

## **SUMMARY**

Over 40 years of experience in engineering, process assessment, research and development, and plant-oriented studies for the nonferrous industry worldwide. Primary emphasis has been on chemical processing and hydrometallurgy, particularly for copper. Technology has included heap, dump, vat, agitation, bio-, and in-situ leaching, plus metal value recovery. Additional experience in leaching other metals, particularly gold and silver. Also extensive work in comminution and flotation, solvent extraction and electrolytic processes, environment control and assessment, pyrometallurgy and mining. Coverage includes new and existing operations, new mineral prospects, new technology, laboratory and pilot plant programs, due diligence assessments contractor liaison. Experience is presented in reverse chronological order with most recent projects listed first.

## **CREDENTIALS**

Ph.D., Metallurgy (1968); Pennsylvania State University  
B.S., Metallurgical Engineering (1964); Carnegie Institute of Technology  
Qualified Professional member of The Mining & Metallurgical Society of America  
(No. 01003QP, with specialty in metallurgy)  
Registered Professional Engineer, Texas (No. 53603)  
Patents: U.S. No. 3,723,598 for SO<sub>2</sub> removal  
U.S. No. 4,152,142 for smelter slag processing

## **EXPERIENCE**

### **Metal Production by Leaching and/or Flotation**

Currently teamed with Ausenco to develop, manage and interpret the copper leach testwork program for the Aktogay oxide project in Kazakhstan. This involves both smaller column tests for different process variables and confirmatory tests using large (multi-tonne), full height columns for each of the major ore types. An important consideration is the extreme cold at the site during the winter.

Now completing work for a private client to help restart a small milling and flotation operation in the western U.S. The mill is now retreating existing tailings, mixed with high-grade copper-silver-gold ore from a series of closely spaced skarn deposits. One aspect of the work has been to develop, manage and interpret milling and flotation tests on existing tailings, stockpiled ore and ore from previously unmined deposits. The work has also included development of pre-float steps for gravity-recoverable gold and magnetic recovery of a salable magnetite product for use in heavy media plants. A separate agitation leach program is also under way to assess the feasibility of recovering the oxide copper from the final flotation tails using either sulfuric acid or ammonia.

Retained as consulting metallurgist by Peregrine Metals Ltd. for their Altar copper project in San Juan Province, Argentina. Originally managed the leach portion of the Phase 1 testwork. Then managed Phases 2 and 3 of the metallurgical testwork, an integrated program covering flotation and copper heap leaching. This work supported issuance of a Preliminary Assessment and updated NI 43-101 report. A separate program was conducted to study recovery of gold from the leach cap and an adjacent epithermal quartz resource.

Retained by Geologix Explorations, Inc. as metallurgical consultant. Has prepared due diligence reports on potential acquisitions in Mexico. Managed a metallurgical testwork

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program on for Tepal. This included milling and flotation for the sulfide resource in a copper-gold porphyry deposit. The program also involved cyanide leaching for gold recovery from the oxide cap, including use of SART technology to deal with the cyanide-soluble copper. A Preliminary Assessment for the project had already been completed. The current program supported development at the prefeasibility level.

Teamed with GRD Minproc as leach consultant on the definitive feasibility study for Marcobre S.A.C's Marcona Copper Project on Peru's southern coast. More recently provided additional consulting services directly to Marcobre. The main activities centered on treatment of the overlying oxide ore. Participated in design of an integrated testwork program involving bottle roll and column leach tests, which led to selection of a vat leach flowsheet for the project. The work culminated with design and operation of a vat leach pilot plant run in Peru. Activities included detailed interpretation of the test results and extrapolation of leach extraction and acid consumption to the commercial operation. Additional activities included in-depth reviews of the design and engineering packages for the SX-EW facilities.

Participated in an in-depth internal review of Rio Tinto's La Granja project in Peru. The main focus was copper heap leaching and control of copper-bearing acid drainage from mine waste dumps. Provided consulting services to Energy Resources of Australia, Ltd. for their Ranger uranium heap leach project. The main focus was on scale-up criteria for extrapolating test data to the commercial operation. Proposed solution management practices were also reviewed. Several changes were recommended in both areas.

Assisted a confidential client with preparation of a due diligence study on acquisition of a polymetallic (Cu-Zn-Pb-Ag) deposit in Peru. Also conducted an operations improvement program on the client's existing copper leach/SX-EW operation in Arizona. Prepared scoping studies on use of cementation to recover copper at small leach operations in Armenia and Zambia.

Served as consultant to Kennecott Utah Copper on their project to design and install a small SX-EW facility at the Bingham Canyon mine. Construction of the plant is currently suspended. When complete, the plant will recover copper from adverse mine water before final treatment and discharge.

