications include water balance control and increased copper concentration in heap and dump copper leach operations, tankhouse bleed stream treatment to separate/recover copper and cobalt from iron, and removal of PLS/Electrolyte suspended solids/colloids to eliminate "crud" formation during copper SX/EW. Similar applications are under development to provide ionic separations in copper refinery bleed streams, copper smelter acid plant streams, as well as organic/LIX removal from aqueous electrolyte and raffinate streams. Copper mine wastewater EMS| applications include treatment of copper leach solution contaminated groundwaters for copper recovery and treatment of unwanted heap/dump drainage to provide enhanced precipitation, a smaller precipitation plant, improved operating costs and better quality discharge water, particularly in terms of TDS and sulfates. A discussion of the EMS| technology and general separation results on typical process solutions and wastewaters will be presented. HW Process Technologies, Inc. commercial installations treating copper pregnant solutions and leach solution contaminated groundwaters are in-place at an old Asarco smelter/refining operation, Mexicana de Cananea copper mine, and a major U.S. copper mine, with several additional installations pending. Several case studies, including results from a selection of these installations, will be included with detailed capital, operating cost, and system payback data.

4:35 PM
Advanced Cast Stainless Steels for Copper Industry Pumps: *Arto K. Riihimaki*[1]; [1]Ahlstrom Pumps Corporation, Karhula 48601 Finland

The description deals with duplex stainless cast steels and austenitic high molybdenum steels used in pumps for severe condition service. The main modern nitrogen alloyed duplex cast steels are presented in the ASTM standard A-890. Two grades of high molybdenum austenitic stainless steels there are presented in ASTM A-744 (-96) standard i.e. CN-3MN and CK-3MCuN. The latest and most corrosion-resistant stainless steel grade is AVESTA 654 SMO|. Avesta Sheffield the trademark owner has granted Ahlstrom Pumps license to produce the material. This new stainless steel as pump material for severe service has improved properties in the hydrometallurgy and electrorefining processes of metal and especially in the copper industry compared to duplex stainless steels. The paper deals briefly with the foundry process to manufacture high alloy stainless steel pump castings. The AOD-method (AOD= Argon Oxygen Decarburization) is an important prerequisite for the melting of low carbon, high chromium and molybdenum alloyed nitrogen steels. The properties of these steels are included. The main topic is the corrosion resistance of the above-mentioned pump materials in severe service. Results of short-time erosion and corrosion tests are discussed and compared with the results of plant tests. Practical results of pump materials performance in severe service for the copper industry are given. The new high alloyed cast stainless steel (main elements: Cr~24%, Ni~22%, Mo~7,3% and N~0,5%) has shown improved corrosion and erosion properties as process pump material in several severe service applications e.g. in the metal industry.

5:00 PM

Mine Site Production of Value Added SX-EW Copper Products - The Alternative to Cathode: *Stephen J. Kohut*[1]; John J. Pio[1]; Mark D. Precup[1]; [1]ElectroCopper™ Products Limited, 1255 W. Baseline Rd., Suite 288, Mesa, AZ 85202 USA

Until recently SX-EW technology has only been used to produce conventional cathode for the cyclical commodity marketplace. Unlike electrorefining, SX-EW lends itself to the integration with the downstream manufacturing technologies for direct mine site production of value added products. The integration of SX-EW and downstream manufacturing results in the elimination of redundant process steps, the cost savings, and the access to value added product markets which can buffer the producer from swings in the cathode market. SX-EW production of copper powder and powder-based products has been demonstrated at the pilot plant level. The SX-EW process has been successfully redesigned to meet the more specific demands of engineered products. Challenges include the solution purity, the cell ventilation, the high current density operation and the product handling. Successful demonstration of mine site production of value added SXEW products opens up new non-commodity marketplaces to the mining industry.

5:25 PM

Copper Production from Leaching Solutions with an Innovative Process Competitive to Traditional Solvent Extraction - Electrowinning: *M. Olper*[1]; M. Maccagni[1]; C. J. N. Buisman[2]; C. E. Schultz[2]; [1]Engitec s.r.l., via Borsellino e Falcone 31, Novate Milanese, Milano 20026 Italy; [2]Paques Bio Systems B.V., P.O. Box 52, Balk 8560 AB The Netherlands

Today, copper production form direct leaching of oxidized copper ores followed by solvent extraction-electrowinning (SX-EW) accounts for about 15% of the total primary world output. SX-EW is well-accepted process with an operating cost in the range 16-20 cents/lb. copper for small and medium size plants, depending on the plant size and local conditions. However, this technology presents some drawbacks that affect the operating cost and cause environmental concerns. ENGITEC and Paques Bio Systems have developed a new process that avoids the solvent extraction step and operates the copper electrowinning step at a lower cell voltage because of the depassivation of the anodic reaction. The consequence of this new concept is that the direct operating cost is in the range 10-12 cents/lb of copper. This new process is composed by the following steps: Selective precipitation of copper from leach solutions by biogenic H_2S, yielding CuS and regenerating acid. Leaching of the CuS with a ferric fluoborate solution to dissolve copper and produce elemental sulphur that is recycled back to the H_2S biogeneration step. Electrowinning of copper fluoborate solution in a diaphragm cell with the ECUPREX Process, producing copper cathodes and regenerating the ferric fluoborate solution to be recycled back to the leaching step. Biogeneration of H_2S from the elemental sulphur generated during the leaching step, with the nutrient source for the anaerobic bacteria selected from a wide range of organic substances and/or some industrial by-products containing carbon and hydrogen. The paper describes all process steps with particular reference to the biological H_2 generation technology. Also discussed is the capability of the ECUPREX Process to treat copper sulfide concentrates and copper matte.

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A Look at Leach SX-EW with 2020 Vision: *Sharon K. Young*[1]; [1]Versitech, Inc., 1438 W. San Lucas Dr., Tucson, AZ 85704 USA

What might an ideal leach-to-cathode/product system look like in the next century? The paper looks at the synergies of the 60's and 70's that led to the highly effective copper leach SX-EW system of the 90's. Standing in the year 2020 focuses on what breakthrough technologies might make possible a next-generation leach/extraction/metal recovery system. Many of the pieces of such a technology have been developed, even piloted: in situ leaching, enhanced bioleaching, heap leaching of fine particles, resin in pulp, ion exchange, alternate anode reaction electrowinning, novel anode coatings. With nearly non-existent research on the part of individual large companies, the greatest challenge may not be inventing the technologies but rather inventing an industry "will-to-create."

Mineral Processing: Metallurgy

Monday PM Room: Jerome
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: H. J. D. Galaviz, Great Western Chemical; J. Menacho

2:00 PM

An Empirical Equation for the Recovery - Enrichment Ratio Curve (AREV Model): *Marco A. Vera*[1]; J-P. Franzidis[1]; E. V. Manlapig[1]; [1]The University of Queensland, Julius Kruttschnitt Mineral Rsch. Ctr., Isles Rd., Indooroopilly, Brisbane QLD 4068 Australia

This paper proposes a simple two-parameter model for the typical inverse relationship between recovery and flotation concentrate grade. The model is based on the mineralogical limitations, imposed by the material properties. One parameter (R*) describes the proportion of metal content which is floatable, and the other (b) is the rate at which the fastest floating particles are being contaminated by the other less valuable particles present in the mineral system. One significant feature of the recovery-grade curve is that initial recovery (i. e. R —> 0) is at the purest attainable mineral grade, but as recovery rises the cumulative grade of the concentrate tends to the feed grade. The ideal recovery-grade curve for a particular mineralogical system can be obtained by release analysis: the release analysis curve determines the maximum or limiting separation efficiency. The model proposed in this work is similar to the linear recovery—cut-off grade model of Dell (1), but has the advantage of describing the whole curve.

2:25 PM

Development of an "On-line" E_h-pH Electrochemical Sensor for the Flotation Process Control: *Christian C. Hecker*[1]; Juanita Ramirez[1]; Ernesto B. Beas[2]; Fernando

M. Cartes[2]; [1]Universidad de Concepción, Dept. de Ingenieria Metalúrgica, Edmundo Larenas 270, Casilla, Concepción 53-C Chile; [2]Codelco-Chile, El Teniente Div., UGA - MINCO, Millan, Rancagua 1040 Chile

An E_h-pH electrochemical sensor developed for on-line pH and redox potentials copper sulfide flotation process control was studied. The electrochemical sensor ceU includes two metallic platinum electrodes, a metaffic antimony electrode and a high impedance reference cell, which are polarized with a potentiostat. For pH and redox potential determinations, the Sb and platinum electrode potentials are measured, respectively, against the polarized electrochemical reference system. The behaviour of this electrode configuration has been investigated in a laboratory scale. An electrochemical sensor device has been successfully installed and checked in El Teninte Colon Concentrator's SAG line feeding the copper flotation rougher circuit.

2:50 PM

Effect of Clay Slimes on Copper, Molybdenum Flotation from Porphyry Ores: *S. Bulatovic*[1]; D. M. Wyslouzil[1]; C. Kant[1]; [1]Lakefield Research Limited, 185 Concession St., Postal Bag 4300, Lakefield, Ontario, Canada K0L 2H0

The presence of clay adversely affects the floatability of copper and molybdenum during processing porphyry copper/molybdenum ores. In addition, reagent consumptions are much higher than when treating clay-free ores. Ores containing kaoline, brammollite, illite and montmorillonite were examined in the laboratory to determine how clay minerals affect the floatability of copper and molybdenum, and to find a possible solution to alleviate the harmful effect of clay slimes. It was demonstrated that the presence of clay mostly affects floatability of coarse and middling particles, and reduces selectivity. The results of the research work showed that there may be several possible ways of reducing the detrimental affects of clay slimes on flotation, some of which include a) use of alternative flowsheets, b) Rotation at reduced pulp density, and c) the use of special frotbers. The applicability of the findings in plant practice are discussed.

3:15 PM

Technological Development for Igarape Bahia/ Alemao Copper-Gold Project: *Vânia L. L. Andrade*[1]; Nilce Alves dos Santos[1]; Rinaldo Pedro Nardi[1]; [1]Companhia Vale do Rio Doce - CRVD, Rsch. Ctr., BR 262 km 296, Santa Luzia, MG–Brazil

Igarape Bahia Mine is located in Carajas area, northern Brazil. Currently Companhia Vale do Rio Doce operates there a CIP/ heap leaching plant treating an oxide gold ore containing about 4 g A /t and 0,2% Cu, which produces 11 t of gold per year. Recent geological survey has identified a significant copper-gold reserve underneath the oxide gold ore. The processing aspects of this copper-gold sulfide ore are described in this paper. It includes ore characterization studies, grinding and flotation tests, orebody variability assessment, flowsheet selection and preliminary economical evaluation. Emphasis is given to studies aimed at depressing fluorine bearing minerals to achieve a clean and marketable flotation concentrate.

3:40 PM Break

4:10 PM

Gold Occurrence in the Sar Cheshmeh Prophyry Copper Ore and Its Behaviour during Beneficiation: *Mohammad Mehdi Salari Rad*[1]; Masami Tsunekawa[1]; Tsuyoshi Hirajima[1]; Tetsuro Yoneda[1]; [1]Hokkaido University, Grad. Sch. of Engr. Min. Process. Lab., Kiat 13, Nishi 8, Sapporo, Hokkaido 060-8628 Japan

An investigation of gold distribution in the mill products of Sar Cheshmeh beneficiation plant demonstrates that on average 44% of the gold is routinely recovered as a by-product in the copper concentrate, and the remaining is lost to the tailing. In order to evaluate the causes of gold losses, the distribution and mode of gold occurrence in the Sar Cheshmeh ore and mill products were studied. Searching for gold within samples and within individual grains of sulfide minerals was carried out by SEM in the backscattered electron mode and SIMS, respectively. The mineralogical distribution of gold revealed by microbeam techniques were combined with the results of relevant metallurgical experiments including, sizing, heavy liquid separation, and diagnostic leaching tests, and the nature and location of gold in the ore and mill products were determined. The combined results of the experimental approaches pursued suggest that while there are some gold in solid solution and/or colloidal size within sulphides of the Sar Cheshmeh ores, "visible" gold is the principal form of gold occurrence at Sar Cheshmeh.

4:35 PM

Lead Ions and Sphalerite Recovery in Copper Rougher Flotation: C. Sui[1]; *J. C. A. Grimmelt*[1]; F. Rashchi[1]; R. Rao[1]; J. A. Finch[1]; [1]McGill University, Dept. of Mining and Metall. Eng., 3610 University St., Wong Bldg., Montreal, Québec, Canada H3A 2B2

A common objective in many Cu/Zn concentrators is to reduce the loss of Zn to the Cu-concentrate. One suspected source of the problem is accidental activation of sphalerite by heavy metal ions such as lead. One method of quantifying surface metal ion concentration is extraction With ethyl-diamine-tetra-acetate (EDTA). This was used to survey Cu-rougher flotation at three Cu/Zn concentrators: Les Mines Selbaie, Falconbridge's Kidd Creek division, and Hudson Bay Mining and Smelting. Although all have less than 0.2% galena in the ore, Pb ions proved an abundant extractable metal. From a laboratory study a model of surface coverage of lead species generated by an ore was combined with an estimate of surface concentration of lead required to activate sphalerite to explore the possibility of accidental activation. Ores with Pb-grade as low as 0. 1% can produce sufficient Pb to be a potential problem.

Movement of Copper and Industrial Outlook: Markets and Trends

Monday PM Room: Copper
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: C. Twigge-Molecey, Hatch Associates, Ltd., 2800 Speakman Dr., Mississauga, Ontario, Canada, L5K ZR7; Norbert L. Piret, Piret & Stolberg Partners, Consulting Engineers, Duisburg D-47279 Germany

2:00 PM

Global Copper Consumption into the New Millennium: *Gary A. Campbell*[1]; [1]Michigan Tech University, SBE, 1400 Townsend Dr., Houghton, MI 49931 USA

This article is an analysis of world consumption of copper for the years 1976-1996. It is done to provide a comparison of what has happened over this time period with the trends of previous years in order to learn more about world copper consumption and to forecast world copper consumption trends into the new millennium. The analysis begins by documenting the geographic trends of consumption of copper for the years 1976-1996 by both region and key individual countries. Then, variables based on the intensity-of-use hypothesis and the intensity-of-use technique are selected and tested against the observed consumption behavior by using the correlation coefficient technique. The statistical results and their implications for the consumption of copper into the new millennium are discussed.

2:25 PM

The Chilean Copper Smelter Management Way: *Sergio Demetrio*[1]; Miguel Ángel Durán[2]; Ruben Alvarado[3]; Leonel Contreras[4]; Jorge Ahumada[5]; Ernest Mast[6]; José Sanhueza[7]; Edmundo Morales[8]; [1]ConOpti S.A., Cerro San Ramon 1491, Las Condes, Santiago, Chile; [2]Chagres Smelter, Compañia Minera Disputada de Las Condes, Catemu, Chile; [3]Caletones Smelter, El Teniente Div., Codelco-Chile, Rancagua, Chile; [4]Potrerillos Smelter, El Salvador Div., Codelco-Chile, Potrerillos, Chile; [5]Chuquicamata Smelter, Chuquica-mata Div., Codelco-Chile, Calama, Chile; [6]Altonorte Smelter, Noranda Chile S.A., Antofagasta, Chile; [7]Paipote Smelter, ENAMI, Copiapó, Chile; [8]Ventanas Smelter and Refinery, ENAMI Refinery, Quintero, Chile

Over a period of nearly a hundred years throughout this century, the company direction and management of copper smelters in Chile has evolved from one characterized by a paternalistic, autocratic style to one which empowers the local management team and people for running the smelter as a successful business. This paper discusses the evolution of the present style of management amidst changes in the Chilean Government, the mining industry and society since the beginning of this century.

2:50 PM

The Group of Experts on Minerals and Energy Development and its Role Regarding Copper Mining Sustainability in the Asia-Pacific Region: *Tomas Astorga*[1]; Raul F. Campusano[1]; [1]GEMEED-APEC, Minerals and Energy Exploration and Dev., Ministry of Mining, Teatinos 120, 9th Floor, Santiago, Chile

APEC, the Asia Pacific Economic Cooperation is the forum of 18 economies, having a combined GDP of approximately 56% of the total world income, and over 45% of global trade. Its mining sector produces a large portion of the main minerals and metals in the world. In 1997, APEC economies produced 67% of world copper output, 55% of gold, and over 45% of other base metals. Mining in APEC captures more than 60% of the total mining investment in the world. Against this background, the Expert Group on Minerals and Energy Exploration and Development, in short GEMEED, was created in 1996, under the auspices of the APEC Energy Working Group. The sustainable development of mining activities is a main concern in APEC and GEMEED. Several programs related to the subject are actively being pursued by the Expert Group. Among them, it should be noticed the creation of an Environmental Cooperation Sub Group coordinated by Japan, whose main aim is to encourage proposals related to the environmental soundness of mining projects in the region. Also, it should be noted the existence of a Database Steering Committee whose focus is the development of an information network related to mining opportunities in the region. GEMEED is a gathering of experts from all the APEC economies. As such, it represents a privileged forum to discuss policy issues related to mining. On this regard, the paper focuses on concrete actions taken by GEMEED to enhance the sustainability of the copper activity in the region.

3:15 PM

The 21st Century: A Century for the Chuquicamata Mine: *Juan H. C. Rojas*[1]; [1]Codelco Chile, Division Chuquicamata, Chuquicamata, Chile

The Chuquicamata mining and metallurgical complex is the main division belonging to Corporacion Nacional del Cobre de Chile (Codelco-Chile) and it accounts for 50% of the 1.4 Mt of fine copper output of the Corporation. It has been producing copper since 1915. The paper refers to the challenges that Chuquicamata has to solve in the near future. These challenges are: the increasing operation costs associated to a 800 m depth pit with low prices in an overstocked copper market; the increasing people's sensitivity to environmental preservation; and, the transformation needed for achieving high levels of organizational effectiveness. According to Corporate policy, Chuquicamata is making efforts to switch from a management style focused on supply to a management style focused on demand side of the industry. In this direction, we attempted to establish strategic alliances to develop both new copper products and uses, to rise the metal demand. In more than 80 years of operation, Chuquicamata had exploited just one third of its geological resources. The exploitation of the remaining two third is a huge engineering challenge, taking into account the depth of the deposit, the impurities content, the decreasing ore grades and the transportation distances for waste dumping. All of those factors are relevant in the economic process of transforming geological resources into ore reserves. Chuquicamata has other limitations. First, a 20,000 people town just aside the pit that limits the mining

rates because of dust generation; second the scarceness of water in the desert area where Chuquicamata deposit is located; and, finally, the new tailing pond is a problem which solution will demand huge engineering efforts and investments. People are the principal factor associated to a company success. In this field, Chuquicamata has been progressing, but much more efforts from people will be necessary to reduce production costs for being successful as any other price-taker within the copper industry. Chuquicamata must develop the skills of its Supervisors to transform them into leaders and entrepreneurs, who additionally have the challenge of passing on their knowledge to non-professional workers. It is an ethic commitment to assure personal and professional growth of workers, as the only sustainable way to get real and integral success.

3:40 PM Break

4:10 PM
Chile's Mining and the Application of the Basel Convention: *G. E. Lagos*[1]; [1]Catholic University of Chile, Ctr. for Mining, Avda. Vicuña Mackenna 4860, Macul, Santiago, Chile

This paper analyses the scope and instruments employed by the Basel Convention for regulating the transboundary movement of hazardous wastes, the present and projected hazardous waste regulations of Chile, reviews the Chilean import/export trade of wastes of the period 1985-1995, and discusses the influence that the Basel Convention has had on mining trade, its perceived benefits and costs, and possible effects on Chile's trade of the application of the Convention's Decision III/1. There is no quantitative estimation as to the effect of the Convention on the general volume of imported or exported materials destined for recovery, recycling, reclamation, or reuse. All recycling imports, with the possible exception of residues of petroleum oil, which occurred during the decade 1985-1995, can be classified tentatively as non hazardous. The entry into force of the Convention has had several effects on Chile's trade. It has brought home the need to have a comprehensive hazardous waste legislation, it has been a base for applying import restrictions, which in all likelihood, would have otherwise not been applied. The benefits and costs of this import restriction, as well as those of the multilateral export ban are analyzed.

4:35 PM
Copper, Market Growth Potential and Threats in the Asia Pacific Region: *Thomas Astorga*[1]; Raul F. Campusano[1]; [1]GEMEED-APEC, Dept. of Mining, Teatinos 120, 9th Floor, Santiago, Chile

APEC, the Asia Pacific Economic Cooperation is the forum of 21 countries having approximately 56% of the total world income, and over 45% of global trade. In 1997, APEC economies produced 67% of the world copper output, 55% of gold, and over 45% of other base metals. Mining in APEC captures more than 60% of the total mining investment in the world. New and emerging economies are now appearing in the demand scenery, such as China. New trends in the international environmental regulations are posing questions related to the use of copper in different industrial and consumption applications. These may have a strong impact on future trade of copper. New applications are also appearing based in new technology fields. The paper examines the growth potential of the copper market in main consumer and highly populated economies of APEC, incorporating analysis of various interrelated factors. It also analyses the outlook of the copper supply. Its conclusions point to the need to implement demand outlook models. Finance and economic reforms will open important avenues for trade growth in basic metals, particularly copper. Changes in the consumption patterns of highly populated countries will add to better perspectives of copper demands. The recovery of a fast pace of economic growth in the APEC region will bring new demands for copper, especially as a consequence of high tech applications. More extended policies focused in the need for developing energy efficiency programs and schemes will add to this picture.

5:00 PM
Trends and Insights into Worldwide Copper Acquisition Activity: *Douglas B. Silver*[1]; [1]Balfour Holdings, Inc., 10 Inverness Dr. East, Suite 104, Englewood, CO 80112 USA

Of all the base and precious metals, copper continues to receive the greatest amount of investment. Worldwide copper acquisition activity has increased during the past half decade because of multiple government privatization programs, the opening of Central African markets and the dismantling of Communism. Examining the large number of transactions also provides insights into negotiating techniques as they relate to local business cultures, the probable flow of future capital and development activities and the dynamics of foreign investment. This presentation will also provide quantitative statistics of these issues. It will summarize the terms of these recent copper resource transactions, assess their significance from a technical and geographic perspective and provide insights about the future of copper exploration, development and mining.

Pyrometallurgy-Operations: Session II

Monday PM Room: Estrella
October 11, 1999 Location: Pointe Hilton Resort

Session Chair: Phil Mackey, Noranda Technology Centre, Pointe Claire, Québec, Canada; N. Santander, U. de Chile and U. Mayor, Dept. of Metallu. Eng., Santiago, Chile

2:00 PM
Copper Smelter Waste Heat Boiler Technology for the Next Millennium: Rauno Peippo[1]; *Hannu Holopainen*[1]; Jari Nokelainen[1]; [1]Foster Wheeler Energia Oy, Relanderinkatu 2, Varkaus FIN-78200 Finland

Horizontal Waste Heat Boiler (WHB), today's proven and dominating technology for copper smelter gas cooling, has been utilized by the industry for over half a century. During this time development has taken place in geometry, flow characteristics, cleaning technology and design details. This development has been driven by improved understanding of the spe-

cific process requirements, gained both by wide experience and by utilizing new emerging design tools, like computer flow modeling. It had to wait till mid 90's to unite effective and proven Spring Hammer cleaning technology and the process benefits gained by gas guiding vanes or baffle wall in the copper smelter WHB design. The new design has demonstrated improvement in gas cooling efficiency and the process conditions down stream in form of less dust sticking problems in the boiler and precipitators. Reduced weak acid production has also been reported as a result of the design. The theoretical aspects, computer flow modeling results and actual benefits measured in old smelting line modernization are discussed. Experience from modernization projects such as Phelps Dodge, Atlantic Copper, Mexicana de Cobre, and Nippon Mining, Saganoseki, are discussed. In mechanical design there has been development resulting improved gas tightness with less corrosion and better control of dust sulfation. An essential improvement is the integration of the boiler hopper and dust removing conveyor. Having no steel plate casings in the hopper and conveyor section but using of boiler tube membrane instead eliminates thermal expansion differences. The dust conveyor will be effectively cooled against hot dust lumps falling down while the acid dew point corrosion is prevented in the cooler sections of the hopper. Conceptual features are presented of a new generation Copper Flash Smelter WHB presently under construction at Boliden Mineral, Skelleftehamn, Sweden, where the latest development and innovations are adopted.

2:25 PM

Tons and Profit from Understanding Gas Cooling and Heat Recovery: *Kurt A. M. Westerlund*[1]; *Olaf Piehl*[1]; *Wolfgang Abeck*[1]; [1]Oschatz GambH, Dept. of Non-Ferrous Gas Hand. & Heat Recovery, Westendhof 10-12, Postfach 102843, Essen D-45028 Germany

The basic function of primary gas handling downstream non-ferrous pyrometallurgical processes is cooling hot sticky gases to treatable temperature levels (e.g. entering ESP). That means managing efficient the critical gaseous components from a molten via a sticky to a solid phase. The article outlines the modem gas cooling methods combined with efficient heat recovery. Examples of the alternative use of recovered steam energy are outlined; as e.g. drying of concentrate and power generation. The heat transfer impact of the insulating dust is called fouling and circumstances causing fouling are described. Modem cooling surface design and cleaning techniques to keep fouling in reasonable limits are described. Leakage and false air ingress into the gas handling lines often limits smelting capacity. The objective is generally to minimize the infiltration of air but it still takes place at open interfaces (e.g. at reactor hood, feed port). Leakage—air at furnace roofs for example—can be reduced to a minimum by adopting the pressure gas sealing used at present In-Bath-Lance furnaces. Modernization and optimization methods to de-bottleneck existing waste heat boiler gas cooling capacity by highly efficient surface cleaning systems and false air avoiding (e.g. bundle roof boxes, dust discharge) are detailed described.

2:50 PM

Analysis of Recent Advances in Sulfuric Acid Plant Systems and Designs (Contact Area): *Leonard Joel Friedman*[1]; [1]Acid Engineering & Consulting, Inc., P.O. Box 811539, Boca Raton, FL 33481-1539 USA

The contact process for the production of sulfuric acid has been used commercially since before the turn of the century (1880's), and rapidly replaced the chamber process after the development of vanadium catalysts in the early 1900's (1910's-1920's). Plant size has increased from a few tons per week to single train units in excess of 4,000 tons per day. Much of the history of the contact process is in the minds of the few remaining early process pioneers that started in the industry in the 1920's and 1930's, and in sulfuric acid industry books published in 1921, 1925, 1936, and the last Deucker and West in 1959. Since those not familiar with history are doomed to repeat the failures and mistakes of the past, this paper includes a brief history of the contact process along with the history and development of equipment and materials in each equipment area of the process. The main focus of the paper is to present the development and analysis of equipment and materials in the contact session of the sulfuric acid plant from the dry tower to stack. Note: Previous works by L. J. Friedman provide analysis of developments in the gas cooling, cleaning and purification sections of metallurgical and spent acid regeneration plants. The discussion of each equipment area includes the history and development of the equipment, current design alternates, and an analysis of each leading to a recommended design. Good designs are highlighted, and gimmicks and marginal problems prone designs exposed.

3:15 PM

Gas Handling and Cleaning at the Potrerillos Smelter: *Leonel Contreras*[1]; Pedro Reyes[1]; Benjamin Martinich[1]; René Bustamante[2]; [1]Codelco-Chile, División El Salvador, El Salvador, Chile; [2]Universidad de Santiago de Chile, Departamento de Ingeniería Metalurgia, Av. Libertados Bernardo O'Higgins 3363, P.O. Box 10233, Santiago, Chile

The gas treatment system, MALIGAS (in Spanish MAnejo y LImpieza de GASes which means handling and cleaning of gas), is part of the Codelco-Chile Potrerillos Smelter decontamination plan, which includes the newly designed system for the cooling and cleaning of the gas generated from a Teniente Converter and four Peirce Smith Converters. The gas generated in the process is captured by water cooled hoods and mixed with air. Then the gas enters a cooling pre-chamber which utilizes a water cooled screen to capture and remove the coarse and semi-fused particles. At this stage, the gas loses a portion of its heat with temperature falling below 608ºC which is a necessary condition to avoid damage to the pipes, ducts and other metallic structure of the gas handling system. The gas is further cooled at the Radiation Cooler to a temperature ranging between 315 and 380ºC. The gas is conditioned to avoid damage to the electrostatic precipitators that are designed to clean the gas by removing significant amount of dusts from the gas stream. This gas stream is currently discharged to the stack, however, it will be treated in a sulfuric acid plant that is currently under construction and is scheduled for commissioning during the sec-

ond half of 1999. The gas handing and cleaning system has been operated without any significant interruptions. Minimal emissions of SO_2 and dusts in the work place are noted. The system requires minimum maintenance. The key to the high availability of the system is due to the good performance of he Radiation Cooler, which efficiently cools the gas before entering the electrostatic precipitators (ESPs). This enables the ESPs to remove the dusts efficiently.

