



Hydrometallurgy
Abstracts

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Improvement of Cu, Ni and Te recovery from copper anode slime at the tank house in Naoshima smelter and refinery

Toshikazu Kawai, Mitsubishi Materials Corporation, Japan
Isamu Ueda, Mitsubishi Materials Corporation, Japan
Takahiro Uno, Mitsubishi Materials Corporation, Japan
Osamu Inoue, Mitsubishi Materials Corporation, Japan

Abstract

The expansion project to enhance the E-scrap recycling business at the Naoshima Smelter and refinery (NSR) was completed successfully in 2016, and NSR reached the E-scrap treatment capacity of 110,000 tons. Increasing the amount of E-scrap treated, however, has raised impurities in copper anode. Electrorefining of anode with high impurities degrades quality of electrolytic copper and increases the load on slime leaching process.

In order to maintain stable copper electrorefining operation and increase recovery of valuable metals such as Cu, Ni and Te, the by-product processes in the tank house have also been strategically enhanced. The nickel sulfate process was modified to maximize nickel recovery from electrolyte in 2014 and 2018. Subsequently, the leaching process for copper anode slime and the copper telluride process were replaced with the autoclaved-leaching process and the process with a series of reaction tanks respectively in 2020.

Improvement of leaching capacity of copper anode slime and recovery of Cu, Ni and Te has contributed to positive cycle of the whole recycling business of E-scrap at NSR.

Investigations on the selective reduction of arsenic from copper concentrates by alkaline sulfide leaching

Karsten Meiner, Aaron Weigelt, Alexandra Thiere, Michael Stelter, Alexandros Charitos, TU Bergakademie Freiberg, Germany

Abstract

Arsenic is one of the critical elements in the copper refining process which causes environmental and health risks and is therefore penalized if the content in the concentrates for smelters is too high. Today the only available technique on an industrial scale to remove arsenic from copper concentrates is partial roasting and subsequent immobilization of arsenic as scorodite. With partial roasting a residue content of 0.3 wt.-% As or less in the calcine can be ensured, depending on sulfur and calcium concentrations in the concentrate. In comparison to partial roasting, the selective leaching of arsenic within an alkaline sulfide solution is independent of sulfur and calcium in the concentrate and usable even for material that cannot be treated by roasting. The new hydrometallurgical process is investigated followed by the precipitation of arsenic sulfide to immobilize the arsenic. The hydrometallurgical route is investigated as a viable option for concentrate pretreatment. Parameters associated to both the leaching and precipitation steps are part of the experimental investigation considered here. The leaching residue and the liquid phase are subjected to chemical analysis by AAS, XRD and SEM-EDX. The arsenic sulfide obtained after the precipitation step is subject to standard elution tests (after drying) to ensure that the proposed processing route is environmentally sustainable.

Duplex and High-Alloyed Austenitic Stainless Steel Material Selection for Hydrometallurgical Processes in the Copper Production

Eeva Koivisto, Outokumpu, Finland

Claes Tigerstrand, Outokumpu, Sweden

Mikko Palosaari, Outokumpu, Finland

Abstract

Production of copper today involves often hydrometallurgical processes where the metal is extracted from the ore by sulphuric acid solution. The solution usually contains impurities such as chlorides, dissolved metal ions and in some cases, process is run at elevated temperatures. The correct material selection for the process equipment operating in these conditions is crucial for the long service life.

The most common multipurpose austenitic stainless steel grades type 304 and "acid proof" 316 are often considered too expensive as construction materials over carbon steels due to their high and volatile price. In addition to this their corrosion performance is somewhat limited. However, dual-phase austenitic-ferritic Duplex stainless steels are often cost efficient alternative as a result of their corrosion resistance and high strength. This family of stainless steels is by it's nature lean with volatile nickel and therefore show cost stability. High-alloyed austenitic stainless steel grades on the other hand are developed for most corrosive acidic conditions.

Correct stainless steel material selection for each application is crucial as local corrosion mechanisms may cause rapid deterioration and damages or leakages to the process equipment. This paper will show stainless steel material selection principles by compiling laboratory studies and decades of experience working with the mining industry. In addition to corrosion, other factors such as abrasive wear resistance, weight saving potential and sustainability are considered. Finally some reference cases of successful material selection in the industry are showcased.