Consulting metallurgist to Tethyan Copper Co. for their Tanjeel copper leach project in Pakistan. Consulting metallurgist to confidential client for due diligence evaluations on three copper mine-to-leach properties (Chile, Mexico and U.S.A.) being considered for acquisition. The main areas reviewed were the metallurgical testwork, the proposed leach parameters and designs for the heap leach and SX-EW facilities.

Leach-SX-EW consultant to Rio Tinto for the technical evaluation of the Escondida sulfide run-of-mine (ROM) leach project. The main areas under review included the copper recovery, the design of the forced aeration system and the potential for heating the leach dump through pyrite oxidation.

Metallurgical consultant to Phelps Dodge for a detailed review of the proposed metallurgical parameters for leaching both the Dos Pobres and San Juan oxide ores in the Safford district. The parameters for the Dos Pobres ore body were confirmed, but Phelps Dodge was advised to do further testing on a representative sample of San Juan ore. Phelps Dodge has now developed the property.

Lead Technical Consultant on a detailed risk assessment of a potential run-of-mine (ROM) dump leach operation at Newmont's Batu Hijau mine in Indonesia. The main concern was

the water balance associated with the heavy seasonal rains at the site, plus the potential impact this could have on the proposed SX-EW operation.

Lead Process Engineer for the Phelps Dodge 27 / 28 Dump Leach Expansion Project, including studies and engineering to increase the capacity of the Miami leach dump by more than 45 million tons. Trade-off studies included evaluation of four alternatives for PLS pumping systems.

Process Specialist for Ivanhoe Mines Ltd. and its operating subsidiary, Myanmar Ivanhoe Copper Company Limited. Responsible for assisting the present Sabetaung-Kyisintaung copper heap leach/SX-EW operation with improvements in appropriate plant areas and for providing conceptual engineering for the adjacent undeveloped Letpadaung deposit. Both projects are located in a typical tropical setting with distinct dry and monsoon seasons.

Process Specialist for the El Abra ROM leach project in Chile. The project involved a major on-site leach testing program and feasibility study to determine if the present heap leach system could be expanded to include low-grade run-of-mine ore. Any increase in production would utilize spare capacity in the SX-EW operation and have a low incremental cost. The project was implemented.

Lead Process Engineer on the leach/SX-EW portion of the Cerro Negro Project in Peru (65-tpd cathode). Duties focused on interpretation of metallurgical test results and their extension to the design of the leach system, analyses of the optimum crush size and heap stacking alternatives, and details of the leach, SX-EW and process water systems.

Lead Process Engineer for Cobre Mining Company's planned Hanover Mountain Project in New Mexico, a 10-million stpy heap leach operation with 75 stpd of copper cathode output via SX-EW. The scope included evaluation of metallurgical test results and selection of commercial leach system parameters, analysis of conveying vs. trucking for crushed ore placement, and all details of SX, EW, and process water facilities. The project was never completed, as Phelps Dodge acquired the company.

Conducted an in-depth review of the Intec copper hydrometallurgical process.

Consulted on Hierro Mantua copper leach project in Cuba, the Sanyati poly-metallic heap leach operation (Cu, Co, Mn and Zn) in Zimbabwe, and the Erdenet copper dump leach project in Mongolia.

Project Engineer and Process Consultant on Kennecott Utah Copper's Bingham Canyon heap leach/SX-EW field test on refractory ore. Scope of the project included design of the 1500-kt ore heap, the leach solution distribution-collection system, the heap aeration system, and the SX-EW facilities. Provided ongoing technical support for the field tests and management of extensive parallel column leach programs conducted at a third-party laboratory and at Rio Tinto's corporate laboratory in Bundoora, Australia. Microbial activity was a significant factor in the leach process and was studied and optimized in both the test heap and columns.

### **Pressure Leach**

Project Manager on a study of three process alternatives for treating molybdenite concentrates. All three use an autoclave for the initial oxidation step and carry through to production of chemical-grade molybdenum products. Rhenium is also recoverable as a by-product. The work involved development of complete process packages and capital and operating cost estimates for each alternative.

Process Specialist for interim engineering and operability review for Kennecott Utah Copper Corporation's US\$95 million Moly Oxide Project in Utah. The facility uses a novel hydrometallurgical process to treat molybdenite concentrate to produce high-quality technical-grade molybdcic oxide. Aker Kvaerner's work included significant process and design engineering plus evaluation of testwork data, and development of capital and operating cost estimates. Project manager on further process modifications being pursued by a potential partner in the project. These will produce ammonium dimolybdate and chemical-grade molybdcic oxide, as well as the technical grade material.