3:40 PM Break

4:10 PM
Process Gas Handling in Copper Metallurgy: *M. A. Cocquerel*[1]; C. Cuadra[2]; T. Moya[2]; [1]Kvaerner E&C, Dept. of Tech., 12657 Alcosta Blvd., San Ramon, CA 94583 USA; [2]Kvaerner E&C, Pyrometallu. Specialists, Santiago, Chile

External process energy requirements and air pollution control regulations formulated to limit particulate and SO_2 emissions are impacting on smelting and converting technologies and the corresponding process and secondary gas handling systems. This paper presents an overview of the different technical solutions used for cooling and dedusting the process gases in the different pyrometallurgical copper concentrate stages, including: drying, smelting, converting, slag cleaning and fire refining. The main principles of the process gas handling systems are presented and a qualitative technical and economical comparison is discussed in relation to process changes, energy recovery and marketing or disposing of the various sulphur fixation by-products. Finally, a brief review of the methods for fixing sulphur contained in the process and secondary gases is presented.

4:35 PM
Peirce-Smith Converter Hood Improvements at BHP Copper: *Ovidiu Pasca*[1]; John Bryant[1]; Paykan Safe[2]; Brian Wiggins[2]; [1]BHP Copper, San Manuel, AZ USA; [2]Gas Cleaning Technologies, Dallas, TX USA

Several improvements in converter equipment and operation at BHP Copper have reduced the converter cycle time as necessitated by an increase in flash furnace output. The resulting higher intensity performance of the Peirce-Smith Converters has had a major impact on the dust handling and off-gas cleaning systems. This paper describes work carried out on the design of a new converter hood with particular reference to the thermal analysis and hood performance aspects. Changes in converter cycle time and campaign life as result of the process and equipment improvements are discussed in a separate paper

5:00 PM
Upgrading of the Teniente Technology: *Pedro Morales C.*[1]; Roberto Mac-Kay S.[2]; [1]Codelco-Chile, Direct. of Tech. Innov. and Res., Huérfanos, Santiago 1270 Chile; [2]Codelco-Chile, El Teniente Div., Caletones Smelter, Millan, Rancagua 1040 Chile

From its beginning in the 1970's, the Teniente Converter has consistently achieved continuous improvement, and has contributed to the competitiveness and sustainability of Codelco's copper operations. The later introduction of the Slag Cleaning Furnace technology has helped to create a full technology package, referred to as the Teniente Technology. This paper outlines the features of a new research and innovation program designed to bring the Teniente Technology as a modem, competitive technology into the 21st century. The overall objectives and features of the program are described and discussed. It is fully anticipated that these activities will help position the Teniente Technology as a world-class modem technology, well-integrated and operating in a fully continuous mode in conjunction with the other units at the plant, a competitive technology which operates in harmony with respect to environmental regulations.

5:25 PM
Modification of the Mount Isa Copper Converters to Feed a New Sulphuric Acid Plant: *Richard Hollis*[1]; Adrian Werny[1]; Gregory Yeowart[2]; [1]Fluor Daniel Pty Limited, 300 Ann St., Brisbane 4000 Australia; [2]Mount Isa Mines Limited, Mt. Isa, Queensland 4825 Australia

The Mount Isa copper smelter was expanded in 1998 to a capacity of over 250000 t/y anode copper. This tonnage will be produced from a single stream consisting of an Isasmelt smelting furnace, and four Peirce-Smith converters—one of which was installed as part of the expansion project. During the course of the expansion project Mount Isa Mines Limited (MIM) signed an agreement with WMC Fertilizers, Ltd. (WMCF) to supply sulphur containing smelter gases over the fence to a new sulphuric acid plant to be built by WMCF. This will result in a further increase in copper production by reducing the time when smelting is curtailed by Air Quality Control restrictions. As well as the need to modify the primary gas system to connect to the acid plant, the hoods and crossover ducts and their support structures on the original three converters require placement, and secondary ventilation was also needed to improve converter aisle hygiene. Each of these areas was addressed by the project. Preliminary ideas for carrying out the modifications were found to have a serious impact on converter aisle operations, and would have led to a production loss of over 50000 tonnes of copper. Following benchmarking in other copper smelters, a suitable construction plan was developed and carried out to minimise this loss. This paper describes the methodology and construction plan adopted.

Smelting: Technology Development, Process Modeling and Fundamentals: Technology Development II

Monday PM Room: Goldwater
October 11, 1999 Location: Pointe Hilton Resort

Session Chairs: Jan Matousek, 8547 E. Arapahoe Rd., #J149, Greenwood Village, CO 80111-1430 USA; Antonio Luraschi, INDEC, International Engineering Consulting Services, Avda. Providencia 2653, Of. 512, Santiago, Chile

2:00 PM
Converter and Bath Smelting Vessel Design - Blast Delivery and Tuyere Performance: A Reassessment of Design Characteristics: *A. E. Wraith*[1]; P. J. Mackey[2]; C. A. Levac[3]; P. Element[4]; [1]University of Newcastle,

Dept. of Mech., Mats. and Manuf. Eng., Newcastle upon Tyne NE1 7RU UK; [2]Noranda Technology Centre, Pointe Claire, Québec, Canada; [3]Fonderie Horne, Metallurgie Noranda, Noranda-Rouyn, Québec Canada; [4]Noranda, Inc., Mines Gaspe, Murdochville, Québec, Canada

The tuyere flow rates of Peirce-Smith converters and bath smelting reactors are rendered particularly sensitive to accretion formation, bath depth variations and the general aerodynamic design of the blast delivery system by the limited pressure-flow properties of the conventional single stage centrifugal blower. This sensitivity is examined in terms of tuyere practice, vessel management and fixed engineering parameters for Peirce-Smith converters and the Noranda Reactor by use of the flow resistance factor, R*. New understanding of the effect of accretion growth on the flow behaviour of individual tuyeres shows that blowing rates and hence throughputs could be optimised by careful attention to operating detail even within present plant constraints. The concept of the resistance vector is introduced to elucidate comparisons between different practices and to provide reference standards for optimisation. On this basis, the benefits of introducing quite moderate changes in the pressure-flow properties of the blast delivery system are considered. In view of recent developments in the flexible use of converters as hybrid bath smelting vessels for matte production, the foundation is now laid for a searching consideration of relationships between vessel volume and shape, blowing requirements, tuyere performance and production rates, the detail of which will be examined more appropriately in a forthcoming paper.

2:25 PM

High Oxygen Shrouded Injection at Falconbridge: *A. A. Bustos*[1]; J. P. Kapusta[1]; B. R. Macnamara[2]; M. R. Coffin[2]; [1]Air Liquide Canada, Inc., 1250, Boulevard René-Lévesque Ouest, Montréal, Québec, Canada H3B 5E6; [2]Falconbridge Limited, Falconbridge, Ontario, Canada POM 1S0

Four Air Liquide Shrouded Injectors (ALSI) were installed and operated for over one year in a Peirce-Smith converter at the Falconbridge nickel smelter in Falconbridge, Ontario, Canada. A shrouded injector consists of an inner pipe and an annulus, through which high oxygen enriched air and nitrogen flow, respectively. The nitrogen cools the injector and protects the refractory in the vicinity of the injector tip, allowing for substantial increases in oxygen flow rates to the converting reactions. Several injector designs were tested to study the effect of changes in the cross-sectional area and changes in the entrance geometry of the annulus. An optimum design would minimize the injection pressure required for a given flow rate to achieve choked flow conditions at the tip of the injector. The operation of the ALSI was simple and did not require any special care or maintenance, either between blows or between converter cycles. In particular, the shrouded injectors did not require punching, as is the case with conventional tuyeres. In terms of refractory performance, the ALSI, operating at 30-40% oxygen enrichment, were superior or equal to the conventional tuyeres, which operated at 21-23% oxygen. The results of the demonstration program led Falconbridge Limited to implement the ALSI technology on a commercial scale. The paper presents the demonstration program results in terms of gas flow rates, accretion formation, punchless operation and refractory wear.

2:50 PM

A Fluid Dynamic Simulation of a Teniente Converter: *M. Rosales*[1]; R. Fuentes[1]; P. Ruz[1]; Jorge Godoy[2]; [1]Institute for Innovation in Mining and Metallurgy (IM2), Avenida del Parque 4980, Ciudad Empresarial, Huechuraba, Santiago, Chile; [2]CODELCO-Chile, El Teniente Div.

Using the k-ε turbulence model, a mathematical fluid dynamics simulation of the flow characteristics in a Teniente Converter has been conducted. Two cases were studied: Transversal sections in the smelting-converting zone; and a three-dimensional simulation that includes the walls of the reactor. The calculations give the velocities field, the gravity waves amplitude, the splashing behaviour, the phase distribution and the shear stress distribution. The latter helps to explain the pattern of refractory lining wear. The calculation includes the approximate shape and dimensions, and the eventual coalescence of bubbles.

3:15 PM

A Waterless Caster for Matte/Slag Granulation: *Frank Mucciardi*[1]; Enzo Palumbo[2]; Ning Jin[3]; [1]McGill University, Dept. of Metall. Eng., 3610 University St., Montreal, Québec, Canada H3A 2B2; [2]Noranda Technology Centre, 240 Hymus Blvd., Pointe-Claire, Québec, Canada H9R 1G5; [3]McGill University (now with Cosworth Technologies, Detroit, MI USA)

With the increasing trend to continuous smelting and converting, granulation of copper matte is gaining prominence as a means of decoupling the smelting and converting operations. Moreover, granulation is also being seen as a possible avenue to using higher grade oxygen in converters. By feeding cold solid matte, the oxygen concentration can be increased to compensate for the lower enthalpy feed. This leads to a higher grade of SO_2 in the off gas and a lower total flow rate. Current granulation technology relies on the cooling of a falling matte film by water jets. This technology while effective has several drawbacks including those related to safety. Noranda and McGill University have developed a new process (patent pending) for solidifying copper matte (or slag). It overcomes many of the negatives of current technology. The system is based on an air cooled twin roll caster. This new system uses no water and instead incorporates heat pipe technology to transfer the heat from the solidifying matte to the cooling air to produce a thin strip of 1 to 2 mm in thickness. Testing of a prototype unit demonstrated its viability. This paper describes this newly developed, twin roll casting system that is completely waterless. The advantages of this process as well as the findings from several tests are also detailed.

3:40 PM Break

4:10 PM

Ferrous Calcium Silicate Slag to be Used for Copper Smelting and Converting: *Akira Yazawa*[1]; Yoichi Takeda[2]; Shigeatsu Nakazawa[3]; [1]Tohoku University, 16-32 Niizaka, Aoba-ku, Sendai 981-0934 Japan; [2]Iwate University, Dept. of Matls. Sci. and Tech., Ueda 4-3-5, Morioka 020-0066 Japan; [3]Tohoku University, Dept. of Metallu., Grad. Schl. of Eng., Aoba-ku, Sendai 980-

8579 Japan

The composition of ferrous calcium silicate slag is located on the tie line between FeO_x and calcium silicates in ternary FeO_x-SiO_2-CaO system. This slag has never been used as copper smelting slag because of high sulfidic copper solubility. However, when the dissolved copper in slag is just oxidic, as in direct white metal production or in converting process, this slag is quite attractive and can be regarded as the third copper smelting slag after fayalite and calcium ferrite slags. Based on the authors' studies on phase separation thermodynamics and laboratory experiments, it was clarified that the oxidic copper loss in this ferrous calcium silicate slag become the minimum not only %Cu in slag but also the total copper loss when the amount of slag is taken into account It has been proven that calcium ferrite slag is suitable for continuous converting where the dissolved copper is oxidic, but there exist some drawbacks such as limited solubility of silica, low lead removability and too high fluidity. To overcome these difficulties accompanying traditional slags, ferrous calcium silicate slag is the hopeful alternative. In view of the general trends of modem copper smelting processes, the interesting features of this new slag system are discussed.

4:35 PM

Technology for Decreasing Refractory Wear in the Mitsubishi Process: Fundamental Research and its Application: *Fumito Tanaka*[1]; H. Sato[1]; Nozomu Hasegawa[1]; [1]Mitsubishi Materials Corporation, Cntrl. Rsch. Instit., 1-297 Kitabukuro-Cho, Omiya, Saitama 330-8508 Japan

In April 1999, a two-year campaign of the Mitsubishi furnaces was achieved at Naoshima Smelter; the present one is expected to be extended much longer. An overview of basic technology for decreasing refractory wear in the Mitsubishi Process is presented. One of the main features of the process is the use of top blowing lance technology which has a different effect on the furnace refractory than other conventional processes. The refractory wear of concern is hearth wear caused by top blown powder injection, wear of the side wall caused by splashing droplets, and wear of the bath level refractories caused by surface waves of melts in the furnace. These have been systematically investigated for many years. This paper describes the results of various model tests and their application to practical furnace design and operation.

5:00 PM

Interaction between a Gaseous Vertical Jet and a Liquid Surface - A Theoretical and Experimental Study: *L. Salinas*[1]; R. Fuentes[1]; [1]Institute for Innovation in Mining and Metallurgy (IM2), Avenida del Parque 4980, Of. 131, Huechuraba, Santiago, Chile

Lance injection of gas and particles into a molten bath is currently practised in metallurgical processes (Mitsubishi lances for example). Several experimental and theoretical studies have been conducted in the past on this topic. However, neither detailed calculations nor experimental studies of local flow patterns have been published. In the present work, a numerical simulation of the interaction of a gaseous vertical descending jet and a liquid surface was done, using the turbulence k-ε model. There is a fair agreement between the calculated and the experimental values. The results of this study demonstrate that it is crucial that the gas jet velocity profile and turbulent characteristic are correctly formulated in order to correctly simulate the system.

5:25 PM

Extending Lance Life in Top Blowing: *Frank Mucciardi*[1]; G. Zheng[1]; Ning Jin[2]; [1]McGill University, Dept. of Metall. Eng., 3610 University St., Montreal, Québec, Canada H3A 2B2; [2]McGill University, now with Cosworth Technologies, Detroit, MI USA

While flash smelting and converting are capturing a greater share of the market, injection through circular injectors will remain with us for the foreseeable future. The use of top lances for injection is a key feature in several processes (e.g. Mitsubishi, Ausmelt). Tuyeres, on the other hand, are incorporated into a number of processes (e.g. Noranda, Peirce-Smith). To date no lances or tuyeres are cooled by an external source. The reagent provides the bulk of the cooling. With limited cooling, it is normal to have substantial wear on the nozzles - especially in the case of lances. To overcome the issue of wear, a new patented injector (lance or tuyere) has been developed by Noranda and McGill University. This novel unit is based on heat pipe technology. It can operate for an extended period of time without wearing. Enhanced lance/tuyere life is achieved by operating the injector at a low enough temperature that promotes the formation of a thin frozen layer on the outer body of the unit. The vaporizing and condensing substance within the unit acts to cool the high heat flux portions and dissipate the heat to areas of low heat flux outside the vessel. A fairly large number of tests have been conducted with a prototype unit. The tests have shown that the heat pipe lance is a viable unit. In this paper is detailed a test which illustrates how the lance functions when pure oxygen is injected into copper matte. In addition, the findings from a basic study of a heat pipe in high heat flux environments are also presented.

Plenary Lectures: Session II

Tuesday AM — Room: Flagstaff/Goldwater/Indigo/Jerome
October 12, 1999 — Location: Pointe Hilton Resort

Session Chairs: S. Demetrio, ConOpti S.A., Cerro San Ramon 1491, Las Condes, Santiago, Chile; C. Diaz, University of Toronto, c/o Dept. of Metallurgy and Matls. Sci., Toronto, Ontario, Canada

8:30 AM

The Draft GBN Global Scenarios and the Forces Driving Them: *Peter Schwartz*[1]; Steven Weber[1]; [1]Global Business Network, 5900-X Hollis St., Emeryville, CA 94608 USA

This paper presents GBN's "Global Scenarios" for the first decade of the 21st century. We describe a set of key scenario actors and develop 6 driving forces in demography, technology, climate change, macroeconomic change, globalization, and geopolitics.

We argue that a set of major challenges to world systems of commerce and politics will coalesce in the next several years. We develop four scenarios which differ according to how these challenges are handled, and which scenario actors play the key roles in managing the transition.

9:15 AM
The Financial Performance of the Copper Industry: Some Comparisons: *Peter Kettle*[1]; [1]CRU International Limited, 31 Mount Pleasant, London WCIX OAD England

This paper describes the performance of the copper industry over a period of some two decades and examines the theme that improvements in operating efficiency have not been matched by improved returns on capital. The financial performance of the copper industry is analysed using CRU's MICA database. Regression analysis indicates a two percentage point increase in operating margins but no increase in returns on capital. The gain in operating efficiency appears to have been mainly achieved in the mid 1980's. The investment boom of recent years has resulted in a rapid increase in the industry's level of debt and gearing ratio (now some 47%). Data on 44 copper mine projects is used to show the linear relationship between scale and capital costs. Typically new capacity costs some US$5,000/tpy. The relationship between cash costs and capital intensity of projects is also plotted. The greater attention now being focused on efficient use of capital means that capital intensity rankings will become increasingly important in determining which projects go ahead.

10:00 AM Break

Copper Applications and Fabrication: Fabrication

Tuesday AM Room: Copper
October 12, 1999 Location: Pointe Hilton Resort

Session Chair: Mahi Sahoo, Natural Resource Canada, Ottawa, Ontario, Canada K1A 0G1

10:30 AM
Mechanical Properties of Selected Brasses Cast in Permanent Molds: *F. A. Fasoyinu*[1]; R. Bouchard[1]; J. Thomson[1]; M. Sahoo[1]; [1]CANMET, Matls. Tech. Lab., 568 Booth St., Ottawa, Ontario, Canada K1A 0G1

The mechanical properties of yellow brass (C85800), high strength yellow brass (C86300), and high manganese brasses (C99700 and C99750) cast in permanent molds have been studied. The tensile properties as well as fracture and impact toughness of these alloys are strongly dependent on the chemical composition. Alloys and/or compositions exhibiting relatively high zinc equivalent often exhibited high ultimate tensile strength and yield strength with significant reduction in ductility (% elongation). In order to achieve optimum properties with a good balance between strength and ductility, a calculation of the zinc equivalent before alloy preparation can be useful.

10:55 AM
Rheology and Metal Forming of Fire-Refined Copper (FR): *Carlos Camurri*[1]; [1]Concepción University, Dept. of Metall., Casilla 53-C, Concepción, Chile

Results from the Metallurgical Department of the Universidad de Concepción showed that fire-refined copper could be rolled without previous remelting for deoxidation. The goal of this work was to determine the rheology of fire-refined copper using tensile tests at different temperatures and strain rates, as well as Ford plane compression tests. This was done in order to simulate and calculate rolling process variables. For rheology hardness coefficients, values between 0.28 at 600ϒC and 0.46 at ambient temperature were obtained. The sensibility coefficient for strain rate m varied between 0.056 at 600ϒC and 0.006 at ambient temperature. The activation energy for plastic flow Q in the considered temperature range was found to be 1436 cal/mol.

11:20 AM
The Effect of Nickel on the Mechanical Properties of High-Strength Yellow Brass: *D. G. Schmidt*[1]; [1]R. Lavin and Sons, Inc., 3426 S. Kedzie Ave., Chicago, IL 60623 USA

Tests were conducted on C86200 high-strength yellow brass in order to ascertain the effect of a low level of nickel on the mechanical properties of this alloy. A series of two alloys was studied, one of which had a nickel content of 0.85% and the other with <0.05% nickel. Copper and aluminum content ranged from 62.5% and 64% and 3.2% to 4.6% respectively. When compared by zinc equivalents, a nickel addition of 0.75% in high-strength yellow brass does not act like copper but raises the tensile strength, 0.5% yield strength and BHN while lowering the elongation.

11:45 AM
Grain Refinement of Copper Base Alloys: *M. Sadayappan*[1]; F. A. Fasoyinu[1]; M. Sahoo[1]; [1]Materials Technology Laboratory (CANMet), 568 Booth St., Ottawa, Ontario, Canada K1A 0G1

The grain refinement characteristics of four low-lead and lead-free copper base alloys for plumbing applications were investigated. These are leaded yellow brass (C85800), SeBiLOY III (C89550), silicon brasses (C87500 & C87800) and silicon bronzes (C87600 & C87610). Boron and zirconium were found to be the most effective grain refiners for copper alloys produced using the permanent mold cast processes. The study indicates that the type of grain refiner to be used is dependent on the alloy type, alloying constituents and their content. After grain refinement, hot tearing resistance of the alloys was improved but mechanical properties remained unaffected. Alloys refined with boron are prone to the formation of hard spots, which will have adverse effect on the surface quality of the castings during polishing and buffing.

12:10 PM
Improved Rod Plant Level Control with UNAC: *A. A. Shook*[1]; C. A. Shelton[1]; [1]BHP Copper Smelting and Refining, 200 S. Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA

For relatively little capital outlay, the metal delivery control systems in the BHP Copper Rod Plant at San Manuel was significantly upgraded using the UNAC process simulation and control system (CICS

Automation, Newcastle, Australia). An accurate simulation of the metal delivery process was developed with UNAC, which was then used to design robust controllers capable of dealing with plant complexities such as noise, time delays, and nonlinearities. This controller was implemented online using UNAC. Thanks to the extensive preparatory simulation, the controller worked immediately and required no additional online "tuning." Operator response has been favorable, and the UNAC control system has become part of the standard operation of the plant.

12:35 PM

Application of Mechanical Alloying Processing to the Formation of Copper-Carbides Alloys: *Victor Vergara*[1]; M. López[1]; R. Benavente[1]; C. Camurri[1]; B. Cartes[1]; J. Jiménez[2]; [1]University of Concepción, Dept. of Metallu. Eng., Casilla 53-C, Concepción 00187 Chile; [2]Centro Nacional de Investigaciones Metalurgicas, Av. G. del Auro, Madrid 8-28040,Espana

Four copper composites were obtained by mechanical alloying, using as dispersed phases of four carbide powders; they were: boron carbide, chromium carbide, silicon carbide and zirconium carbide. The purpose of this work was to study some characteristics of these compounds and their feasibility for use as materials for electrical equipment. Raw materials used were copper powder finer than 150 mesh, and 2-4 vol % of powder carbides finer than 325 mesh. The alloying process was carried out using both a Spex 800-D mill with tungsten jars and balls and a hardened stainless steel jar and balls, the purpose of which was to measure the degree of contamination induced by the milling media. The changes in particle size, morphology and microstructure of copper alloys were studied with SEM and TEM for each alloyed powder. The degree of saturation of copper by the carbides was measured by X-ray diffraction. Sound samples were obtained by hot isostatic pressing at 1073ΥK. The best characteristics were obtained for the compound copper-chromium carbide, based on their hardness, tensile strength and electrical conductivity values. The other alloys failed due to their excessive brittleness after hot pressing.

Electrorefining: Refinery Operations III

Tuesday AM Room: Indigo
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: J. Garvey, Cyprus Miami Mining Corporation, Claypool, AZ 85532 USA; M. Ramos Rada, Mexicana de Cobre S.A. de C.V., Refineria La Caridad, Nacozari, Sonora, C.P. 84340 Mexico

10:30 AM

Antimony Removal by Ion Exchange in a Chilean Tankhouse at the Pilot Plant Scale: E. A. Román[1]; J. C. Salas[1]; *J. E. Guzmán*[2]; S. Muto[3]; [1]IM2, Instituto de Innovación en Minería y Metalurgia, S.A., Filial Codelco-Chile, Av. del Parque 4980 Of. 131, Huechuraba, Santiago, Chile; [2]División Chuquica-mata, Codelco-Chile, Chuquicamata, Chile; [3]Mesco, Inc., Eng. Div. of Mitsui Mining and Smelting Co., Ltd., 2-10-5 Ryogoku, Sumida-ku, Tokyo 130 Japan

An ion exchange pilot plant, provided by Mesco, Inc., was tested for antimony control in the electrolyte at three Chilean tankhouses for copper electrorefining: Chuquicamata, Potrerillos and Enami-Ventanas. The pilot plant, with a nominal extraction capacity of 1.2 kg Sb/day, worked connected to both experimental and commercial circuits, performing a total of 310 loading and elution cycles. An innovation in this process is the use of a chelating organic elution reagent, which presents some advantages over the traditional 6N HCl. This new eluent is amenable to continuous regeneration and recycling with high recovery efficiency. Antimony removal starting at initial concentrations of 0.5 to 0.6 g/l of Sb down to steady concentrations of 0.1 to 0.06 g/l Sb, resulted in the production of High Grade copper cathodes with Sb contents below 0.1 ppm. Anodic slimes showed Sb contents below 1%.

10:55 AM

Reduction of Silver Losses during the Refining of Copper Cathodes: P. Barrios[1]; A. Alonso[1]; *U. Meyer*[1]; [1]Atlantic Copper, S.A., Avda. Francisco Montenegro, s/n, Huelva E-21001 Spain

Over a period of one year, an in-depth investigation was carried out in a conventional copper refinery to understand the behaviour of silver in copper electrolysis. The increase in silver content in the cathodes increases almost lineally with the duration of electrolysis, and the silver content of the electrolyte between the electrodes shows similar behaviour. The silver content of the cathode deposited daily depends directly on the silver concentration of the electrolyte and this, in turn, is strongly influenced by its internal temperature. The average temperature between the electrodes rises from the first to the second and to the third crop, because of the increase in the distance between the electrodes and the heat generated by the passage of the current. The mechanism of dissolution of silver from the anode, and its passage to the cathode, are discussed. Following the change to the Isa system, it was proved that the results and conclusions are analogous. Based on these results, a reduction of more than 20% in silver losses in the cathodes was achieved.

11:20 AM

Current Efficiencies at High Current Density for Various Cathode Cycles: *I. M. Santos Moraes*[1]; [1]Caraiba Metais S.A., Via do Cobre n° 3700 A.I.O. - COPEC, Dias D'Ávila, Bahia 42-850-000 Brazil

Achieving high current efficiencies when operating at high current densities is a goal for every refinery, whether conventional or permanent cathode technology is employed. To obtain higher current efficiency at increased current density at Caraiba's Tankhouse, the production team decided to change the cathode cycle from eleven to thirteen days, reducing cathode cycle to one per anode cycle. The idea was to reduce the anode-cathode spacing and consequently reduce the potential for short-circuiting them. With respect to current efficiency, the overall result was not much better than that obtained with the normal operating conditions. A new attempt to obtain higher current efficiency at high current density was implemented by going back to two cathode cycles per anode cycle, this time reducing cathode life to ten days. This approach yielded the high-

est current efficiencies. This paper presents the data generated with the three operating conditions: normal practice, a single cathode cycle per anode cycle, and two cathode cycles per anode cycle with a reduced cathode cycle time. It compares the productivity achieved with each set of operating conditions. An analysis of the main operating parameters as well as the advantages and disadvantages involved with each condition is also presented for future reference.

11:45 AM

Maintaining High Efficiencies While Increasing Current Density: F. Begazo[1]; R. M. Underwood[1]; A. G. Storey[1]; V. R. Alarcón[1]; [1]Southern Peru Copper Corporation, Ilo, Peru

The most common approach to increase production in copper refineries is to increase current densities. However, if these increases are not well thought out beforehand and are not properly and effectively controlled, the end results could be reduced plant performance and a deterioration in cathode quality. Both of these factors result in lower efficiencies and increased costs. At the Ilo Refinery of Southern Peru Copper Corporation, a modernization and expansion program was implemented shortly after the Refinery was purchased from Minero Peru, in 1994. This program was intended to increase production from 195,200 mtpy of cathode to 227,000 mtpy over a 3-year period. Part of this production increase would come from increasing current density. During the period from 1994 to 1997, current density at the Ilo Refinery was increased from 218 A/m2 to 230 A/m2, while plant efficiencies were maintained at consistently high levels. The current efficiencies were maintained at >97.5% and time efficiencies were maintained at >98%. During 1998, additional increases in current density were implemented while the high plant performance was maintained at the same levels. By the end of 1998, the current density was 241 A/m2, while current efficiency and time efficiency of 98% were maintained. This paper describes the control processes used at the Ilo Refinery to maintain high plant performance levels while increasing the current density. Additionally, expected plant performances from extended test programs at current densities up to 280 A/m2, for future production increases, are reviewed and discussed.

Hydrometallurgy: Biohydrometallurgy

Tuesday AM Room: Hopi
October 12, 1999 Location: Pointe Hilton Resort

Session Chair: Corale Brierley, Brierley Consultancy LLC, Highlands Ranch, CO 80163 USA

10:30 AM

Copper Bioleaching: State-of-the-Art: *Corale L. Brierley*[1]; James A. Brierley[2]; [1]Brierley Consultancy LLC, P.O. Box 260012, Highlands Ranch, CO 80163 USA; [2]Newmont Metallurgical Services, 10101 E. Dry Creek Rd., Englewood, CO 80112 USA

Bioheap leaching, commercially applied for secondary copper ores and agglomerates, is rapidly gaining popularity. Bioleaching of chalcopynite concentrates is imminent. Copper bioheap leaching encompasses the bioleaching of acidified and agglomerated coarse, secondary copper ore, stacked on permanent or on/off pads. The stacked ore is irrigated with raffinate containing bacteria. LME-grade cathode copper is produced by SX/EW. Low capital and operating costs, rapid start-up, environmental benefits, operational simplicity and a good performance record make bioheap leaching an attractive technology. This paper looks at the state-of-the-art of copper bioheap leaching and chalcopyrite concentrate leaching, the risks, the benefits, costs, bioheap performance and the future prospects of copper bioleaching.