### **Bio-Leach**

Process/Project manager on a confidential project to develop a polymetallic bio-leach system at the demonstration plant level. The feed was a blend of various concentrator streams. The demonstration plant was to utilize parallel tank leaching and heap leaching on the same feed. Testing was done to compare the performance of the optimized leach circuits and select the approach to be used in the commercial facility. Work on the demonstration plant reached the final feasibility stage when one of the partners withdrew from the project. An earlier phase of the work focused on a pressure oxidation route for treating the concentrate.

Process Engineer on the first phase of the Newmont Gold bio-leach project. This involved design of the demonstration plant that successfully produced gold and set the design basis for the commercial plant. Consulted to the project during basic engineering of the full-sized plant in order to translate the results from the demonstration project into final design criteria and flowsheets.

Process Manager on Haib Copper Project in Namibia. Work focused on development, coordination, and evaluation of integrated hydrometallurgy program conducted at various third-party laboratories. Testing involved conventional bio-leaching of both whole ore (columns/heaps) and concentrate (stirred reactors). Attention was also give to Mintek's proprietary "BFIG" process in which bio-regeneration of the lixiviant takes place in one vessel and chemical leaching takes place in another, both operating under optimum conditions for their own sets of reactions. Project included development of conceptual flowsheets, designs, and cost estimates for heap leaching and roast leaching with SX-EW.

Owner's Engineer for Girilambone copper heap leach-SX-EW project in Australia, involved from initial column testing through plant start-up. Directed commercialization of the heap aeration system to stimulate bacterial activity and copper leaching.

### **Cyanide Technology**

Program Manager to support Augment Technologies in developing the DuPont proprietary copper/gold cyanide technology. Specific applications included a copper/gold heap leach at Newcrest's Telfer operation in Australia, recovery of copper and cyanide from a Merrill-Crowe barrens stream at the Est Malarctic mine in Quebec, and recovery of copper and silver from Polish flotation tailings.

### **Arsenic**

Experienced in two areas of arsenic metallurgy: (1) treatment of arsenic-bearing smelter flue dusts, and (2) treatment of refractory sulfide ores containing arsenopyrite and other arsenic sulfides.

Worked on the successful development of a hydrometallurgical route for treating flue dusts containing principally lead, copper, and arsenic at Kennecott. The process started with a sulfuric acid leach of the dusts in an autoclave operated under oxidizing conditions. Spent leach liquor was used to slurry the dusts being fed to the autoclave where copper and molybdenum were solubilized, while the arsenic was precipitated as an insoluble ferric arsenate. After liquid-solid separation, molybdenum was recovered as chemical grade calcium molybdate via solvent extraction and precipitation with lime. Copper was recovered by cementation on iron for return to the smelter. Spent solution was then recycled to provide the source of iron to stabilize the arsenic.

Involved with several processes, both chemical and biological, for oxidizing refractory sulfidic and arsenical ores. In general, the objective in these processes has been to at least partially oxidize the sulfides and arsenides so that the copper and/or gold are more easily leached with commonly used lixiviants. A portion of this work has been done on the proprietary processes being developed by Newmont Mining Company and DuPont Specialty Chemicals.

### **Uranium**

Manager of Technology, participated in two in situ uranium projects in Wyoming. Also worked on the recovery of uranium from copper leach liquors using ion exchange, SX and precipitation of yellow cake.

### **Earlier Experience in Leaching and Other Technologies**

Manager of Technology responsible for directing process engineers on numerous inorganic chemicals, minerals, and metals projects. Lead Process Engineer for feasibility study on Quebrada Blanca copper leaching project and for engineering study of seabed mining and processing cobaltiferous marine crusts. Manager for worldwide technology study of the barite and antimony industries; for numerous copper projects involving heap/dump leaching, cementation, ion exchange, and SX-EW; for projects to produce metallic salts; for study of sulfur recovery from gypsum; and for projects to reprocess spent petroleum catalysts. Participated in start-up of Mt. Gunson copper leach operation in Australia and consulted on bacterial leaching of copper.

Process Manager for major mineral project in South Africa, a prototype demonstration plant to chemically process phlogopite ore and produce cell grade alumina plus by-product potash and magnesia. Also involved with feasibility studies on the Dos Pobres and Cochise copper heap leach-SX-EW projects in Arizona, the Morenci Southside expansion, the Carmacks Copper Oxide heap leach project in northern Canada, and Sutter Gold's Lincoln mine project in California.