10:55 AM

Bacterial Heap Leaching of Covellite: *Sergio Bustos*[1]; Romilio Espejo[1]; Cecilia González[1]; Randolph E. Scheffel[2]; [1]Lakefield Research Chile S.A., Los Ebanistas 8585, La Reina, Santiago, Chile; [2]Metallurgical Consultant, 25778 Summergreen Ln., Golden, CO 80401 USA

Covellite resulting from an original 0.5 % Cu(tot) chalcocite ore has been leached in columns at different temperatures, in the lower range of 10 - 20ϒC, under acid-ferric bacterial leaching conditions. Dissolution of copper from covellite depends on the rate and extent of sulfide oxidation by ferric ion. While it is recognised that the dissolution of sulfide minerals is electrochemical in nature, an apparent chemically controlled dissolution pattern was measured with activation energy of 78.09 kJ/mol (18.66 kcal/mol). Ferric iron is the main oxidant and its production and availability will depend on the bacterial activity developed in the system. This activity is characterised by the population size and by the specific oxidation rate of the bacteria. Bacterial growth was followed directly by the number of bacteria appearing in the column effluent solutions and indirectly by the generation of ferric iron or by the total oxidation observed in the columns. These results have been interpreted by using the heap oxidative capacity parameter, which indicates an equivalent ferric production of about 0.07-0.15 kg Fe^{+3}/t/day at 20ϒC. Although bacterial activity decreases to about 0.03 kg Fe^{+3}/t/day with decreasing temperature, a significant bacterial oxidation is still observed at 10ϒC. However, extended lag times are observed, which delay the start of bacterial growth to times concurring with covellite leaching. Under these conditions, bacterial activity is displayed through a population controlled by the rate at which ferrous iron is released from the reducing covellite surface. These results suggest the potential benefit of including some kind of inoculation when operating at lower temperatures. Also, heat loss control and/or heat addition to the heaps should be considered during process design and operation of ferric bacterial heap leaching of secondary copper sulfide ores at temperatures lower than 20ϒC.

11:20 AM

Bioleaching of Chalcopyrite in the Presence of Silver: Solids Characterization: A. Alvarez[1]; M. Luisa Blazquez[1]; *Antonio Ballester*[1]; Felisa Gonzalez[1]; E. Salinas[2]; Monserrat Cruells[3]; Antonio Roca[3]; [1]Universidad Complutense, Dept. Ciencia de Materiales, Facultad de Ciencias Quimicas, Madrid 28040 Spain;

[2]Universidad Autónoma de Hidalgo, Instituto de Ciencias de la Tierra, Pachuca, Hidalgo, Mexico; [3]Universidad de Barcelona, Dept. d'Enginyeria Quimica i Metallurgia, Facultat de Quimica, Marti i Franques 1, Barcelona 08028 Spain

In this work, mesophilic and thermophilic cultures have been used in the presence of silver as a catalyst. Chalcopyrite and byproducts of bioleaching were characterized in order to: a) obtain information about the kinetics control of the process, and b) explain the different behaviour observed during the mineral attack. With thermophilic microorganisms (68ϒC and Norris medium as nutrient) the reaction stopped at approximately 65% copper extraction, with and without Ag ion addition as a catalyst. The remaining chalcopyrite appears surrounded by hydroniurn jarosite (with ammonium ion in substitution in the "alkaline site"), goethite and elemental sulphur. With mesophilic cultures (35ϒC and 9K medium as nutrient) the reaction stopped at approximately 25% copper extraction (without Ag) and approximately 85% extraction (with Ag). In both cases, the remaining chalcopyrite was surrounded by agglomerates of ammonium jarosite (with hydronium ion substitution in the "alkaline site") and some iron oxides and/or hydroxides.

11:45 AM

The Application of Bacterial Sulfate Reduction Treatment to Severely Contaminated Mine Waters: Results of Three Years of Pilot Plant Testing: *R. W. Hammack*[1]; H. Dijkman[2]; [1]U.S. Dept of Energy, Fed. Energy Tech. Ctr., P.O. Box 10940, Pittsburgh, PA 15236 USA; [2]Paques BV, Balk, The Netherlands

Results for the treatment of a problematic mining wastewater using bacterial sulfate reduction (BSR) are presented. Specifically, a BSR pilot treatment plant (250 L per day) was used to treat Berkeley Pit simulant to discharge standards with the selective recovery of separate Cu-and Zn-sulfide concentrates. Concentrates recovered in these tests contained greater than 50% of the target metal and met specifications for sale to existing smelters. The biological component of the treatment was found to be surprisingly robust. Scaling and solid/liquid separation problems were encountered but considered normal for sulfide treatment. For Berkeley Pit water, capital costs for BSR treatment was found to be comparable to high-density sludge lime treatment. The value received from the sale of recovered copper and zinc concentrates paid for all the operating costs.

12:10 PM

Biotechnology in the Mining and Metallurgical Industries: Costs Savings through Selective Precipitation of Metal Sulfides: H. Dijkman[1]; *C. J. N. Buisman*[1]; H. G. Bayer[2]; [1]Paques Bio Systems B.V., P.O. Box 52, AB Balk NL-8560 The Netherlands; [2]Kennecott Utah Copper Corporation, P.O. Box 112, Bringham Canyon, UT 84006-0112 USA

The PAQUES Bio Systems' core technology, marketed under the name THIOPAQ , consists of various high-rate biological processes for metal-sulfur-water systems, complemented with common solid/liquid and gas separation steps. Sulfur species are converted to sulfide, which is a valuable component as it can be used for metals reduction and precipitation. Selective recovery of valuable metals can be employed, leading to revenue from metal values. In this paper, biotechnological systems for the treatment of metal sulfate solutions and dilute SO_2 gases are described. These installations can be designed to either produce predominantly aqueous (NaHS) or gaseous (H_2S) sulfide. The emphasis here is on hydrogen sulfide gas. The main case history discussed is the demonstration plant that ran on hydrogen gas at Kennecott Utah Copper. Three years of operating experience clearly show that sulfate reduction with hydrogen gas is a viable option. Furthermore, the selective recovery of copper from leach water with the hydrogen sulfide produced was shown to be very effective.

Mineral Processing: Operations II

Tuesday AM Room: Jerome
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: Scott Bird, Kennecott Copper Company; Damon Fisbeck

10:30 AM

A Simulator for Crushing - Screening Plants: *George Grandy*[1]; Cristian Araya[2]; [1]Kvaerner Metals E&C, Dept. of Tech., 12657 Alcosta Blvd., San Ramon, CA 94583 USA; [2]Kvaerner-Metals E&C, Tech. Dept., Nva. Tajamar 481, p.19, Santiago, Chile

Kvaerner experience is being used to develop software to design or simulate crushing and screening plants. The model techniques discussed are presently being used for open-circuit plants and are being extended to closed circuit plants. The program contains a library of routines, each representing a piece of equipment or unit operation, which are assembled into one of several open-circuit plant configurations. Routines include gyratory primary crushers; standard secondary and shorthead tertiary cone crushers; single, double or triple deck screens; and stockpiles, feed bins and belt conveyors. The program uses steady-state models to simulate the performance of crushers and screens that have small residence times and quickly reach equilibrium when operating conditions and/or parameters are changed. The dynamic aspect of the total circuit model concerns the storage units within the circuit, i.e. stockpiles and bins, and, in the closed circuit configuration, circulating loads and size distributions. In many cases, just vendor's catalog data are necessary for a pre-feasibility simulation; in other cases, actual plant test data are required to obtain more accurate simulations. The entire plant is shown in a single graphic screen so the user can see all the relevant information he might want, and soft-keys are provided for the user to make on-line parameter changes and observe the effects on storage elements, equipment feed rates and the final product size distributions. The model also reports equipment utilization in percentage, power consumption, and other related operating information, and soon, will be able to report estimated capital and operating costs.

10:55 AM

Magnetic Collection of Grinding Ball Fragments from SAG and Ball Mill Circuits: *Daniel A. Norrgran*[1];

Michael J. Mankosa[1]; [1]Eriez Manufacturing Company, P.O. Box 10608, Erie, PA 16514-0608 USA

Grinding ball fragments discharging from SAG mills and ball mills causes extreme wear to downstream processing equipment. These ball fragments, recirculating in a milling circuit, will cause excessive wear to sumps, pumps, hydrocyclones, and interconnecting piping. A magnetic separation system to remove grinding ball fragments from the mill discharge has been developed and successfully applied in the milling circuit. This magnetic separation system—termed Trommel Magnet—was first applied at the Escondida copper concentrator in Chile. The Trommel Magnet consists of an arc of permanent magnets mounted at the discharge end of the trommel screen. The magnetic arc attracts the ball fragments and removes them from the process stream. This retrofitted magnetic separation system removed 126 metric tons of ball fragments from the circulating load of a single ball mill in the initial 24 hour period. The mill has since stabilized and the magnetic separator is currently removing 7 metric tons per day of ball fragments. The retrofit of the Trommel Magnet has: 1. Extended the pump life and the hydrocyclone life approximately 300 percent; 2. Provided a 5 percent increase in the throughput of the mills by removing grinding ball fragments that contribute very little to the grinding process. Variations of the Trommel Magnet have also been developed for removing grinding ball fragments directly from the mill discharge without the use of a trommel screen. In each case, permanent magnets are used to collect the ball fragments from the mill discharge stream prior to reporting to the sump. These other systems have been designed and fabricated for in-plant test work.

11:20 AM

Milling for the Millennium: *Stuart M. Jones*[1]; R. Fred Pena[1]; [1]Svedala Industries, Inc., Grinding Div., 240 Arch St., York, PA 17405 USA

This paper describes the state of the art of grinding in the Copper Industry today including descriptions of the largest equipment and design features which allow processing of as much as 100,000 mtpd in a single mill line. We include a typical flowsheet, control philosophies, and maintenance techniques which result in low cost production which is essential in today's market.

11:45 AM

Metal Seated Ball Valves for the Flow Control of Abrasive Fluids: *Malcolm J. Harrison*[1]; [1]Valvtechnologies, Inc., Mining & Minerals Processing, 5904 Bingle Rd., Houston, TX 77092 USA

The problems associated with the flow control of abrasive slurries and solids laden fluids creates reliability problems in many mining operations. Conventional valves such as pinch, knife gate and plug types cannot always function reliably in such harsh operating environments. Due to the technological advances in the hard coating industry, ball valves can now be produced with internal surfaces protected from the erosive effects of these applications. Pressures well in excess of the capability of conventional 1000 kPa working pressure valves can now be handled reliably. The significant advantages of minimizing down-time and lowering maintenance costs can now be realized with metal seated ball valves.

12:10 PM

Next Generation Sedimentation Equipment for Ultimate Thickening: *Alex Probst*[1]; Jim Bowersox[1]; [1]Dorr-Oliver, Inc., 333 South Allison Pkwy., Suite 304, Denver, CO 80226-4656 USA

With low metal prices and increasing value placed on plant water and tailings disposal areas, it is becoming essential to maximize the efficiency of solid-liquid separation processes. Since its inception over 25 years ago, the use of flocculants has grown exponentially. While flocculants play a crucial role in the sedimentation process, they are also a major operating cost. Recent innovations are revolutionizing the industry once again. New thickener designs are doubling thickener-loading rates while reducing flocculant consumption. The feedwell, as the heart of the thickener, is undergoing many significant metamorphoses. With CFD and other advanced computational analysis, feedwell technology is being examined more thoroughly than ever before. The result is that the thickener previously thought of, as a "Black Box" is now being mapped and controlled with state-of-the-art technology. This paper will examine recent design improvements in all aspects of thickeners in order to project the look of the thickener of tomorrow.

Pyrometallurgy-Operations: Session III

Tuesday AM Room: Estrella
October 12, 1999 Location: Pointe Hilton Resort

Session Chair: Patricio Barrios, Atlantic Copper, Avda. Francisco Montenegro s/n, Huelva 21001 Spain; G. A. Eltringham, BHP Copper Smelting and Refining, 200 South Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA

10:30 AM

Copper Metallurgy at the KGHM Polska Miedz S.A. - Present State and Perspectives: *Józef Czernecki*[1]; Zbigniew Smieszek[1]; Zdzislaw Miczkowski[1]; Jerzy Dobrzanski[2]; Marian Warmuz[2]; [1]Institute of Non-Ferrous Metals, ul.Sowinskiego 5, Gliwice 44-100 Poland; [2]KGHM Polska Miedz S.A., ul. M.C. Sklodowskiej 48, Lubin 59-301 Poland

The Polish copper concentrates are characterised by low content of sulphur and iron. At KGHM Polska Miedz S.A. two copper production technologies are in use. The shaft furnace process is used at the Legnica Copper Smelter and the Glogow I Copper Smelter. A single-stage direct to blister Outokumpu flash smelting process is used at the Glogow II Copper Smelter. Melting copper concentrates in the shaft furnaces is carried out in a reducing atmosphere and the product obtained is a matte. Instead, a result of melting copper concentrates by an oxidising flash process blister copper of a quality similar to that of converter copper is obtained. The annual copper production at KGHM Polska Miedz S.A. excedes 450,000 tons. Another important metal is silver produced from slimes from copper electrolysis (about 1000 t/y). Moreover, such metals as Pb, Ni, Se, As, Au and other precious

metals, including Pt and Pd, are recovered from various semiproducts. This paper presents technological flow sheet of the copper production in plants using the shaft furnaces and in another plant in which a single-stage flash process is applied. Characteristics of products, methods of their utilisation, main parameters of particular technological operations, and advantages and shortcomings of the solution applied are presented. There are also discussed the natural environment protection as well as directions of the KGHM Polska Miedz S.A. plants modernisation.

10:55 AM

Breaking New Ground - Recent Developments in the Smelting Practice at ZCCM Nkana Smelter, Kitwe, Zambia: *Godwin Beene*[1]; Enock Mponda[1]; Milton Syamujulu[1]; [1]Zambia Consolidated Copper Mines Limited, Nkana Smelter, P.O. Box 22000, Kitwe, Zambia, Central Africa

During recent years, copper and acid production from Nkana Smelter has formed a significant proportion of ZCCM's total output, but a number of problems affecting the smelter over the last decade have only been recently overcome. This paper discusses recent developments in the smelting practice, highlighting some of the operational problems experienced and associated solutions. The smelter performance over the decade is discussed and the innovations in the smelting technology employed to sustain production in the wake of limited re-capitalization are dealt with in detail.

11:20 AM

Competitiveness of the Outokumpu Flash Smelting Technology - Now and in the Third Millennium: *P. Hanniala*[1]; L. Helle[1]; I. V. Kojo[1]; [1]Outokumpu Engineering Contractors Oy, P.O. Box 862, Espoo FIN 02201 Finland

In the day-to-day life the copper business of today is influenced directly by the ever-increasing general concern about the environment. In addition to that the inherent shortcomings of the copper smelting business, have since many years been the falling real price level of the metals and the relatively high initial capital investments required for the production units. These shortcomings have been compensated for by high productivity, low specific operating costs, low metal inventory and unbeatable technological superiority. Thus today more than 50% of the world primary copper is today produced by utilizing Outokumpu Flash Smelting Technology. This figure is expected to grow at an increasing speed in the near future. Characteristic for the Outokumpu Flash Smelting technology is high flexibility for a wide grade of concentrates and the highest sulfur capture owing to at the same time competitive investment and operational costs. The Flash Converting technology offers new options for copper production and optimization of the mine-concentrator-smelter production chain. In the following years it is expected that the trend in copper making is that higher grade concentrates are produced at the mines. Thus increasing amount of high grade concentrate will be available for direct-to-blister Flash Smelting causing an overall cost reduction in copper smelting i.e. both in capital and operational costs. In the 90's new technologies based on Outokumpu Flash Smelting technology have been taken into operation, thus eliminating the noncontiguous Peirce-Smith converting process step. New innovative solutions have been used in the latest projects, as in Kennecott Utah Copper, where the new Kennecott-Outokumpu Flash Converting process was started up in 1995. Also, in 1995 the new DON process was started at Outokumpu Harjavalta nickel smelter followed by the Fortaleza nickel smelter in Brazil in 1997. The aim of the continuous development work at Outokumpu has been the expansion of the direct-to-blister process towards lower grade concentrates. The most recent example of this is the start-up at the Olympic Dam smelter in Australia, where the existing direct-to-blister Flash Smelting furnace was replaced with a new one having a capacity of 200 000 t blister copper per annum in just one smelting step.

11:45 AM

Developments in Direct-to-Blister-Smelting at Olympic Dam: *Arthur G. Hunt*[1]; Steven K. Day[1]; Rosalind G. Shaw[1]; Robert C. West[1]; [1]WMC Resources Limited, Olympic Dam Operations, P.O. Box 150, Roxby Downs 5725 S. Australia

Smelting using the direct-to-blister process commenced at Olympic Dam on July 31, 1988. The unique nature of the Olympic Dam ore body led to the selection of the direct to blister smelting process. Significant improvement in the design of the furnace and the understanding of the fundamentals of the process and its operation has occurred in the 10 years of operation. The paper will discuss the operation of the #1 Smelter and the design, preparation for start up and early operating experience of the #2 Smelter.

12:10 PM

Expansion of Onsan Smelter: *J. H. Lee*[1]; S. W. Kang[1]; H. Y. Cho[1]; J. J. Lee[1]; [1]LG Metals Corporation, Onsan Plant, 70 Daejung-Ri, Onsan-Eup, Ulju-Kun, Ulsan 689-890 Korea

LG Metals Corporation started its 2nd smelter operation at Onsan along with the existing flash smelter on January 31, 1998. Onsan smelter has been producing about 140,000 tons of copper from concentrates with the flash smelting line since 1979. In accordance with an increase in domestic copper demand, LG Metals Corporation decided to expand smelting and refining capacity by introducing 2nd smelter line using the Mitsubishi continuous process and a new tankhouse in 1995. After two years' expansion works consisting of engineering, procurement, construction and a successful commissioning test, the total smelting capacity of Onsan smelter increased to 340,000 tons of copper from concentrates. This paper describes the smelting facilities, operation result, problems encountered and improvements during the start-up and early operation of Onsan's new smelter.

12:35 PM

First Year of Operation of the Noranda Continuous Converter: Y. Prévost[1]; *R. Lapointe*[1]; C. A. Levac[1]; D. Beaudoin[2]; [1]Noranda, Inc., Horne Smelter, P.O. Box 4000, Rouyn-Noranda, Québec, Canada J9X5B6; [2]Noranda, Inc., Technology Center, 240 Hymus Blvd., Pointe-Claire, Québec, Canada H9R 1G5

The Noranda Continuous Converting Process was commissioned in November 1997 at the Horne Smelter at Rouyn-Noranda, Québec, Canada. It has completed over 18 months of successful operation. Excellent team work and technical expertise contributed

to achieve targeted production levels and environmental goals after only a few months of operation. The operating results have demonstrated the flexibility of the process in producing blister copper from a variety of copper feed materials including a combination of molten and solid copper matte, reverts and fluxes. This paper describes the startup activities and process optimization tasks performed during the first year of operation of the new Noranda Converter.

Smelting: Technology Development, Process Modeling and Fundamentals: Process Modeling and Control I

Tuesday AM Room: Goldwater
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: Carlos Landolt, Inco Limited, Ontario Division, Sudbury, Ontario, Canada; Larry Southwick, L. M. Southwick & Associates, 992 Marion Ave., Suite 306, Cincinnati, OH 45229 USA

10:30 AM
Real Time Data Management to Improve Productivity of Mining & Metallurgical Operations: *O. A. Bascur*[1]; J. Patrick Kennedy[2]; [1]OSI Software, Inc., Houston, TX USA; [2]OSI Software, Inc., San Leandro, CA USA

Applying the latest information technologies in mining and metallurgical complexes has become a serious challenge to management and technical teams. Emerging component design is changing the way the user relates to the desktop. Connectivity between mining and metallurgical process operations and their business systems has become a reality. Expanded use of plant information on the desktop is a standard tool for revenue improvement, cost reduction and adherence to production constraints. The industrial component desktop support access to information for continuous improvement and innovation by staff personnel and engineers. Collaboration between groups enables the implementation of an overall process effectiveness index based on losses due to equipment availability, production recovery and quality rate. The integration of information from mining, mineral processing and metallurgical performance monitoring increases production efficiency, even when many elements cannot be measured directly. Three case studies of large mining/metallurgical complexes are highlighted.

10:55 AM
Databases and Software for Thermodynamic Simulation of Copper Smelting and Converting: *Sergei A. Degterov*[1]; Arthur D. Pelton[1]; Manuel Zamalloa[2]; [1]École Polytechnique de Montréal, Ctr. de Recherche en Calcul Thermochimique, C.P. 6079, Station Centreville, Montréal, Québec, Canada H3C 3A7; [2]Noranda Technology Center, 240 Hymus Blvd., Pointe-Claire, Québec, Canada H9R 1G5

A thermodynamic database for the slag, matte and liquid copper phases in the Cu-Ca-Fe-Pb-Zn-Si-O-S system has been developed for the ranges of compositions of importance to the production of copper. When used with the Gibbs energy minimization software and other databases of the F*A*C*T thermodynamic computing system, this database will permit the calculation of matte-slag-copper-gas phase equilibria that take place during copper smelting and converting. The calculations reproduce within experimental error limits all available experimental data on phase diagrams, activities of components, enthalpies of mixing, matte - alloy miscibility gap and tie-lines. The calculated solubilities of Cu in both S-free slag and slag equilibrated with matte are also in good agreement with experiment under all studied conditions, such as at SiO_2 saturation, in equilibrium with Fe, Cu or Cu-Au alloys, at fixed oxygen or SO_2 partial pressures and at different contents of Pb, Zn and CaO in the slag. Sulfide contents (sulfide capacities) of the slags are predicted within experimental error limits. The distribution of Pb and Zn among matte, slag, copper and gas has been calculated. The calculations are in good agreement with experimental data and predict the distributions under conditions which are difficult to study experimentally, such as at magnetite saturation or under various oxygen partial pressures and iron to silica ratios in the slag.

11:20 AM
Thermochemical Modeling of Smelting Operations: *Alastair L. Davies*[1]; John F. Castle[1]; Philip J. Gabb[1]; Marielle A. S. Siraa[1]; John A. Gisby[2]; A. J. Weddick[3]; [1]Rio Tinto Technical Services, P.O. Box 50, Lower Castle St., Castlemead, Bristol BS99 7YR UK; [2]National Physical Laboratory, Centre for Mats. Measure. and Metrology, Queens Rd., Teddington, Middlesex TW11 0LW UK; [3]Kennecott Utah Copper Smelter, 12000 West 2100 South, Magna, UT 84011 USA

The MTDATA computer software package consists of a rigorous implementation of an algorithm for calculating chemical phase equilibria by the technique of Gibbs free energy minimization and a database of the thermochemical properties of common materials, such as slags, mattes, metals, gases and aqueous solutions. We have used MTDATA to contribute to our understanding of the chemical reactions occurring in several specific unit operations of the Kennecott Utah Copper Garfield Smelter. The following two examples illustrate the range of environments to which the method is applicable. Calculation of the liquidus phase relations of the FSF fayalite and FCF calcium ferrite slags helped in the early diagnosis of several operating problems. Calculation of the deportment of fluorine between the FSF offgas and the FSG scrubber liquor helped in the identification of operating conditions under which significant hydrogen fluoride concentrations could be introduced to the contact section of the acid plant. Without the painstaking assessment of solution phase properties undertaken over many years, these calculations would not be possible.

11:45 AM
Process Modeling for KUCC Smelter Studies and On-Line Furnace Control: *Marielle A. S. Siraa*[1]; Alastair L. Davies[1]; Philip J. Gabb[1]; A. J. Weddick[2]; [1]Rio Tinto Technical Services, P.O. Box 50, Lower Castle St., Castlemead, Bristol BS99 7YR UK; [2]Kennecott Utah Copper, Smelter, 12000 West 2100 South, Magna, UT 84044 USA

A program of work was undertaken at the Kennecott Smelter and Refinery to model the com-

plex. This effort contributed a total of eight models of the plant: flash smelting furnace, flash converting furnace, slag concentrator, anode furnace, offgas scrubbing system, acid plant, hydrometallurgical dust treatment plant, and the precious metals plant. Some of these models have been used in a variety of investigations ranging from offgas capacities for a steam generation analysis to an examination of impurities. The culmination of this enterprise has resulted in an on-line control scheme for the flash smelting and flash converting furnaces. These two process control schemes incorporate their respective steady-state heat and mass balances that are executed in response to feed changes while a feedback loop calculates when product grade and temperatures deviate from setpoints. This system has been put into place to improve furnace control and on-line time.

12:10 PM

Quantification of the Dynamics of the Flash Smelter: I. H. Bonekamp[1]; *J. H. Groeneveld*[1]; M. A. Reuter[1]; G. Gopos[2]; P. Kuhn[2]; A. Lossin[2]; P. Willbrandt[2]; [1]Delft University of Technology, Dept. of Raw Mats. Proc., Mijnbouwstraat 120, Delft 2628 RX The Netherlands; [2]Norddeutsche Affinerie Aktiengesellschaft, Hovestrasse 50, Hamburg D-20539 Germany

Norddeutsche Affinerie has operated an Outokumpu type flash smelter for more than 25 years. In recent years, the concentrate smelting capacity was increased to 750,000 tpy, double of the initial design capacity. Maintaining this high performance level requires very good metallurgical process control. It is not enough to base this control on thermodynamics and kinetics since the furnace is highly dynamic. Understanding these dynamics and being able to quantify them can have significant financial benefits. A mass and energy balance model was developed and is discussed based on measured data. At this time the model is based on the major elements copper, iron, sulfur and silica. With it is possible to quantify the differences of the various material streams such as matte, slag, flue dust, matte carry-over to settling furnace, etc. Comparing the reconciled energy balance model with the fundamental thermodynamic model makes it possible to quantify the dynamics. These dynamics are related to input parameters using methods such as statistics and neural nets. In the future this database will be used to improve the understanding of the dynamic process as well as the dynamic process control.

12:35 PM

Software for the Analysis of Flash Smelting Data: *Serban Motoiu*[1]; [1]Institute for Nonferrous and Rare Metals, Heavy Metals Lab., 102 Biruintei Blvd., Bucharest 73856 Romania

Data acquisition is widely used for controlling flash smelting furnaces. A Romanian smelter from which a large amount of data can be collected uses such a technique. A computer program was developed for interpretation of the data. Inputs to the program are the process data files. Abnormal data are identified using standard statistical techniques; they can be edited if necessary. The following methods can be used for the analysis: linear correlation (single or multiple), polynomial correlation or comparison of two average values. Time variation graphs and histograms can be displayed. The random balance method was used for determination of significant parameters influencing the process performance. Not all process parameters are recorded, and some of them are not even measured. The software can compute some of these parameters such as: air flow rate required and the oxygen content of the gas exiting the reaction tower. The software was used for the interpretation of a large amount of process data. The analysis showed that the process did not operate properly at some times.

Smelting: Technology Development, Process Modeling and Fundamentals: Gas Handling

Tuesday AM Room: Flagstaff
October 12, 1999 Location: Pointe Hilton Resort

Session Chair: Carlos Diaz, University of Toronto, c/o Dept. of Metallurgy and Matls. Sci., Toronto, Ontario, Canada

10:30 AM

Optimization of Smelter Off-Gas Handling System: *B. C. Curson*[1]; A. A. Shook[1]; [1]BHP Copper Smelting and Refining, 200 South Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA

A comprehensive simulation of the gas handling system in BHP Copper's San Manuel smelter was developed using AFT Fathom software, with the objective of minimizing SO_2 emissions while maximizing smelter throughput. Once verified with plant data, the simulation quickly revealed the complex interactions occurring between individual converters and the flash furnace. The increased understanding provided by the simulation allowed novel, counter-intuitive control strategies to be developed and tested successfully.

10:55 AM

Comparative Productivity and Quality Evaluation of Copper Smelting Gas Cooling Techniques: *Rene Bustamante*[1]; Jaime Fernandez[1]; [1]Universidad de Santiago de Chile, Depto. Ingenieria Metalúrgica, P.O. Box 10233, Santiago, Chile

The subject of this paper is a comparative evaluation of different copper smelting gas cooling techniques, using "productivity and quality" criteria. The first section presents a brief description of the operation of the radiant and the evaporative cooling systems, focusing on the differences between each other, in particular regarding: a) mass and energy balances; b) gas flow, temperature and composition; c) dust concentration and recovery. This section includes a brief discussion of the "client-server chain," i.e. the links between the cooling equipment and the down- and up-stream operations. More in particular, the up-stream server relationship impacts on the operating stability of the furnace, and in turn on furnace down-time and Cu production losses; and the down-stream client relationship affects the operation of the electrostatic precipitators, in terms of workload and cost of handling larger quantities of dust of a given dust

size. The second section deals with the development of indexes to measure and compare value added through the "utilization, productivity and quality" that can be expected of both cooling methods at the physical and economic levels, and the impact on the overall smelter productivity and the final cost composition of copper. The final section presents the results and includes a discussion of the comparative advantages and disadvantages of both cooling systems.

11:20 AM

Alkaline Arsenic Leaching from Smelter Flue Dust and Leaching Solution Regeneration: *Antelmo V. Robles*[1]; Ana E. Serna[1]; Manuel A. Sández[1]; [1]Mexicana de Cobre, S.A. de C.V.; Complejo Metalúrgico, Dept. de Investigación y Nuevos Procesos, Carr. Nacozari-Agua Prieta Km 21.5, Nacozari, Sonora 84340 México

The main goal of the present work is to propose a viable alternative for selective arsenic elimination from copper smelter flue dust without the need of a global leaching scheme for all the individual components of the flue dust. Using this alternative, the inherent copper recovery problems are avoided. Arsenic precipitation is also considered for regenerating the solution and completing the process cycle. The experimental results for arsenic extraction and precipitation are satisfactory. Concentration of NaOH used was relatively low. The main reason for succeeding in high arsenic extraction and low NaOH consumption is due to the previous water washing of the flue dust. Water washing dissolves much of the iron and copper that are present in certain percentage as sulphate.

Copper Applications and Fabrication: Applications - I

Tuesday PM Room: Copper
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: K. Kundig, Metallurgical Consultant, 2 School House Rd., Randolph, NJ 07869 USA; H. Larravide, PROCOBRE-Chile, Santo Domingo 551, 2° Piso, Santiago, Chile

2:00 PM

The Copper Motor Rotor and Plastic Injection Molds - New Developments Relying on Copper's Conductivity: *Dale T. Peters*[1]; John G. Cowie[1]; [1]Copper Development Association, Inc., 260 Madison Ave., 16th Floor, New York, NY 10016 USA

Conductivity, both electrical and thermal, are attributes accounting for about 70% of the applications of copper and its alloys. This paper presents results of on-going research into two new applications that depend on copper's excellent conductivity. The Copper Development Association (CDA), together with materials and motor company partners, is working toward a solution to the key problem preventing pressure die casting copper for the conductor bar/end ring structure of the induction motor rotor, i.e., lack of a durable high-temperature mold material. Work is showing that a combination of high-temperature materials and elevated temperature processing gives much improved mold life compared to die steels. Substitution of copper for aluminum in the rotor can result in a 20% decrease in electrical losses in motors consuming 35% of electrical power generated in the U.S. The second development uses the excellent thermal conductivity of several high-strength high-copper alloys to simultaneously improve productivity and part quality in the injection molding of plastic parts.

2:25 PM

A Review of Bismuth and Selenium Modified Copper Alloys for Plumbing Applications: *M. Sahoo*[1]; L. V. Whiting[1]; M. Sadayappan[1]; D. T. Peters[2]; [1]CANMET, Mats. Tech. Lab., 568 Booth St., Ottawa, Ontario, Canada K1A OG1; [2]Copper Development Association, 260 Madison Ave., New York, NY 10016 USA

The development of new alloys containing bismuth and selenium for potable water supplies are reviewed. The new alloys are replacements for the leaded red - and semi-red brasses by the low-lead alloys. SeBiLOYS I and II, for sand casting, and SeBiLOY III replaces the lead containing yellow brass, C85800, for permanent mold casting. As the new alloys use bismuth and selenium, the supply and demand of these elements are discussed. The key casting characteristics discussed are: tendency to dross formation, freezing range (liquidus and solidus temperatures), fluidity, resistance to hot tearing, microstructures, mechanical properties, machinability, grain refinement and corrosion behaviour.

2:50 PM

Influence of Environment on the Copper Patinas: *M. A. Llavona*[1]; A. M. Fernández[1]; J. L. Ibáñez[1]; R. Zapico[1]; [1]University of Oviedo, Dept. of Mats. Sci., U.S. of Mining and Topographic Eng., Reinerio Garcia s/n, Mieres 33600 Spain

The study of the formation and components of copper patina and its conservation has assumed great importance. The changing environment has accelerated the processes of patinas degradation; thus, the exhaustive study of factors capable of affecting the patina formation, growth and durability has assumed great importance for the industrial activity of copper. The main components of the patina, oxides, chlorides, nitrates and sulfates, have been determined; the effect of physical, chemical and microbiological factors on patina formation, particularly the influence of acid rain, natural organic matter, particles and microorganisms have been defined. The effect of different electrolytic solutions that accelerate the formation of copper patinas has been determined, and a review of the state of knowledge of the formation and evolution of metal patinas has been made.

3:15 PM

Copper for Long-Term Isolation of High Level Nuclear Waste: *Lars O. Werme*[1]; [1]Swedish Nuclear Fuel and Waste Management Company (SKB), P.O. Box 5864, Stockholm SE-102 40 Sweden

Already the KBS Project proposed copper as a suitable material for encapsulation of spent nuclear fuel. The basis for this choice was the thermodynamic stability of copper in water and the fact that deep granitic groundwaters in Sweden are oxygen-free. With a limited supply of oxidants, a copper canister would

have the potential for a very long service life. The research and development work aiming at encapsulating nuclear fuel entered a new phase in 1993, when SKB launched its Encapsulation Plant Project. Within this project, SKB has: designed a facility for encapsulation of nuclear fuel; laid down the design premises for a canister for disposal of nuclear fuel; tested and developed fabrication methods for copper canisters; evaluated the long term chemical and mechanical behavior of the canister; made preliminary plans for a factory for the production of copper canister; constructed a canister laboratory for full scale testing of the key operations in an encapsulation plant. The conclusions of this project were that a canister consisting of an outer layer (50 mm) of copper over an insert of cast nodular iron would provide sufficient corrosion protection and would have sufficient mechanical strength. This canister can be produced by several methods of which forming from rolled plates, hot extrusion, and "pierce and draw" have been tested at full scale. The canister will be sealed by electron beam welding in the encapsulation plant, and the integrity of the weld will be verified by ultrasonic testing and high-energy radiography. The final development work in this area will be performed in the canister laboratory.

3:40 PM Break

4:10 PM

Study of the Effect of Sulfide Ions on the Corrosion Resistance of Copper for use in Containers for High-Level Waste: *I. S. Escobar*[1]; E. Silva[1]; C. Silva[1]; A. Ubal[1]; [1]Comisión Chilena de Energia Nuclear, Amunategui N° 95, Santiago, Chile

Copper, particularly the oxygen-free grade Cu-OFP, is a candidate material for containers for the long-term isolation and disposal of high-level radioactive waste (HLW) in underground repositories. After having been buried for a few hundred years, all oxygen will have been consumed in the repository, and corrosion of the copper will be caused entirely by contact with dissolved sulfides. Chloride is another potential corrodant, but in deep repositories where groundwater is neutral or slightly alkaline, the effect of chlorides can be ignored on thermodynamic grounds. Thus, the corrosion of copper in the presence of sulfide ion and under reducing conditions has been studied using cyclic voltammetry and Tafel slope measurements. It is possible to determine the effect of sulfide ion on copper corrosion resistance which is minimized at low temperature and also at low sulfide concentration. The presence of anions such as HCO_3—under environmental conditions—produces a beneficial effect because these ions are inhibitors.

4:35 PM

A Spanish-Language Copper Information Database: *Helga Larravide*[1]; Konrad J. A. Kundig[2]; [1]Procobre-Chile, Metallurgical Consultant, Santo Domingo 551, 2° Piso, Santiago, Chile; [2]Metallurgical Consultant, 2 School House Rd., Randolph, NJ 07869 USA

A new on-line database of literature about copper has been created through a joint undertaking by the Copper Development Association, Inc. and PROCOBRE-Chile, with funding provided in part by the International Copper Association, Ltd. The new database will permit Spanish-speaking technologists to access publications maintained by PROCOBRE-Chile by means of standard keyword searches. In addition, a new Spanish-English thesaurus has been written to enable Spanish-speaking individuals to search and access the Technology and Environmental databases of the Copper Data Center, which together comprise more than 80,000 publications dealing with the production, properties, uses and environmental effects of copper. Planned expansion of the new Spanish literature database is described.

5:00 PM

Copper Industry Response to an Environmental Attack on Copper Plumbing Tube: *Dale T. Peters*[1]; William H. Dresher[2]; [1]Copper Development Association, Inc., 260 Madison Avenue, New York, NY 10016 USA; [2]WHD Consulting, 1201 E. Placita Ardilla, Tuscon, AZ 85718 USA

In the United States, the United Kingdom and numerous other countries, copper has long been the plumbing material of choice. This has been the case since the late 1920's in the United States and since World War II in the United Kingdom. However, in recent years the plumbing tube market has caught the eye of the chemical industry and several plastic resins have been introduced to the marketplace as substitutes for copper in household plumbing systems. One of these, polybutylene tube, had so many failures in the United States that a class action law suit was filed, and the manufactures of this product were forced to create a trust fund of nearly one billion dollars to repair damages caused by their product. Chlorinated polyviny-lchloride (CPVC), in rigid pipe form, on the other hand, has been mechanically acceptable albeit its recent introduction precludes the test of time enjoyed by copper tube in this application. This paper reviews the State of California's portrayal of copper's environmental effects and will be largely based on the data and information assembled by the Copper Development Association, Inc. in its presentation to the State of California in August, 1998 in response to the State's Draft Environmental Impact Report for Chlorinated Polyvinyl Chloride (CVPC) Pipe for Use for Potable Water Piping in Residential Buildings. The paper is intended to be used as a model for the use of other copper organizations and individuals in responding to similar situations.

5:25 PM

Copper Electrodes for Resistance Spot Welding of Aluminum: B. Fresz[1]; *J. R. Groza*[1]; S. Stefensen[1]; [1]University of California at Davis, Dept. of Chem. Eng. and Matls. Sci., Davis, CA 95616 USA

Before aluminum can be utilized in automotive bodies, the longevity of the electrodes employed in the resistance spot welding of aluminum must increase. This paper explores the affects of electrode composition on electrode life. To compare these variables, electrode tests were completed on a Taylor Winfield welding machine using, Cu-Cr, Cu-Zr, Cu-Cr-Zr, Cu-Be, and Glidcop® electrodes tested to 12.5%, 25%, 50%, 100% and 150% lifetimes. Electrode diameters were determined via a magnification technique using a PULNIIX video camera attached to a low magnification Wild Heerbrugg stereo-zoom microscope. From these measurements, graphs of electrode life versus face diameter and weld number versus face

diameter were created. Analyses of these graphs suggest that a single failure mechanism is responsible for electrode failure, though the number of welds until failure (100% electrode life) varied with composition (700-2000 welds).

5:50 PM

Progress Report on Development of a Cu-8 Cr-4 Nb Alloy Database for the Reusable Launch Vehicle (RLV): *David Ellis*[1]; Hee Man Yun[2]; [1]Case Western Reserve University, 10900 Euclid Ave., Cleveland, OH 44106-7204 USA; [2]Cleveland State University, 1983 East 24th St., Cleveland, OH 44115 USA

The next generation of Reusable Launch Vehicle (RLV) will utilize regeneratively cooled combustion chamber liners in the engines. The current design calls for using a new Cu-8 at.% Cr-4 at.% Nb (Cu-8 Cr-4 Nb) alloy for the liners. Work is ongoing to characterize the thermophysical and mechanical properties of the alloy from 253 to 800°C, the temperature range to which the alloy will be subjected to during service. The alloy has been commercially produced in quantity for NASA. The powder size has been characterized and the microstructure examined. The powder was extruded into bar using a commercial extrusion press. In addition, samples have been hot isostatically pressed (HIPed) at NASA Glenn Research Center. Both processing methods produced fully consolidated material. Transmission electron microscopy (TEM) revealed highly faulted Cr_2Nb and some elemental precipitates. Cryogenic tensile testing showed the extruded specimens had significantly higher strengths than NARloy-Z (Cu-3 wt.% Ag-0.5 wt.% Zr) even after being subjected to a simulated braze cycle. The Young's moduli (Cu-8 Cr-4 Nb) were lower than NARloy-Z. The lower moduli is highly beneficial for reducing thermally induced stresses in rocket engine combustion chamber liners and similar applications.

Electrorefining: Refinery Operations IV

Tuesday PM Room: Indigo
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: R. D. Hutcheson, Southwire Company, Copper Division, Carrollton, GA 30117 USA; R. Sanford, Kennecott Utah Copper, Refinery Plant, Magna, UT 84044 USA

2:00 PM

A New Starting Sheet Plant at the Toyo Copper Refinery and Productivity Improvements: O. Nakai[1]; *H. Sato*[1]; K. Kugiyama[1]; K. Baba[1]; [1]Sumitomo Metal Mining Company, Ltd., Toyo Smelter and Refinery, Besshi-Niihama District Div., Otu 145-1, Funaya, Saijyo, Ehime, Japan

In the copper electrorefining process, the quality of the starting sheet is one of the basic factors for producing high quality copper cathodes. A highly automated and advanced facility for the production of copper starting sheets was constructed at the Toyo Copper Refinery in 1992, bringing various improvements into an automatic stripping system using stainless steel mother blanks. In 1998, the refinery expanded the tankhouse by another 128 commercial cells, and introduced 64 polymer concrete cells in a first stage conversion. As a result, the Toyo Copper Refinery now has the capacity to produce 103,200 t/y of cathode copper. Construction has led to great improvements in the materials handling facilities and computer associated short-circuit detection technology. This report summarizes the improvements made in the quality of the cathodes and in plant productivity.

2:25 PM

Improvements in the Operating Practices at the Atlantic Copper Refinery: *P. Barrios*[1]; A. Alonso[1]; C. Ortiz[1]; [1]Atlantic Copper, S.A., Avda. Francisco Montenegro s/n, Huelva 21001 Spain

The copper refinery of Atlantic Copper was modernised and converted to the ISA permanent cathodes system in 1995. The technology installed has proved to be an excellent platform for the development of operational improvement. During the years it has been working, a progressive assimilation of the new technology has been achieved and the level of operator knowledge has allowed design production to be reached and surpassed by more than 10%. At the same time, modifications to work programmes using existing equipment, have permitted the incorporation of new cells and the achievement of annual production levels of 250,000 tonnes and productivity of 0.43 t/man-hour.

2:50 PM

Kidd Process Permanent Cathode Technology Advancements: *P. E. Donaldson*[1]; P. J. Murphy[1]; [1]Falconbridge Limited, Kidd Creek Business Development Group, Kidd Creek Metallurgical Division, Timmins, Ontario, Canada P4N 7K1

Since 1992, Falconbridge has made available to the international copper industry, Kidd Creek's licensed refinery process technology under the name of the Kidd Process. This has resulted in the supply and installation of permanent cathodes and associated product handling equipment to refineries in Canada, the United States, South Korea, Chile and Mexico. These installations accommodate both electrorefining and electrowinning process. The growth and industrial acceptance of the Kidd Process has generated technical advancements in the areas of product random sampling, corrugation, marking, labeling, product tracking and data acquisition. In a different area, the expanded development of custom materials processing at Kidd created a need to advance technologically. The process-related problem of high nickel concentrations in refinery electrolyte comprised an increase in current density to >300 A/m^2. The need for nickel removal resulted in Kidd Creek's newly developed Nickel Recovery System. The effective and economical extraction of nickel, along with reduced antimony and bismuth levels, reduces bleed stream volumes and/or neutralization costs and simultaneously produces a marketable nickel carbonate product.

3:15 PM

Teams that Work-Following the Gorilla's Lead: J. W. Holzenthaler[1]; *M. E. Yarish*[1]; [1]Phelps Dodge Mining Company, El Paso Operations, P.O. Box 20001, El Paso, TX 79998 USA

Teams continue to play a major role at the Phelps Dodge Mining Company El Paso Operations, espe-

cially during the present time of low copper prices. The El Paso Operations' teams have taken the initiative during this copper market downturn and have helped reduce operating costs significantly. Because of this, Phelps Dodge El Paso Operations has continued to grow within the team process by creating a total, non-exempt salaried workforce. In the last year alone, the El Paso Operations have implemented three major initiatives to accommodate the team process. The first was the creation of "Guiding Principles", a policies and procedures handbook. Second was the "zero and beyond" safety initiative. Third was team compensation. In addition, the Copper Products Company has now adopted a work-team environment, following in the lead of the refinery.

3:40 PM Break

4:10 PM
Studies on Copper Electrorefining by Factorial Design Methods - A Pilot Plant Experience: *E. M. Alcântara*[1]; [1]Caraiba Metais S.A., Via do Cobre n° 3700, A.I.O. - COPEC, Dias D'Ávila, Bahia, Brasil

This paper describes some aspects about the relationship between copper electrorefining addition reagents and the hydrogen in the cathode. The conditions of electrorefining were studied by factorial design methods. The advantages of this technique are reduction in the number of tests, well organized experiments, improvement in productivity and reliability of results. The dosage of the two main addition agents, glue and thiourea, were varied simultaneously and compared with the hydrogen content in the cathode. The influence of these factors, as well their interactions, were analyzed by statistical methods denominated ANOVA (Analysis of Variance). The increase of thiourea quantities, within of levels studied, influenced significantly at 95% confidence in the hydrogen content in copper cathode.

4:35 PM
Effect of Forced Convection of the Electrolyte on Copper Electrorefining in the Presence of Impurities: *T. Takasu*[1]; F. Noguchi[1]; H. Itou[1]; T. Nakamura[2]; [1]Kyushu Institute of Technology, Dept. of Mats. Sci. and Eng., 1-1 Sensui, Tobata, Kitakyushu 804-8550 Japan; [2]Tohoku University, Institute of Advanced Mats. Proc., Research Center Metallur. Process Eng., 2-1-1 Katahira, Aoba, Sendai 980-8577 Japan

Overall productivity in copper refining is currently determined by the electrorefining process. Previous research showed that forced convection of the electrolyte improves the morphology of the copper deposit on the cathode and suppresses passivation of the anode. In this paper, electrorefining experiments under forced convection were carried out in the presence of As, Sb and Bi impurities, both in electrolyte and in the anode, to determine the effect of the impurities on the electrorefining process. The concentrations of the impurities in the deposit increased with increasing current density without forced convection. An increase in the fluid velocity suppressed the increase in impurity concentration. These concentrations were high, especially in the initial stage of deposition without forced convection, corresponding to a decrease in the cathode potential measured during that period. This indicates that the enrichment of impurities was induced electrochemically. The reason for the decrease in cathode potential was the low concentration of copper ions on the electrode surface because of ion consumption by the electrolysis. The forced convection of the electrolyte enhanced the ionic mass transfer and thus suppressed the polarization and deposition of the impurities. The fluid motion was shown to be effective in achieving electrolysis under high current density conditions.

5:00 PM
Electrochemical Processing of Speiss: *V. A. Luganov*[1]; E. N. Sajin[1]; T. V. Chnyrenkova[1]; [1]Kazak National Technical University, Almatry 480013 ROKazakstan

During the treatment of raw materials containing arsenic and antimony, problems in the distribution of these elements in the process products occur. In a number of cases in processing of copper-bearing materials, it is possible (or necessary) to obtain speiss. The purpose of the present research is to study the theoretical aspects and analyze the technological possibilities of producing copper- bearing speiss and the subsequent electrometallurgical processing with copper extraction as well as arsenic and antimony utilization. Copper arsenide (Cu3As) and copper antimonide (Cu3Sb) are the main components of the speiss. A thermodynamic analysis of the electrochemical oxidation of Cu3As and Cu3Sb, carried out using Pourbaix diagrams, showed that in a pH range from 0 to 2, oxidation potential 0.45-0.55V, ions of copper and arsenic and antimony trioxide are in the equilibrium. The kinetic study has shown, that with an increase in the polarization potential, the dissolution process changes from chemical to diffusion control. An increase in temperature stabilizes the electrolysis process due to dissolution of arsenic trioxide forming on the anode. Electrolysis of speiss using a cathode diaphragm with the solution pH = 1-2, current density 150-200 A/m2 and temperature 60-70°C makes it possible to obtain cathode copper with a current efficiency of 95-96% and to remove the arsenic from the process during the electrolyte cleaning process. The arsenic content in the cathode copper did not surpass 0.002%. As the result of the research, a technological flowsheet for copper-lead speiss processing was developed. At the present time this technology is undergoing pilot testing.

Hydrometallurgy: Metal Extraction

Tuesday PM Room: Hopi
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: Albert Liguori, Oxidor, Dallas, TX USA; Sergio Bustos, Lake Research, Chile S.A.

2:00 PM
Copper Solvent Extraction Oxime Selectivity: Operational Experience at Girilambone Copper Company: *Kym A. Dudley*[1]; A. S. Moroney[1]; M.O. Braaksma[1]; D. J. Readett[2]; [1]Girilambone Copper Company, Booramugga Rd., Girilambone NSW 2831 Australia; [2]Straits Mining Limited, Level 3 Gold Fields House, 1 Alfred St., Sydney NSW 2000 Australia

Basic solvent extraction theory indicates that pH initiates the basis of an oxime's metal complex for-

mation and therefore its selectivity toward certain metal species. The recommended optimum pH for some of the commercial copper reagents is in a range that should maximise copper loading of the oxime. However, this pH range also tends to maximise iron(III) loading under certain operational conditions resulting in low selectivity values. Recent operational parameters at Girilambone Copper Company have highlighted some of these conditions that have a major influence on the oxime's selectivity for copper over iron(III) in the leach solutions. The result is that the pH for maximum copper extraction is no longer within the optimum range to maximise oxime selectivity. Therefore, specific copper and iron(III) pH isotherms have been determined on-site for the changing leach solutions that are fed to the solvent extraction plant in order to optimise oxime selectivity. The influences of solvent extraction plant configurations are also discussed as a controlling parameter.

2:25 PM

A Study of Copper/Iron Separation in Modern Solvent Extraction Plants: *D. C. Cupertino*[1]; M. H. Charlton[1]; D. Buttar[1]; R. M. Swart[1]; C. J. Maes[2]; [1]Zeneca Specialties, Specialties Rsch. Ctr., P.O. Box 42, Hexagon House, Blackley, Manchester M9 8ZS England; [2]Zeneca Specialties, Acorga Metal Extraction Products, 3259 E. Harbour Dr., Suite 100, Phoenix, AZ 85034 USA

Oxime based solvent extraction provides the user with a selective concentration process for copper prior to electrowinning. The selectivity required is largely for copper(II) over iron(III) and this is achieved by the preferential formation of the square planar copper-oxime complex in the organic phase. The copper/iron selectivity of oximes can however, be altered by modifiers or other types of oximes and may be enhanced in the presence of certain esters. Whilst the oxime based SX processes is important for operations leaching copper from laterite ores, the high selectivity will also be significant in processing streams arising from other leaching regimes which are currently under development, for example leaching of sulfide mineral ores. This paper presents some initial results using Molecular Modeling techniques to further our understanding of the nature of the copper/iron-oxime complexation processes together with some plant studies undertaken at a number of different mine sites investigating selectivity, and other properties, for some modified reagents. Some studies of the interfacial properties of the these systems are reported to explain in part the practical observations.

2:50 PM

Investigation of Evaporative Losses in Solvent Extraction Circuits: *M. D. Bishop*[1]; L. A. Gray[1]; M. G. Greene[2]; K. Bauer[2]; T. L. Young[2]; J. May[3]; K. E. Evans[4]; Illa Amerson-Treat[5]; [1]Phillips Mining Chemicals, 1768 Highway 123, Bartlesville, OK 74004 USA; [2]Versitech, Inc., 1438 W. San Lucas Dr., Tucson, AZ 85704 USA; [3]BHP Copper Company, 200 Reddington Rd., San Manuel, AZ 85631 USA; [4]EnviroNet, Inc., 7776 S. Pointe Parkway, W., Suite 160, Phoenix, AZ 85044 USA; [5]Oregon Graduate Institute, Dept. of Environ. Sci. and Eng., P.O. Box 91000, Portland, OR 97291-1000 USA

Loss of organic solvent extraction circuits occurs through several accepted methods. Losses are commonly attributed to entrainment of the plant organic and evaporative loss of diluent. Evaporative losses of diluent have been estimated using various models or by considering all losses over and above entrainment to be due to evaporation. Other possible loss mechanisms are discussed and data on losses during weather conditions are presented. Accurate estimation of evaporative loss is vitally important to the industry due to both cost factors and environmental concerns. Data for and description of the Diffusive Flux Model are presented as an improved method of estimating evaporative losses.

3:15 PM

Crud Formation: Field Studies and Fundamental Studies: *Michael J. Virnig*[1]; Stephen M. Olafson[1]; Gary A. Kordosky[1]; George A. Wolfe[1]; [1]Henkel Corporation, 2430 N. Huachuca Dr., Tuscon, AZ 85475 USA

The formation of crud is a normal part of operating a solvent extraction circuit for the recovery of copper. It periodically must be removed from the circuit. This results in significant costs in terms of manpower, downtime, and loss of circuit organic. Field studies have been carried out that show that the presence of a thermodynamic modifier in the organic phase contributes to crud formation. In an effort to better understand what factors contribute to crud formation, laboratory studies involving competitive adsorption studies with model solids have been carried out. The results of these laboratory studies will be integrated with the results of the field studies to present a better understanding of crud formation

3:40 PM Break

4:10 PM

Solvent Extraction - How to Get Over Hard Times: *Pertti Pekkala*[1]; Raimo Kuusisto[1]; Juhani Lyyra[2]; Bror Nyman[1]; Esa Lindell[3]; Eero Ekman[3]; [1]Outokumpu Engineering Contractors Oy, P.O. Box 862, Espoo FIN-02201 Finland; [2]Outokumpu Research Oy, P.O. Box 60, Pori FIN-28101 Finland; [3]Outokumpu Engineering Services Oy, P.O. Box 863, Espoo FIN-02201 Finland

Outokumpu has 25 years of experience in the SX area. The development of the solvent extraction plants responds to an ever increasing demand for lower operational costs and for adaptability to process disturbances with minimized risks. In this paper the features of the VSF ("Vertical Smooth Flow") SX technology are described, such as the separated pumping and mixing, the homogenous gentle mixing, the droplet coalescence and the ultra pure settling. A major advantage of the mixing technology is the high stage efficiency of above 99 per cent. The connection between this and some features of the settler front section is clarified. The present design of VSF plants is based on experience of existing operations at, for example, Zaldivar, Radomiro, Morenci, Kokkola and Harjavalta. These production plants cover a unit capacity range of 60 to 3,600 m^3/h expressed as a total flow. It is evident that there are no restrictive factors to increase the total flow up to 5,000-6,000 m^3/h by introducing the VSF technology. The copper SX technology has a long history reflecting many individual features of the separate copper SX plants. Still it is necessary to verify all actual running parameters by pilot tests taking into account impurities, chemicals used etc. The design of SX plants is not only about the delivery of equipment but also a process concept, and it is best tailor-made and adapted to specific local requirements.

4:35 PM
Pulsed Column Application in Copper Solvent Extraction: M. Curtis Nielson[1]; *Mark F. Vancas*[1]; [1]Bateman Engineering, Inc., 1860 E. River Rd., Suite 300, Tuscon, AZ 85718 USA

The paper describes the design and operation of pulsed columns as replacements for conventional mixer/settlers. The advantages, which the columns offer, include a reduction in real estate for the plant, elimination of diluent evaporation, containment of noxious vapors and reduced crud formation. In addition to the description of operation, the paper presents the findings of laboratory tests of pulsed columns extracting copper from pregnant leach solutions and also delineates potential advantages of the pulsed column in copper solvent extraction.

5:00 PM
Recent Advances in the Application of Molecular Recognition Technology (MRT) in the Copper Industry: John B. Dale[1]; *Neil E. Izatt*[1]; Ronald L. Bruening[1]; A. I. Reghezza[2]; J. Ch. Vergara[2]; J. A. V. Matta[2]; [1]IBC Advanced Technologies, Inc., P.O. Box 98, 856 E Utah Valley Dr., American Fork, UT 84003 USA; [2]Codelco, Chuquicamata Div., Chuquicamata, Chile

A primary objective of copper mining, smelting and refining operations is the cost-effective, efficient, and environmentally-acceptable control of the level of various metal ions throughout the processing and effluent treatment flowsheets. Effective ionic control maximizes product and by-product quality, allows for broad flexibility in sourcing impurity laden ores, minimizes capital and operating costs, and can achieve zero discharge operations. In order to meet increasingly stringent cost, environmental and product quality requirements, separation technologies are needed that can selectively remove and recover deleterious or valuable ions. Ideally, the subsequently obtained salts or metals can be recycled in the process, disposed of in an environmentally acceptable manner, or sold as valuable by-products. The use of MRT, a highly selective separations technology, has been demonstrated to be a cost effective, efficient, and environmentally-sound treatment for a wide range of cations and anions that are commonly found in copper electrorefining and electrowinning circuits, as well as in environmental treatment operations. These include heavy and transition metals, precious metals, halides and alkali/alkaline earths. This paper will review a number of areas of interest including: recovery and refining of platinum group metals from copper anode slimes, recovery of copper from acid mine drainage streams, extraction of Bi, Sb and Cl from copper electrorefining and electrowinning circuits.

5:25 PM
Direct Cementation and Dissolution of Copper in Di-(2-Ethylhexyl) Phosphoric Acid: *C. Flores*[1]; T. J. O'Keefe[2]; [1]BHP Copper, P.O. Box M, San Manuel, AZ 85631 USA; [2]University of Missouri-Rolla, Metallu. Eng. Dept., Matls. Rsch. Ctr., Rolla, MO 65401 USA

The direct cementation of copper from a loaded D2EBPA 20% vol. in kerosene using zinc, zinc-lead alloy and iron metallic powders was studied. Copper was loaded into the organic solvent from an aqueous copper sulfate solution. Results indicated that copper is reduced spontaneously with relatively fast reaction rates. The effects of several operating parameters such as water content in the organic system, initial copper concentration, reductant surface area, oxygen and nitrogen atmosphere, intensity of the agitation and temperature on the galvanic stripping of copper were studied. For a better understanding of the electrochemical reactions involved in the galvanic stripping, the dissolution of metallic copper in the organic solvent was also studied. Copper did not dissolve unless a small amount of water was present in the organic system. The results and possible reaction mechanisms are discussed.