Principal Program Manager for coordinating work on Kennecott Minerals Company's exploration prospects progressing from core drilling to initial process selection and beyond, including mineralogical evaluation, studies on post-mine processing, initial process flowsheet development, and project feasibility assessments. Principal prospects included a Mexican silver property with a difficult-to-treat manganiferous ore; two Nevada open-pit (low-grade) gold prospects—one well-oxidized and one sulfidic (pyritic); an underground vein-type (high-grade) prospect with base metal sulfides plus gold and silver; and a Duluth gabbro property (copper with nickel, cobalt, and silver-platinum by-products).

Directed all technical phases of Kennecott's copper leaching activities, including development of improved solution management practices, forced aeration of heaps/dumps,

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and an in-depth study of mine waste haulage alternatives, including both material handling costs and recovery of copper from subsequent dump leaching operations. Provided liaison with the company's in-situ leach project in Arizona.

Coordinated effort to increase profitability and metallurgical performance at a Mexican silver-lead operation, including a critical review of the lead flotation approach versus a combination of differential flotation and cyanidation, plus tailings retreatment by agglomeration and heap leaching. Provided liaison with outside contractor during prefeasibility and feasibility studies.

Worked closely with corporate legal group in licensing technology for use outside the company. Activities included initial feasibility assessment of intended application, preparation of contract documents, and liaison with licensee for technology transfer, facilities engineering, construction monitoring, plant start-up, and operating performance.

Managed hydrometallurgy department, providing broad direction and setting priorities in technical programs for three plant areas; copper dump, heap and vat leaching and recovery; copper electrorefining; and by-product recovery and waste treatment. Coordinated and was onsite manager for in-depth performance audit of copper silicate ore leaching operation. The upstream interface was with mine planning to establish ore reserves, constraints on mining rate, and blending potential to control ore grade and type at the crusher. The downstream interface was with sales to establish chemical and cosmetic criteria for marketing the electrowon cathode as electrorefined equivalent. Close liaison with operating division line and staff groups was maintained throughout the project.

Managed overall program relating to water quality, including assessment of water quality, treatment requirements to meet discharge permit limitations, methods for avoiding surface or subsurface losses, and upgrading of existing water treatment plants. Water sources included open-pit drainage, an in-situ leach field reservoir, dump leaching operations, and adverse water from concentrators, smelters, sulfuric acid plants, and electrorefineries. Close coordination with environmental and governmental affairs groups was maintained.

Overall coordinator for solvent extraction development, involving laboratory circuit testing to establish process chemistry, pilot plant operation to confirm chemistry and establish mixer-settler design criteria, and preparation of technical design package. Follow-up activities included contractor liaison, construction monitoring and start-up assistance, and ongoing review of circuit performance and evaluation of new reagents.

Early career work in pyrometallurgical areas included fluid-bed roasting of manganese ore, copper metal-matte chemistry and impurity control, flue gas desulfurization, and fire and vacuum refining of molten copper.

**EMPLOYMENT HISTORY**

2005-	President, Hydrometal, Inc.
2004-2005	Independent Consulting Metallurgist
1994-2004	Aker Kvaerner (and predecessor firms)
1982-1994	Brown & Root
1968-1982	Kennecott Minerals Company

**PROFESSIONAL DATA**

Associations:

Member and (past) Board of Directors: Society of Mining Engineers (SME)  
Member: The Metallurgical Society (TMS); Mining & Minerals Society of America (MMSA); Canadian Institute of Mining and Metallurgy (CIMM)  
Member: Sigma Xi, Tau Beta Pi, Phi Kappa Phi  
Listed in *Who's Who in Science and Engineering*, and *American Men and Women of Science*

Awards:

SME Distinguished Member (2001)  
Arthur F. Taggart Award (SME), 1998 and 2006  
Henry Krumb Distinguished Lecturer (SME), 2006-07  
Milton E. Wadsworth Extractive Metallurgy Award (SME), 2009

Publications:

Books - Editor  
*SME Mining Engineering Handbook, 2nd Ed.*, Littleton, Colorado, 1992  
*Salts and Brines '85*, AIME, New York, 1985  
*Interfacing Technologies in Solution Mining*, AIME, New York, 1982  
*Gold and Silver - Leaching, Recovery and Economics*, AIME, New York, 1981  
*Leaching and Recovering Copper from As-Mined Materials*, AIME, New York, 1980  
*In-situ Uranium Leaching and Groundwater Restoration*, AIME, New York, 1979

Over 50 technical and professional articles, in various handbooks, symposium volumes and journals. Most focus on bacterial and chemical leaching of copper, modeling of copper leaching systems, management and control of leach solutions, and various types of chemical processing.

**CONTACT INFORMATION**

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