Pyrometallurgy-Operations: Session IV

Tuesday PM Room: Estrella
October 12, 1999 Location: Pointe Hilton Resort

Session Chair: Pete Chen, Phelps Dodge Mining Company, Phoenix, AZ 85004-3014 USA; F. Puchi, Efepe, Ingenieros, Santiago, Chile

2:00 PM
Improving Smelter Performance through Development of People: *R. K. Hill*[1]; A. G. Ross[1]; [1]Phelps Dodge Hidalgo, Inc., P.O. Box 67, Playas, NM 88009 USA

The Hidalgo Smelter successfully reduced operating costs by 25% compared to the previous two years through a focused holistic approach to development of its entire workforce. The first phase involved basic team training skills for natural work teams. The second phase provided leadership training via breakthrough education to 40 of the smelter leaders-both hourly and salaried. The third phase stretched out the teams training to include rewards for performance that resulted in hourly teams converting to salaried status-part of a company wide initiative. The fourth phase saw 1998 become the "Year of Safe Cost Reduction" where 7 breakthrough projects focused on different areas of expenditure. Implementation of lean manufacturing as a tool for teams to truly get their arms around what they controlled, introduced accountability and responsibility for operating results at the team level. This will allow the release of experienced supervisors from this role, to a pool of technical expertise, where our future breakthroughs will be designed and implemented.

2:25 PM
The Copper Smelters of the 2010 - A Vision of the Future: *Sergio Demetrio*[1]; Nelson Santander[2]; Marco Solar[3]; [1]ConOpti S.A., Cerro San Ramon 1491, Las Condes, Santiago, Chile; [2]U. de Chile and U. Mayor, Dept. of Metallu. Eng., Santiago, Chile; [3]Masbing Ingenieria, Santiago, Chile

Based on the current reality of the copper smelters industry, besides the advances that have been and are expected for the next few years, the authors present a futurist vision of the processing of copper concentrates and copper smelters in the years 2000. Outlined new development strategies and ways of improvement in this business, including research, development and management of the works that today posses characteristics of a profitable operation, as well as the changes expected with respect to the

entry of new actors and the creation of new products. The authors finally bet for small or tailor-made smelters with ad hoc technology for their raw materials and few units to coordinate devoted to specific concentrates using high technology and low manpower. Considering the in-situ hydrometallurgical route, as well as the pyrometallurgical route in works or conversion facilities that buy or process white metal and produce copper and other metals associated with this such as gold and silver, besides sulfuric acid, plants which should be strategically located in zones with high sulfuric acid price to make this a product which contributes to the profitability of the business.

2:50 PM

Bath Smelting in the Noranda Process Reactor and the El Teniente Converter Compared: *Cameron Harris*[1]; [1]Kvaerner Metals, 12657 Alcosta Blvd., San Ramon, CA 94583 USA

Noranda's Process Reactor and Codelco's Teniente Converter are physically similar vessels, which leads to the commonly held misconception that the two processes are the same. However, notable differences in chemistry, operating philosophy, and construction make them quite dissimilar. This paper compares and contrasts the Noranda Reactor and the Teniente Converter, and attempts to explain some of the apparent differences in behavior and performance. The results of a worldwide survey of most operating Noranda Reactors and Teniente Converters, along with those processes that have ceased operation or are planning to be started-up in the future, are presented.

3:15 PM

1999 Rebuild of the BHP San Manuel Outokumpu Flash Furnace: *David M. Jones*[1]; Ray Cardoza[1]; Anthony Baus[1]; [1]BHP Copper North America, P.O. Box M, San Manuel, AZ 85631 USA

In May 1999 the first campaign of the BHP San Manuel flash smelting furnace (FSF) will be concluded after having set world records for both campaign length and tonnage smelted for an Outokumpu copper flash smelting furnace. This paper reviews planned process and equipment modifications including: the installation of a new 36,000 mt concentrate storage facility; replacement of the existing dryer electrostatic precipitator with a baghouse; modification of the FSF dry charge bin and feed system to achieve mass flow and uniform feed to the concentrate burner; modifications to the FSF and its ancillary cooling systems; modifications to the waste heat boiler and offgas handling system to increase gas handling capacity and improve process efficiency; and improvements to the FSF fugitive gas collection system. A brief review of the planning and execution of the scheduled 45 day shutdown is also given.

3:40 PM Break

4:10 PM

Optimization of the Blast Furnace Process in a Secondary Copper Smelter: *Andreas Nolte*[1]; Ralf Kreymann[1]; [1]Huttenwerke Kayser AG, Postfach 15 60, Lunen D-44505 Germany

In 1999, Huttenwerke Kayser AG (HK) plant in Germany will produce more than 180,000 t/y of electrolytic refined copper. To achieve this production from materials with copper grades from two to seventy percent and diverse copper alloys, HK operates three blast furnaces, one holding furnace, two Peirce Smith converters and two anode furnaces. Technical, metallurgical and economic factors for the ongoing process optimization are outlined. The fluctuating quality and quantity of raw materials renders complex this optimization. The principal variables are the quality and quantity of process consumables: coke, copper-iron, limestone, oxygen, as well as the blending of feedstock and a new organization of the operating crews. The search for new metallurgical process parameters is ongoing. HK started with an intensive research program in November 1997. As a result it will be possible to cut processing costs by about ten percent, to increase the blast furnace capacity by ten percent and to lower the metallurgical losses of copper and tin in the slag by more than ten percent. The presentation concludes with information of future steps to continue the optimization process.

4:35 PM

Distribution and Removal of Impurities in Copper Smelting in Guixi Smelter: *Yuan Zeping*[1]; [1]Jiangxi Copper Company, Yejin Ave., Guixi, Jiangxi 335424 ROC

The distributions of impurities in the copper melt, the slag and the gas phase in copper flash smelting process were under study in the Guixi smelter, particularly during operating conditions of high oxygen enrichment with production of high grade matte. Several methods for the removal of impurities such as As, Sb and Bi in the copper smelting process were developed and implemented at the Guixi smelter. This paper described the effects of high oxygen enrichment, elevated matte grade, high temperature and high production rate on the distribution of impurities, methods adopted at the smelter for the removal of impurities, and the associated benefits in the utilization of these removal techniques which include the mathematical model for material blending, high thermal intensity operation at the flash furnace, extended converter blowing, and injection of slag modifiers consisting of Na_2C0_3 and CaO powder mixture to the converters and anode furnaces.

5:00 PM

The Design of the Ausmelt Technology Smelter at Zhong Tiao Shan's Houma Smelter, People's Republic of China: *E. N. Mounsey*[1]; H. Li[1]; J. W. Floyd[1]; [1]Ausmelt Limited, A.C.N. 005 884 355, 12 Kitchen Rd., Dandenong, Victoria 3175 Australia

The paper addresses the design of the Zhong Tiao Shan Company (ZTS) Houma Ausmelt Technology copper smelter in People's Republic of China. The smelter represents the third copper smelter development using Ausmelt Technology, the first large scale (35,000 tpy blister copper) and the first smelter to use the Ausmelt Technology smelting and converting process steps in separate TSL vessels in a continuously operated process. The project will be realised through the combined efforts of ZTS, Ausmelt and ENFI, the Beijing Non-Ferrous Engineering Institute who provided partial detail engineering services in China. Ausmelt will provide the technology licence, basic and detailed furnace engineering packages and additional technical services including cold commissioning support and hot commissioning supervision.

Pyrometallurgy-Operations: Session V

Tuesday PM Room: Flagstaff
October 12, 1999 Location: Pointe Hilton Resort

Session Chair: Tony Weddick, Kennecott Utah Copper Corporation, Magna, UT 84044-6001 USA; A. Luraschi, CADE-IDEPE, Santiago, Chile

2:00 PM

Furnace Cooling Design for Modern, High-Intensity Pyrometallurgical Processes: *N. Voermann*[1]; F. Ham[1]; J. Merry[1]; R. Veenstra[1]; K. Hutchinson[1]; [1]Hatch Associates, 2800 Speakman Dr., Mississauga, Ontario, Canada L5K 2R7

The increasing need for robust pyrometallurgical furnace construction is driven by two trends in the copper and other base metals smelting industry: the design for increased production within a single furnace line by greatly increasing smelting intensities, which generates high heat fluxes to the crucible walls, and the operational and economic imperatives of maintaining high percentage on-line times and long campaign lives between rebuilds. A key feature of furnaces capable of producing at high rates, while containing intense processes, is a strong, thermally robust wall cooling system. Equally important design aspects include the furnace steel structure, refractories, a cooling water supply and piping arrangement for safety from leaks and disruptions, and instrumentation/controls for monitoring and rapid mitigation of process excursions. Integration of the cooling elements into these furnace systems is essential for optimum performance of the cooling elements, and indeed the entire furnace. This paper discusses the development of a composite copper/refractory water-cooled design, which has been successfully implemented on several copper smelting and converting furnaces, including Kennecott's flash converting furnace, INCO's MK reactor, and Kidd Creek's converting furnace.

2:25 PM

Teniente Converter Slag Cleaning in an Electric Furnace at the Las Ventanas Smelter: *Ricardo Ponce*[1]; Gerardo Sánchez[1]; [1]Empres Nacional de Minería (ENAMI), Las Ventanas Smelter & Refinery, Casilla 126-B, Quintero, Chile

In recent years, ENAMI implemented modernisation plans at its two smelters in order to meet the government's environmental regulations introduced in the early 1990's. The modernisation plans defined the new SO_2 and particulates emission targets, deadlines for compliance, and the revised treatment capacities of the smelters. At Las Ventanas smelter, the principal process change consisted of eliminating the reverberatory furnace. All the smelter feed is currently processed in a 4m diameter, 14m long Teniente Converter, using up to 34% oxygen enriched air. Dry concentrate is injected into the bath through tuyeres. A fuel oil burner compensates for any process heat deficiency. The Teniente Converter high copper content slag is cleaned in an electric furnace. This furnace is also used to melt internal reverts. This paper will discuss the successful operation of the slag cleaning electric furnace.

2:50 PM

Utilization of Excess Reaction Heat in the Mitsubishi Converting Furnace: Osamu "Sam" Iida[1]; Tetsuro Sakai[1]; Hiroshi Kumada[1]; [1]Mitsubishi Materials Corporation, Naoshima Smelter & Refinery, 4049-1 Naoshima-Cho, Kagawa-Gun, Kagawa 761-3110 Japan

In the Mitsubishi converting furnace (C-furnace), molten matte continuously undergoes intensive conversion into blister, and an excess amount of heat is generated, even after taking into account heat loss from the furnace, off-gas, and latent heat of melt. To absorb excess heat in C-furnace, recycled granulated converting slags (C-slag) were wastefully charged in the C-furnace. In contrast, supplementary coal is necessary to make up a shortage of reaction heat in Smelting furnace (S-furnace). To utilize the excess heat of the C-furnace effectively and accommodate the unbalance of heat utilization between S and C furnaces, three technological innovations have been carried out. Spent anode charging facilities in C-furnace was modified, in order to solve some spent anodes hitting and eroding the hearth bricks. Cubic pressed copper scrap charging facilities were installed in C-furnace. Facilities were newly installed in C-furnace to treat neutralized residue from the wastewater and dust treatment plants, previously treated in the smelting furnace. Above innovations led to the further effective utilization of heat, increase in production, and savings in energy costs.

3:15 PM

Improvements to BHP Hartley Platinum's Smelting Furnace: *J. Sarvinis*[1]; S. de Vries[1]; K. Joiner[1]; C. van Mierlo[1]; N. Voermann[1]; F. Stober[2]; C. Rule[2]; P. Majoko[2]; [1]Hatch Associates Limited, 2800 Speakman Dr., Mississauga, Ontario, Canada L5K 2R7 ; [2]BHP Hartley Platinum, P.O. Box CY 2288, Causeway, Harare, Zimbabwe

BHP Hartley Platinum operates an electric smelting furnace to treat Cu-Ni-PGM concentrate at its plant in Selous, Zimbabwe. The furnace, originally built by others, has experienced problems including severe refractory erosion of the sidewall. Hatch Associates has designed several important improvements to the furnace, including: water-cooled copper cooling elements in the slag zone; air-cooled copper cooling fins at the metal level; water-cooled copper tapholes; binding system providing vertical refractory compression; electrode seals; new feed pipes. Novel construction techniques employed on this project to reduce shutdown duration are discussed.

3:40 PM Break

4:10 PM

Electric Settling Furnace Operations at the Cyprus Miami Mining Corporation Copper Smelter: *Jason Eric Sallee*[1]; Vladimir Ushakov[1]; [1]Cyprus Miami Mining Corporation, Dept. of Pyrometall., P.O. Box 4444, Claypool, AZ 85532 USA

Ongoing operations at the Cyprus Miami Smelter involve the use of an electric furnace for final settling of copper matte from discard slag. Proper operation of the electric settling furnace is a major factor in minimizing losses of copper to the discard slag. Recent test work at the smelter has shown improvement in

the operation of the electric furnace with a subsequent improvement with regard to the copper losses. This paper presents a general discussion of the Cyprus Miami Smelter operation, past results with respect to copper losses, recent operational changes and test work, and the subsequent results.

4:35 PM

Control of Tapping and Launder Emissions: *J. H. de Visser*[1]; J. A. Davis[1]; M. M. Weaver[2]; [1]DESOM Environmental Systems Limited, 1211 Gorham St., Unit 1, Newmarket, Ontario, Canada L3Y 7V1 ; [2]Kennecott Utah Copper Corporation, Smelter Eng. Grp., 12000 W. 2100 S., Magna, UT 84044-6001 USA

The transfer of molten metal in smelting or refining operations is typically performed in open trough-type launders that are constructed of either water-cooled copper troughs or refractory lined steel jackets. This transfer can be either continuous or batch. Batch operations transfer metal through an open launder. The uncovered launder has many operational and environmental drawbacks. In order to improve workplace hygiene, designs have evolved toward ventilated launder covers that are connected to secondary exhaust systems that use negative pressure under the cover removing fume and hot gases to secondary fume control devices. In smelting operations, a variety of covers have been employed which insulate the launder and contain the fumes and also provide additional heat along the length of the launder through a series of premix or inspiration-type burners that add combustion products to the normal fume load in the launder. Cover designs have proven to be inadequate in that hinged unventilated covers hinder convenient access while heated ventilated covers are costly to maintain. Covers that employ refractory bricks and overhead enclosure-type exhaust hoods have been somewhat successful, but restrict operator movement and require large volumes of exhaust air. An example is given of a cover and off-gas system for launders that is designed to provide superior insulation and heating capabilities, as well as better control of the fume gases and ease of maintenance. The cover system must maintain the balance between maintaining launder heat and fume removal. The construction of the covers must be able to withstand high internal temperatures and maintain its structural properties.

5:00 PM

Application of Advanced Process Control Principles to Copper Smelting: *A. A. Shook*[1]; S. Crisafulli[2]; R. A. Cockerell[2]; [1]BHP Copper, Inc., P.O. Box M, San Manuel, Arizona 85631 USA; [2]CICS Automation Pty Limited, P.O. Box 570, Wallsend, NSW 2287 Australia

The modern approach to process control seeks maximization of plant efficiency through the pragmatic integration of standard, enhanced and advanced control strategies. This paper describes the application of advanced process control principles to copper smelting processes based upon the experience of the authors. The successful implementation of any form of process control relies upon a combination of many key factors such as instrumentation and a knowledge of the process dynamics. In applications of advanced process control, where the end-user may be either seeking to improve the performance of an existing controlled process or installing a control system for a difficult process, these factors become even more significant. The authors' experience has been that the most successful projects for process control have occurred where there is a detailed understanding of the process to be controlled. This understanding is usually already held on-site, but often the dynamic elements need to be determined by additional studies and testing. This paper will provide a discussion on these and other issues required for applying modern control techniques. A case study at the BHP Copper San Manuel smelter will be incorporated to support the above discussions.

5:25 PM

Recent Operation of the Flash Smelting Furnace at Saganoseki Smelter: *Yushiro Hirai*[1]; Yutaka Yasuda[2]; Mitsumasa Hoshi[2]; [1]Nippon Mining and Metals Company Limited, Tech. Dev. Ctr., Miyata, Hitachi City, Ibaraki 317-0055 Japan; [2]Saganoseki Smelter and Refinery, Nippon Mining & Metals Co. Ltd., Saganoseki, Oita 879-2201 Japan

Saganoseki smelter and refinery had operated two flash smelting furnaces from 1973, attaining 330,000 mtpy of copper production in 1989. In 1996, however, it carried out a "integration of two flash furnaces". That is, it doubled the feeding capacity to one flash furnace to shut down another furnace while maintaining the same production. Single flash furnace operation has successfully started in March 1996 accomplishing a great reduction of the total production cost. The production was reached to 350,000 mtpy in 1997, and further increased to 450,000 mtpy by executing the expansion program with single flash furnace in 1998. This paper introduces results of the single flash furnace operation and describes about an outline of the expansion.

Smelting: Technology Development, Process Modeling and Fundamentals: Process Modeling and Control II/Fundamental Studies

Tuesday PM Room: Goldwater
October 12, 1999 Location: Pointe Hilton Resort

Session Chairs: Frank Jorgensen, CSIRO Minerals, G.K. Williams Cooperative Rsch. Ctr. for Extractive Metallurgy, Clayton South Victoria 3169 Australia; Carlos Landolt, Inco Limited, Ontario Division, Sudbury, Ontario, Canada

2:00 PM

Dynamic Simulation of the Flash Furnace in the Chagres Smelter: *Roberto Parada*[1]; Rene Bustamante[2]; [1]Chagres Smelter, Compañia Minera Disputada de las Condes S.A., Avda. Pedro de Valdivia 291, Santiago, Chile; [2]Universidad de Santiago de Chile, Departamento de Ingenieria Metalúrgica, Casilla10233, Santiago, Chile

A real-time dynamic simulation model has been developed to characterise the flash furnace operation at the Chagres smelter. This model permits the operators to plan the process to meet the Peirce Smith

converters schedules and feed the acid plant with gases that satisfy its best operating efficiency range. Essential control parameters for the furnace (process air enrichment, oxygen coefficient and supplementary heat) are calculated to satisfy process targets such as matte grade, slag silica and matte/slag temperatures. These calculations are carried out with a real-time simulation. Flash furnace control and operational stability permits setting up control strategies that streamline the flow of copper to converters and of sulphur to the acid plant.

2:25 PM

Numerical and Experimental Modeling of the Concentrate Burner in a Flash Smelting Furnace: *F. Guevara*[1]; R. Fuentes[1]; A. Valencia[2]; [1]Codelco-Chile, Instit. for Innov. in Mining and Metallu., Avenida del Parque 4980, Ciudad Empresarial, Huechuraba, Santiago, Chile; [2]Universidad de Chile, Mech. Eng. Dept., Casilla 2777, Santiago, Chile

The paper presents results of physical and turbulent three-dimensional numerical simulation of the gas flow in the wind box and reaction shaft of the concentrate burner of a flash furnace. Physical simulation work was carried out in a 1:5 linear scale model, where the velocity field was measured using a Pitot tube. The mathematical model consists of the three-dimensional averaged Navier-Stokes equations, turbulent kinetic energy and dissipation of turbulent kinetic energy using the Renormalization Group (RNG) theory for the k-ε turbulence model. Computations were performed using FLUENT, based in a finite-volume code. The geometry of the concentrate burner was separated in two sections: wind box and reaction tower. Results obtained at the exit of the wind box were used as boundary conditions for the reaction shaft. The effect of boundary conditions on the numerical results was also studied. Results of physical and numerical simulations show an asymmetry of the velocity field at the exit of wind box. This asymmetry is possibly due to existence of a separated flow in the back of the exit ring. The agreement of physical and numerical results assess the capacity of the turbulence RNG k-ε model to reproduce correctly the behaviour of the velocity field at the exit of the concentrate burner.

2:50 PM

Application of a Reacting CFD Model to Drop Tube Kinetics and Flash Smelter Combustion: *B. R. Adams*[1]; K. A. Davis[1]; M. P. Heap[1]; A. F. Sarofim[1]; G. A. Eltringham[2]; A. A. Shook[3]; [1]Reaction Engineering International, 77 West, 200 S., Suite 210, Salt Lake City, UT 84101 USA; [2]BHP Copper, 550 California St., San Francisco, CA 94104-1020 USA; [3]BHP Copper, 7400 N. Oracle Rd., Suite 200, Tucson, AZ 85704 USA

This paper discusses the use of a reacting CFD model to determine chalcopyrite kinetics in a drop tube furnace and to predict the reaction of a chalcopyrite concentrate in the reaction shaft of an industrial smelter. Reacting CFD codes can be applied to determine the consequences of the interaction of gas with particles and therefore improve the ability to derive kinetic parameters that take into account the temperature and oxidation histories that different particles will see. This paper describes the application of such a model to derive improved kinetic parameters for the pyrolysis and oxidation of chalcopyrite. The reaction shaft model includes the effects of turbulent fluid mechanics, entrained flow mixing, turbulent particle dispersion, heterogeneous particle reactions, radiative and convective heat transfer, and surface and bath deposition rates. Particle reaction and composition characteristics are predicted as a function of particle trajectory and deposition and are used to aid in evaluating shaft performance.

3:15 PM

Numerical Modeling of Heat Transfer of a Smelter Ladle, With and Without a Refractory Lining: *P. Ruz*[1]; M. Rosales[1]; R. Fuentes[1]; J. Averous[2]; [1]Codelco-Chile, Instit. for Innov. in Mining and Metallu., Avenida del Parque 4980, Ciudad Empresarial, Huechuraba, Santiago, Chile; [2]Ecole des Mines de Paris, Corps Techniques de l'Etat, 60 Blvd. St. Michel 75272, Paris, Cedex 06 France

A melt transfer ladle was 3D modeled by means of a mathematical fluid dynamics and heat transfer program. Internal temperature profiles were calculated as a time function for a normal ladle and for a preheated refractory lined ladle. It was shown that in a normal ladle the molten metal cools down quickly forming accretions. By using an inner lining there are practically no accretions build up within a typical time of operation. Therefore, by applying a refractory lining to a melt transfer ladle and keeping it at a moderate to high temperature it is possible to reduce cold dope circulation in the smelter.

3:40 PM Break

4:10 PM

Slag Chemistry of the New Noranda Continuous Converter: *Manuel Zamalloa*[1]; Eva Carissimi[2]; [1]Noranda, Inc., Technology Center, 240 Hymus Blvd., Pointe-Claire, Québec, Canada H9R 1G5

The outstanding metallurgical performance of the Noranda continuous converter (NCv) in operation since November 1997 has allowed the company to meet production and environmental targets. This achievement positions this new technology as a strong alternative continuous converting technology for copper production. Knowledge of slag chemistry has been important in this respect. The purpose of this paper is to discuss the effect of key parameters including temperature, oxygen potential, slag composition and levels of copper oxide in slag on the conditions leading to magnetite precipitation, as well as on the conditions affecting the liquidus ranges of NCv slag. The above variables are evaluated using industrial data and thermodynamic predictions. Practical implications of customizing operational fluxing procedures to determine optimum operating windows are also discussed.

4:35 PM

Modeling of Slag-Skimming in a Peirce-Smith Converter: *Jong-Leng Liow*[1]; George E. Assaad[1]; Petar Liovic[1]; Neil Boon Gray[1]; Murray Rudman[2]; [1]The University of Melbourne, Dept. of Chem. Eng., GKW CRC for Extractive Metallu., Parkville, Victoria 3052 Australia; [2]CSIRO, Div. of Bldg., Constru. and Eng., P.O. Box 56, Graham Rd., Highett, Victoria 3190 Australia

The entrainment of copper matte in the slag during the slag skimming stage of a Peirce-Smith converter was studied with a dam break model. Experiments were carried out with a range of fluid pairs

where the lighter fluid was allowed to overflow a weir and the amount of entrained heavier fluid measured. The resulting entrainment is measured as the ratio of the heavy to light fluid withdrawn. The fluid pairs include oil-water, water-glycerol and salt solutions-water pairs to cover a wide range of densities and viscosities. It was found that the Richardson number, Ri, correlates the entrainment well. For the case of the liquid-liquid interface initially at the same height as the weir, the entrainment was found to vary with $Ri^{-1/3}$. The transient flow was simulated with a volume of fluid (VOF) code written in-house and used a stairstep approach to represent flow obstacles. The code was validated against the experimental results with good agreement for the variation of the heights of the two fluid with time. The simulation showed that the prevailing mechanism for entrainment is due to a pressure differential created across the liquid in the converter during pouring resulting in the heavier liquid being rotated upwards and over the weir.

5:00 PM

Some Aspects on Matte Settling in Copper Smelting: *Kim Olof Fagerlund*[1]; Heikki Jalkanen[1]; [1]Helsinki University of Technology, Dept. of Matls. Sci. and Rock Eng., Lab. of Metallu., Espoo FIN-02150 Finland

Theoretically and experimentally determined copper matte settling rate in iron silicate slag has been discussed. Separation and settling rate measurements of sand, homogenised slag and 25%Cu concentrate, 63%Cu industrial, and 71%Cu synthetic copper mattes were carried out by mixing crushed slag and matte samples with silica sand in an alumina crucible and melting at 1300-1350ϒC. Two different types of slag compositions were employed, with Fe/SiO_2-ratio 1.4 and 1.7. The separation rate was followed by taking samples from the melt. As expected, the settling rate of copper matte in fayalite slag depended on the slag composition, where the increasing silica decreased the matte settling rate. Microanalysis of solidified slags showed that the rate of separation of low grade matte was low compared with high grade matte and the presence of a very small size fraction of matte droplets in slag remained unsettled in stagnant fluid. The production of sulfur dioxide gas inside the molten bath was found to be possible up to a certain iron sulfide content in the matte. Also, copper matte settling rates in industrial furnaces have been discussed.

5:25 PM

Effervescence During Desulfurization of Copper Melts: *Ralph Harris*[1]; I. Roumeliotis[1]; [1]McGill University, Dept. of Mining and Metall. Eng., Rm. 2220 Wong Bldg., 3610 University St., Montreal, Québec, Canada H3A 2B2

Blister copper melts of 800 g to 1000 g containing less than I wt % S and up to 3 wt % Ni were desulfurized at 1523 K in air or by a pure oxygen jet blown at 75, 500 and 1000 cm^3/min, from I cm above the melt. Rates of desulfurization and oxygen pickup were measured and visible surface phenomena were photographed and videotaped. It was observed that SO_2 was evolved from Cu-S melts in a manner reminiscent of the effervescence seen in carbonated drinks. The effervescence lasted up to 20 minutes and resulted in the ejection of material up to a height 50 cm above the melt surface. Sporadic discharge of large bubbles was also observed in a Ni containing melt top-blown with oxygen at 1000 cm^3/min. The Cu-S melts top-blown with oxygen experienced faster sulfur elimination as compared to stagnant melts exposed to air and experienced only a single period of turbulent So_2 evolution which occurred almost immediately after oxygen injection commenced. The Cu-S melts exposed to air experienced multiple episodes of effervescence. The stagnant blister copper melt containing nickel did not exhibit effervescent behaviour and experienced a lower rate of sulfur elimination compared to Cu-S melts tested under similar conditions. The present article examines the role of surface phenomena in determining the observed behaviour.

Plenary Lectures: Session III

Wednesday AM — Room: Flagstaff/Goldwater/Indigo/Jerome
October 13, 1999 — Location: Pointe Hilton Resort

Session Chairs: David Geoge, Kennecott Utah Copper, Salt Lake City, UT USA; F. Puchi, Chile

8:30 AM

Copper Extraction from the 60's into the 21st Century: *W. G. Davenport*[1]; [1]University of Arizona, Dept. Matls. Sci. and Eng., #12, Tuscon, AZ 85721 USA

Changes in copper extraction from 1960 till today are documented. The top ten changes have been: replacement of reverberatory smelting by high intensity oxygen rich smelting, growth of the Outokumpu flash smelting to over 50% of the world's smelting capacity, successful development of single furnace coppermaking but only for low slag fall concentrates, replacement of the batch Peirce-Smith converter by continuous converting, but only in a few cases, increased SO_2 capture throughout the industry, mainly as sulfuric acid, development of low initiation temperature "big bight" Cs catalysts for treating the continuous high SO_2 strength gases from continuous smelting/converting, complete replacement of reverberatory anode scrap and cathode melting furnaces by the Asarco shaft furnace, adoption of stainless steel permanent cathodes and automated stripping technology for electrorefining and electrowinning, complete elimination of wire bar casting by continuous bar casting/rod rolling, and development and adoption of extractants for turning weak impure leach solutions into strong pure electrolytes. It is postulated that the biggest possible change over the next 20 years would be complete replacement of smelting/converting by hydrometallurgical processing. However, this seems unlikely due to copper purity, precious metal recovery, and economic concerns. The increasing value of sulfuric acid to many copper companies give chalcopyrite smelting/oxide-supergene leaching a nice synergy especially with the energy credits now coming from continuous smelters and their acid plants.

9:15 AM

Advances in the Copper Industry - Future Development and Environmental Constraints: *W. Marnette*[1]; [1]Norddentsche Affinerie, Hovestrabe 50, Hamburg D-20539 Germany

This plenary lecture discusses some of the issues affecting the pace of developments in the copper industry. This includes developments affecting both the production and uses of copper. Environmental constraints can influence the nature of developments on both the production and consumption side and the impact of these aspects is reviewed as well.

10:00 AM Break

Electrorefining: Anodes and Cathodes

Wednesday AM Room: Indigo
October 13, 1999 Location: Pointe Hilton Resort

Session Chairs: P. L. Claessens, Noranda Technology Centre, Pointe Claire, Québec, Canada HH9R 1G5; J. P. Evans, G. Engineering, Toronto, Ontario, Canada M9W 5X9

10:30 AM
Update on the Contilanod® Process - Continuous Cast and Sheared Anodes: *P. Regan*[1]; M. Schwarze[2]; [1]Hazelett Strip-Casting Corporation, P.O. Box 600, Colchester, VT 05446 USA; [2]Mannesmann Demag Métallurgie, Ohlerkirchweg 66, Postfach 100645, Monchengladbach 41006 Germany

Following the introduction of the Contilanod process over 10 years ago at Copper Range and IMI Refiners, significant changes and advances have been made to this pioneering anode production technique. A new radial flow metal feeding concept has been developed that allows a substantial increase in casting rates on the Hazelett® twin-belt caster. To cut the 45 mm thick continuous anode plate into shaped anodes at rates of 100 t/h or more, a fully moving hydraulic shear designed by Mannesmann Demag has replaced the slower speed plasma cutting torch. Details of the new caster and shear are presented along with operating results from the new lines starting up in 1999 at the Gresik smelter/refinery in Indonesia and the completely revitalized Mansfelder Kupfer und Messing complex in Germany.

10:55 AM
Aluminum Diffusion Protection for Copper Anode Moulds: *J. Riccardi*[1]; A. Park[2]; [1]PGE Industrial, Inc., 3589 Old U.S. 23, Brighton, MI 84114 USA; [2]General Metal Diffusion, Inc., 815 Great Northern Rd., Sault Ste. Marie, Ontario, Canada D6A 5K7

Copper refineries use massive copper castings as moulds into which impure molten copper from a rotary or reverberatory furnace is poured to form anodes for subsequent electrolytic refining. To facilitate removal of the copper anodes from the mould and to prolong the life of the mould itself, it is traditional to spray the mould surface prior to each use with an aqueous slurry of barite, boneash, etc. This slurry application leads to poor housekeeping, operating costs are escalated by the cost of the slurry, and additional problems in the subsequent refining process are experienced because of the carry-over of excess undesirable barite. A one-time application of a diffused layer of aluminum to the surface of the copper mould prior to putting it into service has been found to provide extended mould life and to facilitate anode removal, as well as reducing reagent consumption, thereby reducing operating costs at both the anode manufacturing and refining stages.

11:20 AM
A Mineralogical Study of Nodulated Copper Cathodes: *J. E. Dutrizac*[1]; T. T. Chen[1]; [1]CANMET, 555 Booth St., Ottawa, Canada K1A 0G1

Mineralogical studies were carried out on nodulated copper cathodes from three primary refineries to characterize the nodular growths and to elucidate the causes of the nodulation. Nodulation is often initiated at the surface of the starter sheet or the stainless steel plating blank, although a layer of smooth copper sometimes is deposited before nodulation commences. In some instances, the "roots" of the nodules exhibit a pronounced dendritic texture that is associated with an abundance of cavities. Slimes particles are not usually associated with these growth features which lead to a globular surface deposit. The globules sometimes develop into larger nodules, and this type of nodulation is likely caused by improper addition agent concentrations. The nodules on most cathodes, however, exhibit "roots" at the contact with the substrate that are associated with microcavities and large clusters (>40 μm) of slimes particles. The slimes constituents are commonly Ag powder, PbSO4 and Cu 2(Se,Te) but not AgCu(Se,Te) or Ag2(Se,Te). The size of the slimes clusters, rather than their composition, appears to be the important factor causing the copper to grow into nodules. Tiny individual slimes particles themselves do not appear to cause cathode nodulation.

11:45 AM
Post-Passivation Reactions Occurring at the Anode during Copper Electrorefining: *M. S. Moats*[1]; J. B. Hiskey[1]; [1]University of Arizona, Department of Materials Science and Engineering, P.O. Box 210012, Tucson, AZ 85721 USA

A considerable amount of research has been conducted to determine the causes of anode passivation. Chemical and electrochemical reactions that occur after passivation have received little attention. Chronopotentiometry, linear sweep voltammetry, cyclic voltammetry, and impedance spectroscopy have been used to elucidate three reactions that occur after passivation of commercial copper anodes. These involve the dissolution of silver and subsequent cementation and transformation of selenides, the oxidation of lead sulfate to lead oxide, and oxygen evolution. The amount of silver dissolution depends on the silver content of the anode, the time to passivation, and the molar ratio of Ag/(Se+Te). The oxidation of lead from PbSO4 to PbOx explains a potential plateau of oxygen evolution. Silver affects the duration of oxygen evolution on the PbOx. Anodes containing kupferglimmer display a characteristic oxygen evolution potential. It is believed that kupferglimmer provides a lower overpotential for oxygen evolution than the other slime phases or passivated surface.

Environment, Health & Safety: Session I

Wednesday AM Room: Copper
October 13, 1999 Location: Pointe Hilton Resort

Session Chair: Melinda R. L. Pon, BHP Minerals, San Francisco, CA 94104-1020 USA; R. Cortes, Santiago, Chile

10:30 AM
International Health and Environmental Regulations for Metals: New Challenges for Copper: *Ricardo Badilla-Ohlbaum*[1]; Gustavo F. Lagos[2]; [1]Chilean Mining & Metallurgy Research Centre (CIMM), Avda. Parque A Rabat 6500, Vitacura, Santiago, Chile; [2]Catholic University of Chile, Ctr. for Mining, Avda. Vicuña Mackenna 4860, Macul, Santiago, Chile

Copper has been used by man for a very long time and unlike certain other metals, it is an essential element for life. Its toxicity arises both from a deficit and excess copper exposure/intake. The focus of the current discussions in countries of the European Union (EU) and in some USA States, is based on the concerns, independent of the scientific facts and the economic status of these claims, of the negative influence of copper and other metals on health and the environment. These discussions have influenced the new regulations of copper in drinking water, and the approach to regulate the appropriate levels of copper in surface water, soils and sediments. To illustrate the challenges ahead for copper, the evidence by which the current US Environmental Protection Agency (USEPA), the World Health Organization (WHO) and EU recommendation and regulations regarding copper in drinking water have been derived is presented and discussed. The gaps between the demands for new standards of health and the environment and the practical scientific tools to achieve these goals are presented, and the need to develop new regulating paradigms is also illustrated. The introduction of methodologies for the regulation of essential elements and acute inorganic substances in drinking water is discussed, as well as the status of the present approach contained in the International Program of Chemical Safety Environmental Health Criteria, (EHC) NΥ 170. The impact of the possible restrictions on the use of copper in the EU because of health and environmental concerns in terms of the world market for copper is discussed.

10:55 AM
Human Health Risk Assessment: An Ever-Moving Target: *Jenifer S. Heath*[1]; [1]URS Greiner Woodward-Clyde, 4582 South Ulster St., Suite 1000, Denver, CO 80237 USA

Human health risk assessments can be used in mine permitting, and are frequently used to investigate areas of potential contamination and as a basis for remediation decision making while some states and US Environmental Protection Agency (USEPA) Regions have their own guidance for the conduct of human health risk assessments, USEPA Headquarters guidance and the underlying science are changing and advancing rapidly. Even outside the US, USEPA guidance can affect risk assessment costs and conclusions, which in turn can affect cleanup costs or permitting options. This paper summarizes recent USEPA guidance and scientific evidence related to human health risk assessment for mining sites. This paper is designed for non-risk assessors, and so focuses on the potential applications and implications of the new guidance rather than the mathematical and theoretical details.

11:20 AM
The Development of Environmental Regulations in Poland and Its Influence on the Copper Industry: *Helena Byrdziak*[1]; Jerzy Dobrzanski[1]; Jan Garbaczewski[1]; [1]KGHM Polska Miedz S.A., ul. M.Curie-Sklodowskiej 48, Lubin 59-300 Poland

KGHM Polska Miedz S.A. is a significant European copper producer with production of 447,000 mtpy, operating three underground mines and three smelters. The company has been involved for years in environmental activity, which was stimulated not only by the company itself, but by the development of environmental regulations as well. The first set of regulations, concerning water protection, was established in Poland in 1974, while a comprehensive environmental law was passed in 1980. This law in general requires industry to submit all data of environmental significance to the local authorities. Based on this data, they establish limits concerning emissions into the air, water and ground, the amount of wastes produced and the means of their disposal. A company has to pay fees for each tonne of emitted substances and stored wastes. When the emission of a substance exceeds the limit, the company has to pay a penalty which is about ten times higher than the fees. This approach in general is effective because it forces companies toward reduction of their emissions. The problem is that the law is constantly subject to change and is becoming not only more restrictive but is involving more and more bureaucracy.

11:45 AM
The New Paradigm: ISO 14000 and its Place in Regulatory Reform: *Robert A. Reiley*[1]; [1]Office of Chief Counsel, Dept. of Environ. Protect., Rachel Carson State Office Bldg., Harrisburg, PA 17961 USA

Under the traditional environmental paradigm, industry, stakeholders, and government impact the environment through production, consumption, and regulation. For more than twenty years, this paradigm has survived more or less unchallenged. Environmental action has followed a typical pattern: industry pollutes, the public clamors, government enacts legislation, and industry expenditures for pollution-control equipment soar. In the 1990's, many groups realize that command-and-control techniques may not be the most effective method of dealing with environmental issues in the new millennium. The need for regulatory reform became apparent in the 1980's after an accident at the Union Carbide plant in Bhopal, India. In addition, the prospects of an integrated European market and increased global trade sparked a need for common standards regarding the production of goods and services, which led to the adoption of the International Standards Organization (ISO) 9000 Quality Standards. These factors, and others, triggered the development of the Environmental Management System (EMS). Over the past decade, country-and industry-specific EMSs were developed. However, the ISO realized the need for a single, interna-

tionally recognized standard that would be workable for any type organization. The goal of this standard is to promote economic competitiveness, remove trade barriers, and promote environmental protection. To this end, the ISO 14000 Standards were developed to provide business with a structure for managing environmental impacts. This article argues that a new paradigm has begun to transcend the old. Protection of the environment if shifting from "government drivers" to "market drivers". This shift means that industry and stakeholders, instead of government, are taking the lead to develop ways to protect the environment. This article also argues that government can use this new paradigm, in a time of declining budgets and regulatory reform, to continue to protect the environment through increased compliance monitoring and rigorous enforcement. Specifically, the ISO 14000 Standards can allow the government to reduce compliance costs, streamline permit and reporting requirements, and provide business with regulatory flexibility. Finally, this article argues that ISO 14000 will be central to the regulatory reform effort, because it can be internally implemented with little need for legislative intervention.

12:10 PM

Development and Implementation of a Common Corporate Management System for Safety and Health at International Mining Operations: *Kyle B. Dotson*[1]; [1]BHP Copper, Dept. of Safety, Health and Environ., 550 California St., 5th Floor, San Francisco, CA 94104-1020 USA

A common international safety and health management system was developed. Analysis of selected major safety and health management systems from around the world was conducted. Functional elements of selected systems were grouped to identify common elements and key differences. Common elements were subjected to qualitative judgments of equivalency and then reconciled. With few exceptions, differing elements were revised to achieve cultural neutrality. The resulting 98 system elements were organized according to the NOSA numbering and title scheme. System summaries were produced in Spanish and English. A pre-implementation self-assessment evaluated conformance in three distinct cultures. The consensus 98 element system was internally named the BHP Copper Five Star Safety System Performance Management Guidelines. Development of a common system within an organization with international operations can enhance the ability of the staff function to share resources, programs and subsystem improvements and thereby increasingly protect workers. Common systems can increase the level of management support by demonstrating increased compatibility of the safety and health management function with traditional business objectives. Safety professionals, industrial and occupational hygienists, business managers and the safety and health of workers will benefit from further development and articulation of common systems for safety and health management.

Hydrometallurgy: Electrowinning

Wednesday AM Room: Hopi
October 13, 1999 Location: Pointe Hilton Resort

Session Chair: Robert Washnock, Silver Bell Mining L.L.C., Marana, AZ 85653 USA

10:30 AM

Improved Copper Electrowinning Operations Using Wrought Pb-Ca-Sn Anodes: *R. David Prengaman*[1]; Andres Siegmund[1]; [1]RSR Technologies, Inc., 2777 Stemmons Freeway, Suite1800, Dallas, TX 75207 USA

Wrought lead-calcium-tin anodes developed by RSR Corporation have improved the performance compared with the other lead alloy anodes. These anodes have been in continuous service at various locations around the world for as long as fourteen years. Calcium provides mechanical strength to the anode to prevent the deformation while tin increases the mechanical strength, reduces the rate of corrosion, prevents the formation of non-conducting layers on the anode surface, and dramatically improves the conductivity of the anode. Tin is also instrumental in developing the unique rolled structure of the anode which leads to the reduced rates of corrosion, longer life, and improved oxygen evolution. Cobalt additions to the electrolyte further enhance the oxygen evolution and improve the anode life. Higher current densities and higher operating temperatures reduce the anode life. The unique patented method of attaching the rolled anode sheet to the bus bar substantially reduces the resistance of this important joint and offers the substantial savings in power over the life of anode.

10:55 AM

Electrocatalytic Titanium Mesh Surfaces Combined with Standard Lead Substrates for Process Improvements and Power Savings in Copper Electrowinning: *Kenneth L. Hardee*[1]; Carl W. Brown[1]; [1]ELTECH Systems Corporation, Research Dept., 625 East St., Fairport Harbor, OH 44077 USA

A recent development has emerged which produces a retrofittable low cost anode by attaching disposable, electrocatalytically active titanium mesh over the existing lead anodes. The coated titanium mesh anode operates at potentials of several hundred millivolts lower than the lead anode, providing significant power savings. The exposed lead surfaces are stabilized since most of the current flows through the titanium mesh. With the minimal lead corrosion, the sludge formation is virtually eliminated and the purity of the plated copper is greatly enhanced. Further savings may be realized by the elimination of non-essential chemicals such as cobalt. Since the combination anode is stable and uniform, the plated copper is also more uniform with minimal formation of dendrites, reducing the shorting. Full-size anodes have been tested for over 6 months in commercial copper electrowinning cells. The laboratory and field performance of the stabilized lead anode will be re-

viewed, including the voltage characteristics, the lead stability and the copper cathode purity.

11:20 AM
The Corrosion of Lead Anodes in Copper Electrowinning: *G. Cifuentes*[1]; J. Simpson[1]; L. Cifuentes[2]; G. Crisostomo[2]; [1]Universidad de Santiago, Depto. Ingenieria Metalúrgicia, Av.B. O'Higgins 3363, Santiago, Chile; [2]Universidad de Chile, Depto Inenieria de Minas, Tupper 2069, Santiago, Chile

When the applied current is interrupted in a copper electrowinning plant, and then is back in operation, the lead anodes tend to corrode. In order to decrease the corrosion, the damage protective ("back up") anodic currents are applied during the period of interruption. The current work aims to establish the effect of the concentrations of sulphuric acid, copper and cobalt on the anode corrosion, to quantify the effect of various anodic protection levels on the anode corrosion, to quantify the effect of various anodic protection levels on the anode corrosion and to propose a method to select the appropriate protective current density value.

11:45 AM
Merrlin Composite Anodes for Copper Electrowinning: *Marion Dattilo*[1]; L. J. Lutz[1]; [1]Merrlin, L.L.C., 107500 CR 2000, P.O. Box 184, Rolla, MO 65402-0184 USA

Research has been conducted over the past three years using the composite anodes versus the lead alloy anodes. The Merrlin composite anodes have shown the improved performance in copper electrowinning versus the lead-calcium-tin anodes. Using the composite anodes a 100-150 mV reduction in anode overpotential has been observed versus the lead alloy anodes in sulfuric acid electrolyte. The composite coating has excellent corrosion inhibiting properties, and reduces or eliminates the formation of manganese oxide scale. Laboratory evidences indicate that the use of these composite anodes enhances the process of electrowinning by improving the lead alloy corrosion resistance, lowers the electrode potential, reduces the need for cobalt addition, eliminates the anode cleaning, and reduces the generation of acid mist. Field tests are underway.

12:10 PM
New Anode Compositions for Copper Electrowinning and Copper Electrodeposition at High Current Density: *Jean-Luc Delplancke*[1]; René Winand[1]; Jean-Paul Gueneau De Mussy[2]; Antonio Pagliero[2]; [1]Université Libre de Bruxelles, Metallu. Electrochem. CP165, 50 Ave. F.D. Roosevelt, Bruxelles B-1050 Belgium; [2]Universidad de Concepción, Dept. de Ingenieria Metalúrgica, Facultad de Ingenieria, Casilla 53-C, Concepción, Chile

During copper electrowinning in sulphate electrolyte, intense oxygen evolution takes place at the anode. Lead alloy anodes are progressively replaced by dimensionally stable anodes in order to avoid the cathode contamination by dissolved lead. The electroactive coating of these anodes has to be as cheap as possible, adherent to the substrate, electrochemically stable and has to be efficient at high current density and high temperature. This requirement is even demanding in case of copper electrodeposition for the production of thin copper foils for the electronic industry. The production of thin (20mm thick) copper foils for the printed circuit boards requires high purity copper electrodeposited at a current density as high as 7,000 A/m_2. The choice of a long term coating composition is driven by economics. The purpose of this paper is mainly to review the anode compositions suitable for copper electrowinning and for copper electrodeposition at high current density. A short description of preliminary results obtained with a new anode coating on a titanium substrate is also presented.

Pyrometallurgy-Operations: Session VI

Wednesday AM Room: Estrella
October 13, 1999 Location: Pointe Hilton Resort

Session Chair: Eric Partelpoeg, The Winters Company, Tucson, AZ 85711 USA; William Davenport, University of Arizona, Dept. of Mats. Sci. and Eng., Tuscon, AZ 85721 USA

10:30 AM
Revising Copper Converter History: A Metallurgical "Whodunit": *Larry M. Southwick*[1]; [1]L. M. Southwick & Associates, 992 Marion Ave., Suite 306, Cincinnati, OH 45229 USA

Pneumatic converting (Bessermerizing) of iron revolutionized the steel industry. Bessermerizing of copper (conversion of copper sulfide matte to copper metal) was proposed at almost the same time, but it was slow in being accepted. The differences between iron and copper converting were great and technical problems were substantial. It took 25 years for the process to become viable and another 25 years before a truly economical solution was found. A major economical and productivity problem was the short life for converter refractory linings. The first converters had acid (silica) linings, which were quickly consumed since silica was a flux for the process. Converters had to be relined at least once per day, a laboriously expensive manual process with only the most rudimentary mechanical aids available to assist. The industry was revolutionized almost overnight when finally a viable basic (magnesite) lining was developed. This lasted hundreds of days versus less than one, leading to converters that were easier to operate and which handled larger charges. This change occurred after W. H. Peirce and E.A.C. Smith, with support from the Guggenheim interests, successfully operated a basic lined converter in a copper refinery in Baltimore. While Peirce and Smith are generally given credit for the development and explosive acceptance of this idea, a Pittsburgh industrialist, Ralph M. Baggaley, working in an independent smelter in Butte, Montana, successfully built and operated a basic lined converter four years before they did. In fact, the early support for Peirce and Smith likely occurred because Guggenheim's staff were encouraged after thoroughly examining Baggaley on his earlier successes. The questions of technology primacy between Baggaley and Peirce/Smith are ironically similar to those between Wm. Kelly and Bessemer in converting iron to steel.

This paper will review what Baggaley (and other early researchers) accomplished, examine why he (or they) did not receive credit equal to Peirce and Smith and explore what his (their) place should be in the development of successful basic linings. More suspects than a Victorian Whodunit.

10:55 AM

Development of New Bath Smelting Technology at Mines Gaspe: *J. F. Leroux*[1]; B. Langlois[1]; Y. Massé[1]; X. J. Guo[2]; P. J. Mackey[2]; [1]Mines Gaspé, Murdochville, Québec, Canada G0E 1W0; [2]Noranda Technology Center, 240 Hymus Blvd., Pointe Claire, Québec, Canada H9R 1G5

The Gaspe smelter at Murdochville, Québec, Canada introduced concentrate injection into elongated Peirce-Smith converters sized 1.96m x 12.5m (13 ft. by 41 ft.) in 1996, and commissioned a large, converter-like bath smelting vessel in April 1998. The new vessel, which is sized 4.27m x 16.15m. (14ft. by 53ft.) has several interesting features designed to effectively utilize bath smelting technology for the requirements of the Gaspe smelter. For example, the vessel can operate on concentrate injection at upwards of 60-80 tph rate on an instantaneous basis, can operate as a large Peirce-Smith converter, while it is also fitted with matte and slag tapholes much akin to Noranda Process reactor, and includes a novel cold charge addition system. The new technology will eventually allow the capacity of the plant to increase from about 300,000 tonnes of concentrate per year to over 350,000 tonnes of concentrate per year while improving sulfur capture.

11:20 AM

Converter Operation at BHP San Manuel Smelter: *T. W. Gonzales*[1]; Darren Snashall[1]; Ovidiu Pasca[1]; Robert David[1]; [1]BHP San Manuel Smelter, P.O. Box M, San Manuel, AZ 85731 USA

The BHP San Manuel Smelter operates an Outokumpu Oy flash furnace, conventional Pierce-Smith converters, anode casting facilities, and two double contact sulfuric acid plants. The flash furnace was commissioned in July 1988 and since then, the smelting capacity has been continuously increased to 30% above design. The converter operation was challenged to process larger amounts of matte with existing capacity. Utilization of industrial technological improvements and people technology transformed the Converter Department from a constraint to easily accommodate the new demonstrated flash furnace capacity. This technology also increased secondary consumption, converter campaign life, and reduced operating costs. This paper will describe the important Converter Department achievements in the past five years.

11:45 AM

Concentrate Injection and Oxygen Enrichment in Peirce Smith Converters at Noranda's Altonorte Smelter: *Ernest D. Mast*[1]; Jorge Arrián V.[1]; Juan Benavides V.[1]; [1]Fundición Altonorte, Avenida Antonio Rendic 5032, Antofagasta, II Región, Chile

Noranda's Altonorte custom smelter, located in the 2nd region of Chile, 20 kilometres southeast of the city of Antofagasta, started operations in 1993. Presently, 1150 tonnes per day of new feed are smelted with an 85% sulphur capture. An oxy-fuel reverberatory furnace produces a 48%- 55% copper matte that is treated in 13 ft. x 36 ft.(3.96m x 10.97m) Pierce-Smith Converters (two hot and one blowing). Up to thirty percent of the new concentrate is smelted via dry concentrate injection into the converters. This paper reviews the development of the concentrate drying and injection system, and oxygen enrichment at Altonorte from start-up in 1995 to the present time. The relationship between oxygen enrichment and concentrate injection is reviewed from a theoretical and practical standpoint. Concentrate injection has improved the smelter's productivity and added flexibility to the operations. Due to the relatively high matte grades and the subsequent short converting times, maintaining consistent operations was difficult at times and the smelter has gone through a learning curve. Plant operating results and experiences are presented on the impact of concentrate injection in relation to: feed treatment, blowing times, revert generation, slag quality and refractory wear.

12:10 PM

Refractory Performance in Peirce-Smith Converters at BHP San Manuel Smelter: *T. W. Gonzales*[1]; A. J. Rigby[2]; Ovidiu Pasca[3]; [1]Hot Metals, P.O. Box M, San Manuel, AZ 85731 USA; [2]NARCO Canada, Inc., 4355 Fairview St., Burlington, Ontario, Canada L7R 3Y7; [3]Converter Dept., P.O. Box M, San Manuel, AZ 85731 USA

The refractory performance of Peirce-Smith converters is considered to be mainly determined by effects of process control and refractory installation design. BHP Copper has shown that, over the last four years, considerable improvements in tuyere line life can be affected by maintaining a uniform temperature in the operating converter and by ensuring sufficient and specific placement of expansion allowance in the construction of the refractory brickwork. A combination of optimized crane availability, rapid matte transfer, converter operating practices, new refractory installation techniques and applications has minimized out-of stack time. In addition, larger diameter tuyere pipes and hard piping have increased blowing rates and lowered cycle times, which has resulted in a tuyere line performance in excess of 62,500 tonnes of blister copper before maintenance is required. This paper discusses the refractory installation design changes that were made to increase tuyere line life.

12:35 PM

Use of Microporous Insulation in Copper Holding Furnaces at BHP Copper, San Manuel, AZ: *Iain B. Mackenzie*[1]; Ovidiu Pasca[2]; Arsenio Enriquez[2]; A. J. Rigby[3]; [1]Microtherm, Inc., P.O. Box 62088, Burlington, Ontario L7R 4K2 Canada; [2]BHP Copper, 200 S. Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA; [3]NARCO Canada, Inc., 4355 Fairview St., Burlington, Ontario L7R 3Y7 Canada

In 1997, a thin layer of Microtherm Microporous Insulation was used to replace fireclay brick behind the magnesia/chrome working lining in #5 refining furnace at BHP's San Manuel AZ smelter. A 23Ÿ°C reduction in shell temperature was obtained, together with a large increase in the working capacity of the vessel. There was no sign of metal penetration as a result of the increased insulation. Following these highly favorable results, BHP has introduced this product into all of their refining furnaces.

Smelting: Technology Development, Process Modeling and Fundamentals: Fundamental Studies and Technology Development - I

Wednesday AM Room: Goldwater
October 13, 1999 Location: Pointe Hilton Resort

Session Chairs: Mark Schlesinger, University of Missouri-Rolla, Dept. of Metall. Eng., 1870 Miner Circle, Rolla, MO 65409-0340 USA; Igor Wilkomirsky, Universidad de Concepción, Dept. Ing. Metalúrgica, Edmundo Larenas 270, Concepción, Chile

10:30 AM
Dynamic Modeling of Copper Losses in Slag: *J. W. Matousek*, 8547 E. Arapahoe Rd., #J149, Greenwood Village, CO 80111-1430 USA

Copper losses in smelter slags are typically normalized with some form of the distribution coefficient, written as the ratio of the weight percent assays of metal in slag to the metal in matte or its inverse: L(s/m) = %(Cu)/%[Cu] or L(m/s) = %[Cu]/%(Cu). However, this simple approach ignores the dynamics of the smelting process. It overlooks the effect of the chemical work done in producing a given matte grade from concentrates of different grades—or from a single concentrate blended with varying quantities of copper bearing precipitates or reverts. This paper examines the combined influences of matte grade and the work done in smelting on the copper content of smelting furnace slags. A simple model for the relationship is proposed.

10:55 AM
Dissolution of Copper and Nickel in FeO_x-SiO_2 Base Slag Equilibrated with Copper-Nickel-Iron Matte under High Partial Pressures of SO_2: *Jonkion Marcos Font*[1]; Mitsuhisa Hino[1]; Kimio Itagaki[1]; Ghasem Roghani[2]; [1]Tohoku University, Instit. for Adv. Mats. Proc., Katahira 2-1-1, Sendai, Miyagi, Aoba Ku 980-8577 Japan; [2]The University of Queensland, Dept. of Mining, Min. & Mats. Eng., Brisbane QLD 4072 Australia

As a comprehensive contribution to the understanding of oxygen-blowing of matte smelting, the copper and nickel solubilities between the FeO_x-SiO_2-MgO slag with saturated SiO_2 and the Cu_2S-Ni_3S_2-FeS matte with the N_{Cu} /(N_{Cu}+ N_{Ni}) of 1, 0.75, 0.5, 0.25 and 0, in a MgO crucible were investigated at 1573 K under controlled partial pressures of SO_2 at 0. 1, 0.5 and l atm. The partial pressures of SO_2, S_2 and O_2 were controlled by using an Ar-SO_2-S_2 gas mixture after passing through a sulfur reservoir. It was clarified that, at a given matte grade, the solubility of copper in the slag was independent of pso_2 while that of nickel increased with increasing pso_2. This notable difference was considered to be ascribable to the chemical formulas of the monometallic sulfides in which one copper atom combines with 1/2 sulfur atom while one nickel atom combines with 2/3 sulfur atom. It was also clarified that, at a given iron content in the matte, the po_2 and ps_2 were independent of the matte species. This was ascribable to a_{FeS} in the matte, which was independent of the matte composition, $N_{Cu}/(N_{Cu}+N_{Ni})$, at a given iron content in the matte.

11:20 AM
Development of the El Teniente Slag Cleaning Process: *Gerardo Achurra*[1]; P. Echeverria[1]; A. Warczok[2]; G. Riveros[2]; C. M. Diaz[2]; T. A. Utigard[3]; [1]Codelco Chile, El Teniente Div., Millan 1040, Rancagua, Chile; [2]Universidad de Chile, Dept. Ingenieria de Minas, Av. Tupper 2069, Casilla 2777, Santiago, Chile; [3]University of Toronto, Dept. of Metall. and Mats. Sci., 184 College St., Toronto, Ontario, Canada M5S 3E4

The products of the smelting of copper concentrates in an El Teniente Converter (CT) are: a high grade matte, analyzing 74-76% Cu; and a highly oxidized slag, typically containing 15-20% Fe_30_4 and 4-10% Cu. The El Teniente Division of Codelco-Chile has developed a slag reduction-cleaning process, that is practised in a tilting, horizontal furnace, to recover copper from these slags. The El Teniente slag cleaning process has been successfully implemented at the El Teniente Caletones smelter and various other smelters in Chile. Today, eight such slag cleaning furnaces, each with a capacity of 800-1000 tonnes/day, are in operation in Chile. This paper discusses basic laboratory research and industrial tests that led to substantial reductions in the slag cleaning cycle time and the specific consumption of fuel and reductants. Simultaneously, the slag cleaning off-gas quality was improved. Based on the experimental results, recommendations were made to improve the practice of the El Teniente slag cleaning process. The recommended modifications have been fully implemented at the Caletones smelter.

11:45 AM
Effect of ZnO, Cu_2S and CaO on the Viscosity of Smelting and Cleaning Slags in Copper Pyrometallurgical Processes: *C. M. Acuña*[1]; C. Hú[1]; J. Jara[1]; F. Parada[2]; [1]Codelco Chile, Chuquicamata Div., Subgerencia Fundición de Concentrados, Chuquicamata, Chile; [2]Universidad de Concepción, Depto. Ingenieria Metalúrgica, Casilla 53 C Correo 3, Concepción, Chile

Copper losses in slags are of great concern, specially in smelting and slag cleaning processes. It is widely accepted that the suspension of metallic copper and matte droplets is strongly affected by the viscosity of the slag. The Chuquicamata Division of Codelco Chile produces concentrates high in zinc, an element which reports mainly to the slag phase. The ZnO may affect the viscosity and therefore the copper losses. This work aimed to investigate the effect of lime to control the viscosity of slags, and in turn to control the copper losses. By using the experimental viscosity data and the Stoke's law, the settling rate of matte prills in various slags was estimated. The results indicate the possibility of increasing the recovery of copper and/or decrease the process time.

12:10 PM
The Effect of Minor Components and Flux Additions on the Liquidus Temperatures of the Multicomponent Iron Silicate Slags: *Florian Kongoli*[1]; Ian McBow[1]; [1]Flogen Technologies, P.O. Box 49529, C.P. Du Musee, Montreal, Québec, Canada H3T2A5

Minor components and flux additions can modify the liquidus temperatures of multicomponent slags. In industrial practice, slags with various levels of minor components require various flux additions in order to achieve the lowest possible liquidus temperature. The prediction and the optimization of these combinations can decrease the cost of the overall process. In this work the effect of several minor components and flux additions such as $A1_2 0_3$, MgO, and CaO, on the liquidus temperatures of multicomponent iron-silicate slags has been analyzed in terms of a thermodynamic model. Various simple isothermal and non-isothermal diagrams are presented. These diagrams can be used directly by the process operators to define the optimum conditions under which the fluxes can be used to achieve the desired slag liquidus temperatures.

12:35 PM

Automatic Mineralogical Analysis of Copper Slags: *E. Almendras de Siegel*[1]; P. D. Siegel[2]; [1]University of Chile, Dept. of Mining Eng., Tupper 2069, Santiago, Chile; [2]University of Santiago, Departo. de Ingenieria de Minas, Av. B., O'Higgins 3363, Santiago, Chile

Pyrometallurgical processes have the thermodynamic capability of treating complex and dirty ores and concentrates to produce high purity metals and inert slags. Modern pyrometallurgical processes are environmentally sound and comparative with other processes. However, there is still a need for sensors and other practical tools that permit a rapid evaluation of the performance of these processes. In order to contribute to satisfying this fundamental requirement, the authors developed the IDENT.LA software that permits the automatic mineralogical analyses inorganic materials, including the final and intermediate products of pyrometallurgical processes. This technique allows determining the grain size distribution of mineralized inclusions, the surface relations between metallic phases, and conducting modal analyses of the essential phases that are present in the samples. Three basic automatic operations are performed: creating a representative image of the sample; identifying the metallic and non-metallic phases; and measuring the features of the resulting image. The results are used to evaluate the performance of pyrometallurgical and other processes. In this paper, the authors discuss the application of the technique to a sample of slag from a slag cleaning process that uses a carbonaceous reductant. In this case, process performance impacts not only on the efficient reduction of the slag magnetite and on copper recovery but also on the quality of the process off-gas. The mineralogical analysis of the slag is a valuable tool in assessing process performance and in recommending changes of operating conditions.

Electrorefining: Reactions During Electrorefining

Wednesday PM Room: Indigo
October 13, 1999 Location: Pointe Hilton Resort

Session Chairs: C. Anderson, CAMP of Montana Tech., Butte, MT 59701 USA; M. Van Camp, UM Research, Watertorenstraat 331, B-2250 Olen, Belgium

2:00 PM

Anodic Slimes Characteristics and Behaviour in Copper Refining: *G. Cifuentes*[1]; S. Hernádez[1]; P. Navarro[1]; J. Simpson[1]; C. Reyes[1]; A. Naranjo[1]; L. Tapia[1]; E. Correa[2]; N. Cornejo[2]; R. Abel[2]; [1]Universidad de Santiago de Chile, Depto. de Ingeniería Metalúrgica, Av. B.O'Higgins 3363, Santiago, Chile; [2]Fundición y Refinería Electrolitica Ventanas - ENAMI, Carretera F-30 E N° 58270 Ventanas, Comuna Puchuncavi, V Región, Chile

It is known that the cathode purity and the electrolyte treatment are affected by the solids present in the electrolyte. Anodic slimes properties (e.g., chemical composition, crystalline composition, sedimentation) were studied in copper electrorefining. These properties were modified through anodic composition and current density. In this investigation, we have worked with anode material from the Ventana Smelting, Hernán Videla Lira Smelting (ex–Paipote) of ENAMI (National Mining Company) and El Teniente Smelting of Codelco-Chile (National Corporation of Copper of Chile). The characterization of the anodic slimes was done as a function of current density and anodic composition.

2:25 PM

A Mineralogical Study of the Deportment of Impurities During the Electrorefining of Secondary Copper Anodes: J. E. Dutrizac[1]; *T. T. Chen*[1]; [1]CANMET, 555 Booth St., Ottawa Canada K1A 0G1

Secondary copper anodes are generally rich in Sn, Pb, Ni and Sb, but are notably deficient in Se, Te and Ag. In the secondary copper anodes, most of the Ni, virtually all of the Ag, slightly more than one-fifth of the Pb, about one-third of the As and Sb, and approximately one-tenth of the Sn are in solid solution in the copper. The remaining impurity contents occur as 1-5 µm grain-boundary inclusions in the anodes, and these are mainly Cu2O, SnO2, Cu-Pb-As-Sb-Bi oxide, Pb-Sb oxide, Sn-Ni-Zn oxide, Cu-Sn-Ni oxide, Cu-Sb-Ni oxide (Kupferglimmer) and trace Cu2(Se,Te). Barium sulphate, which originates from the mold wash used in casting, is also present in the anodes. During electrorefining, the BaSO4, SnO2, Pb-Sb oxide, Sn-Ni-Zn oxide, Cu-Sn-Ni oxide and Cu-Sb-Ni oxide inclusions are liberated and accumulate in the slimes layer. Solid solution Ni dissolves and the Ni accumulates in the electrolyte. Solid solution Sn and Pb dissolve, but partly reprecipitate as Sn arsenate and PbSO4, respectively. Solid solution Ag dissolves but rapidly reacts to form Ag2(Se,Te), Ag powder, Ag-bearing Cu2O, (Cu,Ag)SO4 or a complex oxidate phase. Partial dis-

solution of the Cu-Pb-As-Sb-Bi oxide particles takes place; the Pb component is converted to $PbSO_4$, whereas Cu, As, Sb and Bi dissolve. The reacted particles retain the morphology of the original Cu-Pb-As-Sb-Bi oxide phase. Some of the solubilized As, Sb and Bi remains in solution, but much reprecipitates as $SbAsO_4$, As-Sb-Bi oxide, and as a poorly defined oxidate phase which consists mostly of Cu-Ag-Pb arsenate-sulphate. The high Sn contents of secondary copper anodes do not seem to affect the behaviour of the anodes during electrorefining.

2:50 PM

Additive Monitoring and Interactions during Copper Electroprocessing: *D. W. Collins*[1]; J. B. Hiskey[1]; [1]University of Arizona, Department of Materials, Science and Engineering, P.O. Box 210012, Tucson, AZ 85721 USA

Several organic and inorganic substances are widely used to control deposit structure and morphology during the electroprocessing of copper. Methods for monitoring the levels of thiourea, glue and guar gum during electrorefining and electrowinning have been successfully developed under the trade names of Reatrol and CollaMat. Other instrumental methods have been developed for additives and decomposition products associated with the electroplating of copper and other metals. Generally, these methods have been found to be either insufficiently sensitive or lacking in the desired selectivity for some or all of the additives. These procedures have mostly employed DC techniques; i.e., cyclic voltammetry, Tafel analysis, etc. In this work, chronopotentiometry (CP) and AC voltammetry were used to examine the interaction of glue, guar gum, thiourea and chloride during the electroplating of copper onto a platinum electrode. In addition, the interactions between the additives have been explored. It was found that glue in pure electrolyte (H_2SO_4 and $CuSO_4$ only) had no effect on the chronopotentiogram. Glue was only active if chloride ions were present. The addition of thiourea resulted in several different chronopotentiograms depending on the presence of either chloride or chloride and glue. Thiourea used in conjunction with glue and chloride showed a significant increase in the polarization during copper deposition when compared to the electrolyte containing only glue and chloride. The use of a modified channel electrode further increased the sensitivity of CP. The use of AC voltammetry was explored as a technique to monitor some of the additives. AC voltammograms have more spectral detail then their DC counterparts and it is possible to monitor some of the additives at very low concentrations with AC techniques.

3:15 PM

The Use of Electrodialysis for Separating and Concentrating Chemical Species in Acidic Cu-Fe-As-Sb Electrolytes: *L. Cifuentes*[1]; G. Crisóstomo[1]; F. Alvarez[2]; J. Casas[2]; G. Cifuentes[3]; [1]Universidad de Chile, Dept. Ingeniería de Minas, Tupper 2069, Santiago, Chile; [2]Universidad de Chile, Depto. Ingenieria Quimica, Beauchef 861, Santiago, Chile; [3]Universidad de Santiago, Depto. Ingenieria Metalúrgica, Av.B O'Higgins 3363, Santiago, Chile

Electrodialysis (ED), i.e. a technique based on the effects of electrically charged membranes on ions in solution in an electric field, has been applied to Cu-Fe-As-Sb-H_2SO_4 electrolytes similar to those used in copper electrorefining and electrowinning operations. The effects of current density, time and species concentration have been studied in a batch ED cell. The technique has shown to be effective in concentrating and separating a range of ions and points to possible new methods of treating copper electrometallurgy effluents.

3:40 PM Break

4:10 PM

The Influence of Chloride and Glue on Copper Electrocrystallization on Titanium for Thin Film Applications: *A. J. B. Dutra*[1]; T. J. O'Keefe[2]; [1]UFRJ, Metallurgical and Materials Engineering Program, P.O. Box 68505, Rio de Janeiro, RJ 21945-970 Brazil; [2]University of Missouri-Rolla, Mats. Res. Ctr., Rolla, MO 65409-1170 USA

Electrocrystallization studies were conducted in a concentrated acid copper electrolyte to determine the influence of chloride ions and glue on copper nucleation and on the structure of thin copper layers. Electrochemical experiments allied to SEM and XRD examination were performed to characterize the mechanism of nucleation of in the presence of additives at 65°C. Results indicated that most of copper nucleation from a 83g dm-3 Cu^{2+} solution, with 140g dm-3 of H_2SO_4 is achieved in a matter of milliseconds. Although the presence of chloride and glue, at the concentration levels tested, does not seem to substantially modify the nucleation mechanism, the morphology, nuclei density and the copper film structure and orientation are changed by the presence of additives and electrolyte stirring.

4:35 PM

Nucleation and Initial Stages of Growth of Copper Electrodeposited on Anodized 304 Stainless Steel: M. Urda-Kiel[1]; L. Oniciu[1]; *J. L. Delplancke*[2]; *R. Winand*[2]; [1]University Babès-Bolyai, Chem. and Chemical Eng., 11, Arany Janos str. R 3400, Cluj-Napoca Romania; [2]Université Libre de Bruxelles, Dept. of Metall. & Electrochem., 50 Ave. F. D. Roosevelt, Brussels B-1050 Belgium

Stainless steel is increasingly used as a cathode starting sheet. It was shown earlier that even when depositing copper on copper, a substrate-influenced zone appears in the deposit structure, followed by a transition zone and finally by the electrolysis-influenced structure. On copper, the substrate-influenced zone has a thickness of twenty micrometers and on titanium, eventually more than fifty micrometers. Initial nucleation and growth have a considerable influence. In this paper, copper was deposited in a channel cell on four different 304 stainless steel substrates: mechanically polished and anodized, respectively, at 0, +400 and +800 mV/SHE in 1M H_2SO_4 at 20°C. Copper was deposited under electrowinning conditions after solvent extraction (SX) (40 g/l Cu^{++}, 180 g/l H_2SO_4, 20 or 60°C). The results showed that, although Auger surface analyses of the substrates were only slightly different one from another including the oxide thickness, nucleation and initial stages of growth were very sensitive to the surface treatment of the substrate. Potential step and current step methods gave similar results: progressive nucleation followed by 3D diffusion controlled growth. The highest nucleation frequency was observed on stainless steel

anodized at 0 mV/SHE, under various electrolysis conditions. The potential influence of these findings on industrial practice is discussed.

5:00 PM

The Application of Copper Metallurgy in the Recovery of Secondary Precious Metals: *C. Anderson*[1]; T. Fayram[2]; M. Doolin[3]; [1]Montana Tech, The Center for Advanced Mineral and Metallurgical Processing, Rm. 221, ELC Bldg., Butte, MT 59701 USA; [2]UniField Eng., Inc., 2626 Lillian Ave., Billings, MT 59101 USA; [3]GD Resources, Inc., 450 Glendale Ave., Sparks, NV 89431 USA

Most applications of copper metallurgy are geared towards primary production. However, as recycling of materials is a growing industry, one future facility will rely on copper metallurgy as a means of processing precious metals. This paper will discuss the derivation of the proposed copper pyrometallurgical and electrometallurgical unit operations to be utilized in industrial recycling of secondary precious metals.

Environment, Health & Safety: Session II

Wednesday PM Room: Copper
October 13, 1999 Location: Pointe Hilton Resort

Session Chairs: Norbet Piret, Piret & Stolberg Partners, Consulting Engs., Im Licht 12, Duisburg D-47279 Germany; J. Solari, SGA Ibersis, Encomenderos 260, Piso 9, Las Condes, Santiago, Chile

2:00 PM

Environmental Problems and Effluent Treatment in the Chilean Copper Industry: *S. H. Castro*[1]; M. A. Sánchez[1]; F. Vergara[1]; [1]University of Concepción, Dept. of Metallu. Eng., Clean Tech. Grp., P.O. Box 53-C, Concepción, Chile

In 1997 Chile was the world's largest copper mine producer with around 3.4 million metric tonnes of copper. Conventional technology (conminution-flotation-smelting-converting-electrorefining) for copper sulfide ores was used. For copper oxidized ores hydrometallurgical processes (heap leaching-solvent extraction-electrowinning) were employed. Consequently, the most important waste effluents include flotation tailings, gaseous emissions, smelter slags, acidic and alkaline wastewater, electrolytic sludges, solid residues from leaching, etc. The introduction of stricter environmental regulations are forcing the Chilean industry to minimise the generation of waste and promote cleaner production. Gas emissions such as SO_2 and arsenic from smelters and process wastewater are the major problems at this stage. The environmental impact assessment of gas emissions in all six largest smelters namely Chuquicamata, Caletones, Potrerillos, Ventanas, Paipote and Chagres led to design a "decontamination plan." The implementation of this plan resulted in (i) the installation of sulfuric acid plants for SO_2 abatement and (ii) the installation of electrostatic precipitators to remove arsenic oxides condensed from cooling gases. The aim of this paper is (i) to describe the type of waste associated to the various stages of the metallurgical processes and (ii) review the main abatement technologies used in medium and large size companies.

2:25 PM

Hernán Videla Lira Copper Smelter Fulfillment of Environmental Regulations: *Jose A. Sanhueza*[1]; Orlando C. Rojas[1]; A. E. Balocchi[1]; [1]Empresa Nacional De Minería, Fundición Hernán Videla Lira, Copiaoó, Tercera Region, Chile

The environmental regulations and terms issued by the Chilean Government for all copper concentrate smelters have been a very important reason for permitting project developments that drastically decrease the sulfur emissions due to the pirometallurgycal copper process. A remarkable case of the Hernán Videla Lira Copper smelter, located on the Copiaoó Valley and very near some housing-sets of a city of high development, are described. Results of this project's implementation of the control and reduction of off gas emissions, the control and monitoring system, the community conflicts, and the strategy to comply with the demands established by the state environmental institutions, are presented.

2:50 PM

Arsenic Management in Copper Smelting: *Norbert L. Piret*[1]; [1]Piret & Stolberg Partners, Consulting Engs., Im Licht 12, Duisburg D-47279 Germany

During smelting of copper, arsenic in the feed reports to a large extent to the gas phase and some enters the anode copper. From the gas phase it is transferred during wet gas cleaning directly, or indirectly after dust processing, to aqueous solution. During the electrorefining and anode slimes processing, the anode arsenic content is also transferred to aqueous solution. Technology for the efficient removal of arsenic from process streams and cleaning of aqueous effluents is well established. However, the arsenic-bearing products, which thereby are generated, can vary widely in consistency, quality and quantity, from large amounts of gypsum contaminated with water-soluble arsenic compounds to residues with high arsenic content or arsenic products. Arsenic management in a copper smelter not only is involved with the duty of compliance to the gaseous and aqueous emissions standards but also should have as objective the minimization of the generation of arsenic-bearing and, in general, heavy metal-bearing solid waste. The present paper outlines options and the associated economic aspects for minimization of arsenic-bearing solid waste generation, for improvement of the environmental compatibility of the residues to be deposited and for the production of commerciable arsenic compounds under appropriate market conditions.

3:15 PM

Potential Use of Electron Beam Irradiation for Abatement of Lean Metallurgical Off-Gas Emissions: *Loreto Villanueva*[1]; L. S. Ahumada[1]; W. Ellison[2]; A. G. Chmielewski[3]; Z. Zimek[3]; S. Bulka[3]; J. Licki[4]; [1]Chilean Nuclear Energy Commission, Amunategui 95, Casilla, Santiago 188-D Chile; [2]Ellison Consultants, 4966 Tall Oaks Dr., Monrovia, MD 21770 USA; [3]Institute of Nuclear Chemistry and Technology, Dorodna 16, Warsaw 03-195 Poland; [4]Institute of Nuclear Energy, Otwock, Swierk, Poland

An investigation and evaluation has been performed to determine the potential utilization of electron beam irradiation technology for sulfur oxides re-

moval from reduced-SO_2-strength metallurgical gases from copper smelters. These off-gases, though too weak to be converted to usable, concentrated sulfuric acid by conventional means, are characterized by SO_2 content higher than 2,000 ppm and a complex chemical composition, including high oxygen content and its generation occurring in a cyclical, fluctuating pattern. This work was based on information supplied by principal smelter companies in Chile. A laboratory facility with flow rate of 20 NM^3/h and equipped with an electron accelerator of beam energy 800 keV, has been used for testing. Influence on SO_2 removal efficiency of operational parameters such as gas temperature, water vapor content, ammonia feed ratio and irradiation dose was established. The main conclusion of this work, from experimental laboratory tests as well as engineering studies, is that the Electron Beam Process (EBDS) is a cost-effective, simple and appropriate chemical process means for emission abatement. EBDS can, on a site-specific basis, adequately augment SO_2 removal to upgrade overall abatement as required and in an optimal manner.

3:40 PM Break

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Uptake of Copper from Extremely Dilute Solutions by Alginate Sorbent Material: An Alternative for Environmental Control: *J. P. Ibanez*[1]; Y. Umetsu[1]; [1]Tohoku University, Institute for Adv. Mats. Proc., Katahira 2-1-1, Aoba-ku, Sendai, Miyagi-ken 980-8577 Japan

The uptake of copper from extremely dilute aqueous solutions by alginate in the form of protonated dry alginate beads was investigated. Barium was used to cross link the alginate forming the beads. The effect of various experimental parameters such as pH and metal ions concentration on the uptake of copper were studied. The uptake was strongly dependent on the Cu-bearing solution pH up to a value of 4.5. A removal of 100% was achieved when the initial concentration of copper was as low as 8.0 mg/L. The maximum uptake, i.e., the loading capacity, was found to be 167 mg of copper per g of beads. The mechanism governing the removal of copper was found to be ion exchange between protons of the alginate beads and cupric ions of the solution. For this ion exchange process a molar ratio, $d[H^+]/d[Cu^{2+}]$, of 2.0 was determined. EPMA-EDX analysis of the Cu-loaded beads showed a uniform distribution of the ions throughout the structure of the alginate, regardless the solution pH. This may suggest that this sorbent material is a porous ion exchanger having high permeability and capacity. The uptake of copper and of the heavy metals cadmium and zinc by this sorbent is compared.

4:35 PM

Use of Gracilaria Chilensis Biomass for Heavy Metals Adsorption in a Mine Waste Water: *F. Rios*[1]; M. Sanchez[1]; F. Vergara[1]; [1]University of Concepción, Dept. of Metallu. Eng., P.O. Box 53-C, Concepción, Chile

Fundamental research, at laboratory scale, on the biomass adsorption capacity of a liquid mining effluent has been done. The biomass used corresponds to a Chilean seaweed called Gracilaria chilensis. The waste water effluent corresponds to clear water coming from thickeners of a Chilean copper mining operation. The biomass was dried, washed, treated with an acid solution, and then reduced in size. A characterization of Zeta potential was made, finding negative values in a wide pH range with a ZPC equal to 2.5 1. Adsorption tests were made in an agitated system containing an artificial solution of $CUS0_4$ at a controlled temperature of 25 degrees Celsius; also, the effect of pH over the copper absorbed was studied. Maximal adsorption of copper was found at pH equal to 6, and the Langmuir model indicated values for saturation of 52.08 mg/g and for standard free energy of about -21 KJ/mol. Kinetic adsorption was very high and fitted very well with a second order model equation, finding that 90 percent of the adsorption occurred during the initial 10 minutes. After stoichiometric when I mol of copper is absorbed, 2 mol hydrogen are released, showing that the main mechanism to remove heavy metals is the ionic exchange, and the seaweed ensures total discharge of copper absorbed when the pH value is about 1. Experiments done with real waste water from thickeners lead us to conclude that optimal results for copper and molybdenum adsorption are at pH around 3.25 and the remaining treated water may be partially discharged into the water currents, thus showing that Gracilaria chilensis can be used to remove heavy metals easily from liquid effluents in the copper mining industry.

5:00 PM

Tailings Impoundments Management - The Zambian Experience: *Godwin M. Beene*[1]; Peter Chisanga[1]; Alexie Mpishi[1]; [1]Zambia Consolidated Copper Mines Limited, P.O. Box 22000, Kitwe, Zambia

Large scale mining operations started in Zambia in 1913 and rapidly expanded during the post 1930 period with the opening of several mining and processing plants on the present Zambian Copperbelt. As a consequence of poor tailings dumps design methods at the start of the mines, and in view of stringent Government Legislation pertaining to environment in the recent years, Nkana Mine has developed a unique method of dump construction at its current tailings depository, Tailings Dam 15A. This method has enabled the revegetation of the dump retaining walls while construction is still in progress, a situation which was not possible on the older dumps. Cowdung has proved to be a superior fertilizer for providing plant nutrients on the tailings. The new method of dump walls construction and walls rainwater runoff drainage system has almost eliminated tendency of gully formation which is common on older dumps, as rainfall on the Zambian Copperbelt comes in intense thunderstorms. The decanted water from the dump is discharged to the natural environment in a controlled fashion after ensuring that it meets the Zambian Government Statutory requirements.

5:25 PM

Selecting an Economical and Safe Tailings Disposal: *Han Ilhan*[1]; Pedro Repetto[1]; [1]URS Griener Woodard Clyde, 4582 S. Ulster St. Pkwy., Ste. 1000, Denver, CO 80237 USA

This paper discusses and describes aspects of a cost effective and safe tailings impoundment selection. In light of the current low metal prices and recent tailings embankment failures around the world, it is becoming extremely more important to develop tailings

impoundment design that balance cost efficiency with safety. The paper will present critical design components associated with a tailings impoundment which need to be addressed during the planning phase. Procedures for identifying various tailings impoundment alternatives, and evaluation and selection of alternatives are presented.

5:50 PM
The Challenges Posed by Mine Closure in Chile: *Marcelo E. Andia*[1]; Gustavo E. Lagos[1]; Luke J. Danielson[2]; [1]Catholic University of Chile, Ctr. for Mining, Avda. Vicuña, Mackenna 4860, Macul, Santiago, Chile; [2]International Development Research Centre, Plaza Cagancha 1335, P.9, Casilla de Correo, Montevideo 6379 Uruguay

In Chile, a significant amount of mining takes place in varied geographical environments. Mining activity extends from copper and gold deposits located in the Atacama Desert 4.500 meters above sea level to underground coal workings beneath the sea floor. This diversity in location and environment presents many challenges in the development of competitive and environmentally sustainable mining activities. An important future issue will be how to close these mines in an appropriate way once economically exploitable ore reserves have been exhausted. This poses challenges for both the government and companies alike, considering that Chilean law currently lacks legislation specific to mine closure. This paper examines the risks associated with mine closure based on international experience, and identifies those risks specific to Chilean regions. The main regions in Chile where mine closure legislation should be applied are identified.

6:15 PM
Closure or Abandonment of Mining Operations: *Ximena Massone Quiroz*[1]; [1]Chilean Copper Commission, Agustinas 1161, 4° Piso, Santiago, Chile

Chile is the most important copper producer in the world and the mining sector plays a key value in its economy. However, at present the country does not have a satisfactory set of regulations about closure and restoration of mining operations. In our country many mining operations will, in the near future, shut down their activities, therefore, it is of utmost importance to elaborate and enforce a set of regulations to prevent risks and to protect the environment. The present study is focused on reviewing and analyzing the existing national regulations about the closure of mining operations and preparing a comparative analysis with other international regulations of countries with mining experience. The final results of the study will be a legal proposal to regulate the closure of mining operations in Chile, aiming at minimizing the potential environmental adverse impact, internalizing the social costs by the relevant operators and defining all aspects of liability for the environmental damage.

Hydrometallurgy: Electrowinning

Wednesday PM Room: Hopi
October 13, 1999 Location: Pointe Hilton Resort

Session Chairs: Kevin L. Purdy, Phelps Dodge Mining Company, Process Tech. Ctr., Safford, AZ 85546 USA; Douglas Robinson, DREMCO, Phoenix, AZ 85732 USA

2:00 PM
Implementing Technology: Conversion of Phelps Dodge Morenci, Inc. Central EW Tankhouse from Copper Starter Sheets to Stainless Steel Technology: J. R. Addison[1]; B. J. Savage[1]; *Joanna M. Robertson*[1]; E. P. Kramer[1]; J. C. Stauffer[1]; [1]Phelps Dodge Morenci, Inc., 4521 U.S. Highway 191, Morenci, AZ 85540 USA

Commissioned in September 1987, the Phelps Dodge Morenci, Inc. (PDMI) Central Electrowinning (EW) Tankhouse has undergone two major expansions in its eleven-year history. A third tankhouse renovation, which began in November 1998, entails complete conversion of the 548-cell facility from a copper starter sheet based operation to Mt. Isa Process stainless steel mother blank technology. This paper outlines the operating history of the Central EW Tankhouse and reviews the conversion process, the rationale that led PDMI to undertake this project, and describes various design optimizations which have been implemented during the conversion.

2:25 PM
Coulombimetric Reduction: An Evaluation Alternative for Lead-Based Anode Corrosion: *Antonio Pagliero*[1]; Froilan Vergara[1]; Jean Luc Delplancke[2]; René Winand[2]; [1]Universidad de Concepción, Dept. of Metall. Eng., BP 53-C, Concepción, Chile; [2]Universite Libre de Bruxelles, Metallu.-Electrochem. Dept., Bruxelles B-1050 Belgium

The coulombimetric reduction method has been used as an evaluation technique for Pb-Ca-Sn anode corrosion in the LIX-SX-EW process. The proposed methodology involves three consecutive steps, i.e., cleaning, oxidation and reduction. They are carried out in the same experimental unit, in solutions containing 180 g/L $H2_{SO}4$ with and without the addition of cobalt. The authors have worked in a wide range of oxidation current densities, from 150 to 500 A/m2 for in a period from 0.5 to 120 hours. It can be concluded from the results that there would be a linear relationship between the applied electrical charge I*T (Coulomb) and the anode corrosion expressed as transformed Pb mass (mg), for solutions with or without the addition of cobalt. The exception is that for the last one the corrosion rate is 5 times faster, which was observed for every layer. From the evaluation of different corrosion layers, one can point out that its composition is mainly in the form of sulphate. In the presence of cobalt, about 67% of Pb would be as sulphate (PbS04), about 27% as a basic oxide (PbO) and only 6% as oxide Pb02 on the surface. From this result, it appears that great transformations occurred in the

metal/sulphate interface. Without the addition of cobalt, the proportion of oxide Pb02 on the surface increased up to 11.5%. According to the previous statement and considering that Pb was found mainly as sulphate, the authors recommend its determination be used as quality selection criterion. Its evaluation should be performed in the acid solutions with 200 ppm cobalt addition at an oxidation current density of 300 A/m2 for a period of 24 hours.

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A Study of the Spouted-Bed Electrowinning of Copper: V. Jiricny[1]; A. Roy[2]; *J. W. Evans*[2]; [1]Institute of Chemical Process Fundamentals, 165 02 Praha 6, Czech Republic; [2]University of California at Berkeley, Dept. of Matls. Sci. and Mineral Eng., Berkeley, CA 94720
USA

The novel spouted-bed electrode (SBE) is a cathode system where copper is deposited at a high current density in a moving bed of copper particles. Preliminary results on the deposition of copper from acidic sulfate electrolytes using this novel cathode system were described during Copper'95 conference. Despite a high current density, the electrical energy consumption was equal to or lower than that in the conventional electrowinning. The present paper describes more investigations on SBE. The SBE consists of copper particles with approximately I nun diameter onto which copper is deposited from acidic sulfate electrolyte whose composition is similar to conventional electrowinning. Three types of anodes were used in conjunction with the spouted-bed cathode, namely, DSA anode for oxygen evolution, and two novel anodes. One anode is less expensive than DSA; however it showed much promise in energy consumption. At a superficial current density of 2200 A/m^2, the energy consumption was around 1.0 kWh/kg copper.The research activities described in this paper were supported by BHP Copper.

3:15 PM

Guar Concentration Measurement with the CollaMat System: *Peter Stantke*[1]; [1]Norddeutsche Affinerie Aktiengesellschaft, Hovestrasse 50, Hamburg 20539 Germany

In recent years the CollaMat process has been used successfully worldwide in a number of copper electrorefining tankhouses as an instrument for measuring the glue concentration and optimizing cathode quality. Owing to its measuring principles the CollaMat can be used not just for measuring the concentration of active glue but also the activity of other substances, which have an impact similar to glue on the copper deposition. In SX-EW plants guar is frequently used instead of glue as a leveling additive. In our laboratory the effect (activity) and the decomposition rate of guar in copper electrolyte was examined. As expected, the results show that guar has an effect similar to glue on the copper deposition. However, at the same temperature, a greater quantity of guar is required to achieve the same results. As with glue, the decomposition rate (due to hydrolysis) of guar is strongly dependent on the temperature. Therefore, in practice, its on-line monitoring is necessary to guarantee the same guar activity at any time.

3:40 PM Break

4:10 PM

Iron, Chloride and Permanganate Control in Copper Electrowinning Tankhouses: *Richard Shaw*[1]; Juan D. Illescas[1]; Cara Tomasek[1]; Simon Jupp[1]; *David Dreisinger*[2]; B. Wassink[2]; *Dave Readett*[3]; *Tom Lancaster*[4]; [1]Eichrom Industries, Inc., Hydrometallurgy, 8205 S. Cass Ave., Suite 111, Darien, IL 60561 USA; [2]University of British Columbia, Dept. of Metals and Matls. Eng., 309-6350 Stores Rd., Vancouver, British Columbia, Canada V6T 1Z4; [3]Straits Resources Limited, Level 3 Gold Fields House, 1 Alfred St., Sydney, NSW 1220 Australia; [4]Nifty Copper, WA Australia

Iron, chloride and manganese are the three major impurities transferred to copper electrowinning tankhouses via chemical and/or physical entrainment. The control of these impurities via bleeding of tankhouse electrolyte is costly. Recently, Eichrom Industries have developed an improved iron control process and tested this process in a pilot study at the Girilambone Copper Company (GCC). The patented process utilizes a fixed bed ion exchange reactor filled with Eichrom's Diphonix resin. Iron is loaded on the resin and subsequently eluted by a cuprous sulfate eluant. The control of chloride and manganese has been studied using different chemical techniques. The removal of chloride from electrowinning electrolytes was tested using precipitation of chloride as cuprous chloride. Copper wire cuttings are used to produce cuprous ions. Chloride levels are reduced to around 30 ppm in electrolyte at 40ϒC. The removal of manganese using a precipitation process practiced in zinc electrowinning purification has been tested for implementation. The process involves reacting manganous ions in solution with permanganate ions. The reaction produces an insoluble manganese dioxide reaction product. The bench scale and pilot plant results from testing of these purification processes are reported.

4:35 PM

Iron Removal from Leachate by Limestone Precipitation and Direct Electrowinning of Copper: *Baoguo Zhang*[1]; Maurice C. Fuerstenau[1]; [1]University of Nevada, Dept. of Chem. and Metall. Eng., Mackey School of Mines, Reno, NV 89557 USA

A study of iron-removal from copper leachate by limestone precipitation followed by direct electrowinning of copper has been conducted. The influence of the process parameters: amount of precipitant, contact time, temperature, agitation intensity, solution acidity, and initial iron concentration on iron-removal was investigated. The effects of electrowinning time, cell voltage, solution acidity and temperature on electrowinning of copper were also investigated. The leachate contained 1.20 g/l Cu^{2+} and 7.41 g/l total iron at pH 2.27. After contacting with 14 g/l precipitant for 2 hours, 97.5% of the iron was attenuated and 98.4% of the copper was recovered. With the following electrowinning conditions: 3 lead anodes, 3 stainless steel cathodes, 2.5 V, 39.41 A/m2 and 10.7 g/l H2SO 4 copper recovery was 98.4%. Purity of copper powder produced was greater than 99.0%.

5:00 PM

Modeling and Simulation of Copper Electrowinning: *Hossein Aminian*[1]; Claude Bazin[1]; Daniel Hodouin[1];

[1]Laval University, Dept. of Mining and Metall., Ste-Foy, Québec, Canada G1K-7P4

Copper electrowinning (EW) is an important process in connection with the solvent extraction to produce pure and marketable copper cathodes. A phenomenological model was developed to simulate the copper electrowinning process. The simulator is used to predict the operation of the Mines Gaspe pilot plant electrowinning cells put in operation in 1996. Results confirm the potential of the simulator that would subsequently be used for student training, process optimization and assessing the performances of control strategies.

5:25 PM

Application of a Two Phase Hydrodynamic Modeling to an Electrowinning Cell: *Andreas Filzwieser*[1]; Klaus Hein[1]; Peter Paschen[1]; G. Hanko[1]; Herwig Grogger[2]; [1]University of Leoben, Dept. of Nonferrous Metall., Franz-Josef-Strasse 18, Leoben, Styria A-8700 Austria; [2]AVL List GmbH, Hans-List-Platz 1, Graz, Styria A-8020 Austria

The highest current density suitable for the electrowinning process is between 50 to 60% of its limiting current density. One of the most important influences on the limiting current density is the thickness of the hydrodynamic boundary layer near the electrode surface. Therefore, the fluid flow in a copper electrowinning cell is calculated. The numerical simulation—using the CFD-software package FIRE —considers all three different types of the fluid flow, namely, the natural convection, the forced convection by electrolyte circulation and the forced convection by electrochemically induced gas stirring. The simulation of natural convection is based on the different density values in the boundary layer at the electrode surface given by a density/concentration correlation. The copper concentration—linked with the current density by Faraday law—is solved by an additional transport equation. The simulation of the forced convection by the electrochemically-induced gas stirring is done by using a real two-phase calculation. That means that all differential equations are solved again for the second phase. The numerical solution of the fluid flow field is compared with the results of LDA-measurements which were done in a special cell. The software for the LDA enabled a calculation of the void fraction possible and therefore a rough estimate of the mass transfer coefficient through the prevailing gas bubble induced convection can be made by assuming the influence of relative bubble volume.

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A Statistical Approach Study of Copper Electrowinning Parameters: *Damir Valic*[1]; A. S. Tombalakian[1]; A. Alfantazi[1]; R. R. Moskalyk[1]; [1]Laurentian University, School of Engr., 935 Ramsey Lake Rd., Sudbury, Ontario, Canada P3E 2C6

In 1997, 9.2 million tonnes of mined, recoverable copper was produced, of which, 1.8 million tonnes or 19.4% was produced by leaching, solvent extraction and electrowinning. The amount of copper produced by this method grew faster than those attained from concentrate smelting, signifying the growing importance of this low-cost production method. Statistical experimental design, unlike traditional approaches, allows for proper distribution of experiments within the boundaries of factors being studied such that the number of experiments required to develop a sound relationship between the factors and a response is minimized. In the past, very little use has been made of statistical experimental design in copper electrowinning studies. Traditional one-variable-at-a-time approaches are widely employed for this purpose. The present study employs a factorial experimental design to relate current efficiency with current density (180 and 300 A/m^2), copper concentration (25 and 65 g/L), and temperature (40 and 60ºC). Pure synthetic electrolyte with a constant acid concentration of 180 g/L was used throughout the study. The designed study produced a linear relationship where the independent variables of current density, copper concentration, and temperature, and their interactions, were found statistically significant. It was shown that current efficiency could not solely be used as a predictor of copper cathode quality. The quality of the deposit is difficult to be incorporated into a model or relation. It was determined that other measures, such as cathode morphology and crystal structure should be considered. This was done through XRD and SEM analysis.

Pyrometallurgy-Operations: Session VII

Wednesday PM Room: Estrella
October 13, 1999 Location: Pointe Hilton Resort

Session Chair: Chris Newman, Kennecott Utah Copper Corporation, Magna, UT USA; R. Alvarado, El Teniente Division, CODELCO-Chile, Rancagu, Chile

2:00 PM

Online SO_2 Analysis of Copper Converter Off-Gas: *A. A. Shook*[1]; O. Pasca[1]; G. A. Eltringham[1]; [1]BHP Copper Smelting and Refining, 200 South Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA

The off gas from the #5 converter at BHP Copper's San Manuel smelter was analyzed continuously over a period of several weeks using an on-line SO_2 analyzer. These data has shown that the oxygen utilization efficiency of this copper converter was somewhat lower than anticipated, and that oxygen efficiency declines significantly during the copper blow. A sharp reduction in SO_2 generation was consistently observed at the end of the copper blow, which could be used by converter operators to prevent over-blowing and minimize rolling out of stack.

2:25 PM

Arsenic Slagging of High Matte Grade Converting By Limestone Flux: *C. M. Acuña*[1]; J. Zuñiga[1]; C. Guibout[1]; P. Ruz[2]; [1]Subgerencia Fundición de Concentrados, Codelco Chile-Division Chuquicamata, Chuquicamata, Chile; [2]Institute for Mining and Metallurgy Innovation/IM2, Av. del Parque 4980, Ciudad Empresarial, Huechuraba, Santiago, Chile

At the Chuquicamata Division of Codelco-Chile high arsenic concentrates are produced, which at the smelter are processed via the Outokumpu Flash Furnace and Teniente Converters to obtain copper

mattes. In the case of the Teniente Converters the production of matte grade near white metal composition is a common practice since the eighties and provided in pyrometallurgical route no appropriate measures are taken, penalties have to be paid because of arsenic content in the anodes. During smelting huge volume of slag is produced and elimination of arsenic by slagging at this step is not economically attractive. Although during fire refining is possible to eliminate arsenic by use of mixtures of calcium and sodium carbonates this alternative is expensive, takes long process time and decreases the lifetime of the refractory lining. In spite of these facts a reasonably way to control arsenic in metal, and therefore in the anode, is taking action in the converting step. The effects of oxygen and arsenic content in metal, arsenic in white metal and basicity index of the slag upon the distribution coefficient of arsenic between metal and slag were investigated at pilot and industrial levels. The best results are obtained for metals around 7,000 ppm oxygen and 0.3 basicity index slag, which results in a 5.7 distribution coefficient for a 5,800-7,100 ppm arsenic content in white metal, 18%-24% CaO slag at 1473-1523K. Furthermore, no significant/visible refractory wear has been realized.

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Use of Optical On-line Production Control in Copper Smelters: *Willy Persson*[1]; *Wilhelm Wendt*[1]; S. Demetrio J.[2]; [1]Semtech Metallurgy AB, Ideon, Lund S-223 70 Sweden; [2]ConOpti S.A., Cerro San Ramon 1491, Las Condes, Santiago, Chile

The first installation at a copper smelter of a Semtech OPC System for continuous, on-line production control of copper converting in PS converters took place in 1994. At present OPC systems are installed at 19 PS converters. The technology presents to the operator real-time information on the progress of the process he is controlling in the form of optical process parameters, thus facilitating dynamic process control. The optical process parameters are based on time and wavelength resolved registrations of the light emitted by the off-gas flames and identification of correlation between these parameters and characteristic metallurgical process data. The present paper provides a description of the technology as seen by the furnace operators and a summary of operating experiences made during five years of full-scale operation at various smelters, reviews influences from the technology on smelter operational practises and comments on recent developments as regards new applications of the technology.

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Porous Plugs in Molten Copper Production and Refining: *A. J. Rigby*[1]; Michael D. Lanyi[2]; [1]Narco Canada, Inc., Non-Ferrous Mktg., P.O. Box 910, 4355 Fairview St., Burlington, Ontario, Canada L7R 3Y7; [2]Air Products and Chemicals, Inc., Applications Dev., Metals Industries Grp., Allentown, PA 18195-1501 USA

Current practices employing porous plugs to inject nitrogen into molten copper during primary smelting are described. Nitrogen stirring increases heat transfer to the bath, eliminates temperature stratifications, and improves efficiency during the steps of desulfurization and deoxidation. The opportunity to use porous plugs as the means to introduce reducing gases to deoxidize copper is also discussed. Previously reported laboratory results using porous plugs, which point to very high utilization efficiencies of hydrogen when used as the reducing gas, are again reviewed. Advances in the design of the porous plug, and the introduction of a system enabling external replacement of plugs is also discussed.

3:40 PM Break

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Redesigning the Flash Furnace Feed System at BHP Copper: *D. J. Goodwill*[1]; D. M. Jones[2]; T. A. Royal[3]; [1]H. G. Engineering Limited, 400 Carlingview Dr., Toronto, Ontario, Canada M9W 5X9; [2]BHP Copper, Inc., 200 S. Redington Rd., P.O. Box M, San Manuel, AZ 85631 USA; [3]Jenike & Johanson, Inc., One Technology Park Dr., Westford, MA 01886 USA

BHP Copper operates a 3,400 tpd dry concentrate, single burner, Outokumpu flash smelting furnace (FSF) at their San Manuel copper smelter in Arizona. The very fine (-325 mesh), dry concentrate is fed to the burner from a 550 metric ton (nominal) capacity furnace feed bin via two drag chain feeders. During the 10-year history of the furnace, operations have been plagued by serious feed flooding problems. The fine concentrate sometimes becomes aerated during discharge from the bin and flows like a fluid at very high, uncontrollable rates to the burner. This results in upset conditions at the concentrate burner resulting to poor furnace metallurgy. This paper will examine the problems of uncontrolled feed from the furnace bin (i.e. flooding), and instantaneously feeding a flash smelting burner. It will show that a drag chain is a poor choice of feeder when high rates are needed, and that drag chains always produce a funnel flow pattern in a bin. BHP's drag chains cause narrow diameter, high velocity flow channels within the stored material. Consequently, there is insufficient residence time for the concentrate to fully de-aerate before discharge, hence flooding occurs. In addition to the flooding problem, drag chains create a pulsating flow to the concentrate burner due to the tendency for material to slough off in discrete chunks at the discharge end of the slow moving chain conveyor. During the scheduled FSF rebuild in May 1999, BHP intends to remove the drag chains, modify the bin to a mass flow design and to use STAMET® multi-disc feeders to accurately and instantaneously control the rate of discharge from the bins. Air slides will be used to convey the concentrate to the burner.

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Development of More Environment-Friendly and Cost-Effective Drying Facility for Copper Concentrates: *Jarkko Kalevi Partinen*[1]; Shao Long Chen[1]; Olli Tiitu[1]; [1]Kumera Corporation, Tech. Ctr., Kumerankatu 2, Riihimäki, Finland FIN-11100 Europe

Drying is a unit process which has numerous applications in the metallurgical process industry. Kumera Technology Center, being a worldwide equipment and process supplier, has developed sophisticated solutions for both direct and indirect drying. In conventional direct drum drying, the energy is taken from combustion of fossil fuels, requiring energy input and emitting considerable amount of off gases. In modern copper smelters, thermal energy from the off gases is recovered in waste heat boilers making the steam available. Using that steam as the energy source for

concentrate drying, the total volume of off gases can be considerably reduced and releasing of harmful combustion gases into the atmosphere can be avoided. Kumera Technology Center has recently developed and promotes a new steam drying process for drying of copper concentrates. In the development of the new dryer, Kumera's approach has been to combine the best properties of both the steam dryers and the drum dryers. In the design special attention has been paid to overcome problems of excessive wear and clogging and to reduce the required maintenance operations. In this paper the environmental issues and energy consumption related to both direct and indirect drying processes are discussed. The estimated operation costs and emission levels are compared, based on calculations and the data collected from industry. Finally, the development project of the Kumera Steam Dryer is briefly reviewed.

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Indirect Drying of Concentrates at Copper and Nickel Smelters by Means of Innovative, Cost Effective Environmental Technologies: *Christian Monjau Sagedahl*[1]; Hans Joergen Broenlund[1]; [1]Kvaerner Eureka, Proc. Div., Joseph Kellers vei 20, P.O. Box 38, Tranby, Lier N-3401 Norway

The stringent environmental regulations for air pollution regarding emission control, along with the need of dry concentrates to feed autogenous smelting processes, are enhancing the development of cleaner technologies. Indirect drying of concentrates by a Kvaerner steam dryer is a technology with promising results, reducing dust entrainment to the exhaust gas stream and leading to smaller dust separation units. The Kvaerner dryers are designed for a very high availability, a high-energy efficiency, low amount and velocity of exhaust gases, no SO_2, CO or CO_2 emissions combined with a wide range of satisfactory operating conditions and low total operational costs.

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Agglomeration of ESP Dusts for Recycling to Plant Smelting Furnaces: Peter Ryan[1]; *Neil Smith*[1]; Claudio Corsi[1]; Tim Whiteus[1]; [1]Produ-Kake®, Inc., 3285 Mainway, Unit 4, Burlington, Ontario, Canada L7M 1A6

A patented process for agglomeration of Smelter ESP dusts is described. Addition of suitable binders followed by compaction, transforms fine, difficult to handle material into a dry, flowable agglomerate suitable for plant reentry. Details for the agglomeration process metallurgy and laboratory pilot plant testing are discussed. An example of full scale plant operations is described.

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Philippines Associated Smelting Electrostatic Precipitor Upgrade: *Clodualdo C. Conde*[1]; Bob Taylor[2]; Suresh Sarma[3]; Jose Suarez[2]; [1]PASAR, 3rd and 4th Floors Morning Star Ctr., 347 San Gil J. Puyat Ave., Makati, Metro Manila 3120 Philippines; [2]BHA Group, Inc., 8800 E. 63rd St., Missouri, Mo 64133 USA; [3]BHA Group International Private Ltd., Friend's Park Co-op Society, 2nd Floor, Lohia & Jain Business Ctr., Senapati Bapat Marg, Shivajinagar, Pune 411 053 India

In order for Philippines Associated Smelting and Refining Corporation (PASAR) to remain a leader in the copper smelting and refining industry, continuous improvements in plant technology are required. Reliable performance of plant equipment is essential for a competitive smelting operation. PASAR is constantly searching for the best equipment and technology to allow us to manufacture products more efficiently. When the Smelter was commissioned in 1993, the Flash Furnace off-gas treatment system was a constant source of problems. There were frequent shut-downs of the electrostatic precipitator due to material buildups on the discharge electrodes and collecting plates. In 1998, the precipitator was successfully upgraded to eliminate the buildup problems and to increase the collection efficiency. The upgrade greatly reduced down time and maintenance, and the enhanced collection efficiency also eliminated pluggage problems and material losses in the Acid Plant. This extensive precipitator upgrade was accomplished during a 30-day Smelter turnaround.

Smelting: Technology Development, Process Modeling and Fundamentals: Fundamental Studies and Technology Development - II

Wednesday PM Room: Goldwater
October 13, 1999 Location: Pointe Hilton Resort

Session Chairs: Torstein Utigard, University of Toronto, Dept. of Metall. and Mats. Sci., 184 College St., Toronto, Ontario, Canada M5S 3E4; Ralph Harris, McGill University, Dept. of Mining and Metall. Eng., Rm. 2220 Wong Bldg., 3610 University St., Montreal, Québec, Canada H3A 2B2

2:00 PM
Studies on the Reactivity of Copper and Nickel Mattes under Suspension Smelting Conditions: *Johanna Tiina Sjöblom*[1]; H. Yliheljo[1]; Ari Jokilaakso[1]; Jukka Yli-Penttilä[2]; [1]Helsinki University of Technology, Dept. of Mats. Sci. and Rock Eng., P.O. Box 6200, Espoo, HUT FIN-02015 Finland; [2]Huber Testing Oy, P.O. Box 120, Vantaa FIN-01511 Finland

New copper and nickel processes, flash converting and DON, direct high-grade nickel matte smelting, have been developed in order to replace the conventional and not so environmentally friendly PS-converting process. With a laboratory scale laminar-flow furnace the combustion reactions of sulfidic feed particles can be investigated under simulated flash smelting conditions. In the present study, finely ground and screened feed fractions of a copper matte and a nickel matte were flash oxidized in a laminar-flow furnace. The experiments were carried out using 20, 21 vol% and 75 vol% 0_2 in nitrogen, at temperatures 1100 and 1300ºC and reaction zone length of 7.5-16 cm. The samples were quenched in a water film after a specified reaction time. The matte particle reactions were stopped after short residence time intervals in order to obtain a better understanding of the reaction mechanisms. Chemical analysis was used to determine oxidation degree, and optical and scanning electron microscope combined with energy dispersive analysis was used for characterization of

the reacted particles. On the basis of the experimental results the reactivity of the mattes is discussed and possible reaction and dust formation mechanisms are considered.

2:25 PM

Behaviour of Copper Matte Particles in Suspension Oxidation: *Esa J. Peuraniemi*[1]; Juha Jarvi[2]; Ari Jokilaakso[1]; [1]Helsinki University of Technology, Lab. of Mats. Proc. and Powder Metall., P.O. Box 6200, Espoo, HUT FIN-02015 Finland; [2]Outokumpu Research Oy, P.O. Box 60, Pori FIN-28101 Finland

Recently commissioned Kennecott-Outokumpu flash converting was developed to replace the approved but environmentally outdated Peirce-Smith, converting to satisfy the globally tightening emission regulations. In the present study, dust formation and reaction mechanisms of two copper mattes with different experimental parameters were studied in lean suspension conditions. Both mattes had very high copper content of approximately 75 wt% and low iron content of 4.5 wt% and 1.2 wt% Fe. A laboratory scale, vertical laminar-flow furnace with a low feeding rate was used to simulate the phenomena taking place in the reaction shaft of a flash converter. Experimental conditions included temperature of 1300ºC with reaction gas oxygen contents of 20 vol%, 50 vol%, and 75 vol%. In the experiments, sieved particle fractions were fed to the furnace and sampled after short reaction time intervals by quenching them into a water film. Collected particles were analysed chemically for their main elements to define their removal rates. Also, optical and scanning electron microscopy with EDS-analyser were applied to determine phenomena occurring during reactions. Kinetics of oxidation as well as ignition of particles are discussed. Changes in particle morphology, size, and composition are reviewed to describe dust formation and reaction mechanisms.

2:50 PM

Sampling the Shaft of the Olympic Dam Copper Flash Furnace: *D. N. Collins*[1]; F. R. A. Jorgensen[2]; W. J. Rankin[2]; [1]WMC Resources, Ltd., (Olympic Dam Corporation); [2]CSIRO Minerals, G.K. Williams Cooperative Rsch. Ctr. for Extractive Metallu., P.O. Box 312, Clayton South Victoria 3169 Australia

A sampling program was conducted in which both spoon and isokinetic sampling techniques were used to collect samples from the reaction shaft. The samples were then characterised by chemical, XRD and mineralogical analysis. Further information was acquired by measuring the oxygen potential and temperature at the bottom of the shaft using disposable probes. Comparison of the results of the two sampling methods showed that the spoon samples were devoid of material less than 25m. Sulfur analyses on the samples provided information on the extent of reaction, plume shape and recirculation patterns. Disposable probe measurements showed the measurable particle temperatures ranged from 1150 to 1700ºC and that the material falling into the bath had a normalised oxygen potential similar to the slag. These latter measurements combined with the sulphur elimination and mineralogical analyses provided further information on the extent of reaction and enabled the reaction sequence to be ascertained.

3:15 PM

Oxidation of Copper Matte by Gas Injection: *Ron Hiram Schonewille*[1]; James M. Toguri[2]; [1]Falconbridge Limited, Falconbridge Tech. Ctr., Falconbridge, Ontario, Canada P0M 1S0; [2]University of Toronto, Dept. of Metall. and Mats. Sci., 184 College St. W., Toronto, Ontario, Canada M5S 1A4

Experiments were conducted by injecting air-oxygen gas mixtures through a ceramic lance into molten copper matte and measuring the sulphur dioxide content of the offgas. The injection conditions were characterized by measuring pressure fluctuations immediately upstream of the lance and capturing the information on an oscilloscope screen. The parameters investigated were gas flowrate, lance geometry, lance immersion, orifice diameter and melt composition. An overhead nitrogen lance was used in specific tests to create an inert gas blanket directly above the bath surface to inhibit reaction in this region. The extent of oxidation was modeled by separating the gas-liquid contact into three stages; bubble growth, bubble rise and bubble rupture. The contribution of each stage to oxygen utilization was determined by varying the lance immersion and by performing tests both with and without an inert gas blanket. Bubble rise was found to be relatively unimportant, accounting for less than 5% of the total oxygen utilization. Bubble rupture and bubble growth were found to contribute approximately equally, with bubble rupture becoming more important with increasing gas flow rate. This study highlights the importance of reactions taking place above the bath surface in a copper converter.

3:40 PM Break

4:10 PM

Activity Measurement of Minor Elements in Cu-S-Me (Me = Ag, Se, Te) and Cu-Fe-S-Me Matte Systems at 1473 K by Mass Spectrometric Method: *Alireza Zakeri*[1]; Mitsuhisa Hino[1]; Kimio Itagaki[1]; [1]Tohoku University, Instit. for Adv. Mats. Proc. (IAMP), 2-1-1 Katahira, Aoba-ku, Sendai, Miyagi-ken 980-8577 Japan

To evaluate the behavior of minor elements in the copper smelting process, activities of silver, selenium and tellurium at minor concentration were determined at 1473 K within the miscibility gap of the Cu-S-Me (Me = Ag, Se, Te) and Cu-Fe-S-Me systems varied in Fe/Cu ratio. Phase relations between the immiscible metal and matte phases in the foregoing systems were first established by a quenching technique at 1473 K to supplement the activity measurement data. A Knudsen-effusion mass spectrometer, capable of handling complex gaseous systems and relatively small vapor pressures, was adopted for activity determination. Using a multiple Knudsen-cell, the ion intensity of minor element in the sample under study was measured simultaneously with that in a reference sample. Activity was obtained from the ratio between the measured ion intensities as well as the known activity value of the minor element in the reference sample. Limiting activity coefficients of the minor elements were correlated with composition of the matte. Based on the experimental results, the vaporization behavior of the minor elements has been discussed.

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Direct Reduction of Copper-Iron-Silicon Oxide Melts: *Roberto Andrés Parra*[1]; Igor Wilkomirsky[1]; Michel Paul Allibert[2]; [1]Universidad de Concepción, Dept. Ing. Metalúrgica, Edmundo Larenas 270, Concepción, Chile; [2]Institute National Polytechnique de Grenoble, LTPCM, BP. 75, Saint Martin D'Heres 38402 France

The selective reduction smelting of Cu_2O in Cu_2O-FeO_x-SiO_2 melts has been studied at the laboratory level, using as a feed a dead roasted calcine from a copper concentrate. The purpose of the study was to evaluate the kinetic and mechanisms of the indirect reduction with CO and the direct reduction with graphite from 1260ϒC to 1350ϒC. The reduction rate by CO was found to be 10^{-2} to 10^{-1} mole Cu_2O $m^{-2}s^{-1}$. The graphite reduction macrokinetics for FeO and Fe_2O_3 containing melts, was found to be a first order reaction with respect to the Cu_2O concentration, with a kinetic constant of 10^{-4} to $10^{-3}s^{-1}$. The reduction rate was not sensitive to temperature nor to stirring, in the range studied. The measured reduction rate is almost one order of magnitude larger than the observed rate for the direct reduction of FeO.

5:05 PM

Corrosion Testing of Chrome-Free Refractories for Copper Production Furnaces: Michael D. Crites[1]; *Mark E. Schlesinger*[1]; [1]University of Missouri-Rolla, Dept. of Metall. Eng., 1870 Miner Circle, Rolla, MO 65409-0340 USA

As part of a multi-year program for assessing the viability of chrome-free refractories in copper smelting, converting and refining furnaces, dynamic corrosion tests have been conducted on a series of refractories from the magnesia-alumina system, using a ferrous silicate slag. The corrosion rates of the test refractories are compared with those of a reference mag-chrome brick, and recommendations are made for more in-depth evaluations of the more corrosion-resistant materials.