Improvements in overall Copper recovery through CuSX-EW at BHP Olympic Dam

JA Aguirre Carrillo, Senior Development Metallurgist, BHP – Olympic Dam, Australia.

B Nguyen, Production Support Metallurgist, Olympic Dam, Australia

Abstract

BHP Olympic Dam operation utilises Copper Solvent Extraction (CuSX) and Electrowinning (EW) to process Cu from various by-product streams. The overall copper recovery recorded during Financial Year 2020 (FY20) averaged 59%. A number of improvements were completed targeting reliability, operational and metallurgical issues. This paper provides details of the improvements and their contribution in the process performance uplift. A new solvent extractant showed improvements in extraction. A revision of the operational strategy during circuit ramp up/down resulted in the identification of critical deviations that correlate to higher probabilities of dendritic growth in EW. Deviations from original operational design were identified and amended. A filtration system was installed to filtrate circulating electrolyte on three cells, allowing the capture of suspended solids across the tank house. SEM-EDS analysis showed colloidal silica, sericite and quartz, precipitated Cu and Fe sulphates, as well as lead oxide particles associated with lead spalling across the anodes. A new smoothing reagent in EW improved copper cathode quality. A refurbishment of the rectifiers control system improved equipment reliability and stability. By the end of FY21, the overall Cu recovery averaged 74% and current efficiency in EW increased from 68 to 79% including reduction in pre-strip rate, and the total number of recorded dendritic growth events was reduced by 74%.

Keywords: Olympic Dam, Electrowinning, Copper solvent extraction, current efficiency, electrolyte filtration, rectifiers control, operational strategy, copper dendritic growth.



The removal of radionuclides during metallurgical processing iron oxide copper gold uranium ores

James Vaughan, William Hawker, Weng Fu, Kelly Byrne, Efrain Cardenas, Peter Hayes

Metallurgical Engineering program, School of Chemical Engineering, The University of Queensland, Brisbane, Australia.

Abstract

Polymetallic iron oxide copper gold uranium (IOCG-U) ores represent an important source of copper, gold, silver and uranium. The presence of uranium means that associated radioactive daughter elements are also present which may require additional processing stages to produce marketable products. In this paper we examine some examples of ore mineralogy and its impact on metallurgical process selection, the mechanisms of mobilisation and redeportment of the radionuclides during processing, and potential strategies for reduction or removal of uranium and the radionuclides Ra_{226} , Th_{230} , Pb_{210} , Po_{210} .



The Integration of Sherritt's Dilute POX Process with Copper Heap Leaching

Aysan Molai, Sherritt International, Canada
Jan T. Smit, Sherritt International, Canada
Preston Holloway, Sherritt International, Canada
Kelvin Buban, Sherritt International, Canada

Abstract

The treatment of arsenical copper concentrates is a challenging and increasing problem in the copper industry, with decreasing grades and increasing impurity levels in many known deposits, yet to be exploited.

Sherritt's Dilute POX process has been developed to treat complex copper concentrates, including those with high levels of arsenic, using pressure oxidative leaching. Features of this process include high copper extractions, high gold and silver recovery by direct cyanidation of the leach residues, low arsenic levels in the pressure leach solution and the production of environmentally stable leach and cyanidation residues, even from arsenical copper concentrates with over 7 wt% As.

Because Sherritt's Dilute POX process convert the majority of the sulphide sulphur in the concentrate feeds to sulphate sulphur, a Dilute POX plant treating copper concentrates has the potential to be a significant supplier of sulphuric acid to a heap leach operation. This would reduce the cost of acid for heap leaching, and significantly reduce the cost of neutralization and disposal of the sulphate values generated during pressure oxidation. The integration of Sherritt's Dilute POX process with a copper heap leach is presented in this article. Methods to recover copper from the solutions from the integrated operation and to recycle acid values to the heap leach without impacting the water balance of the heap leach operation will be discussed.

Electro reduction of chalcopyrite in ammonium chloride, a novel method to improve its leaching kinetics.

Fernando Ortega, University of Cape Town, South Africa

Jochen Petersen, University of Cape Town, South Africa

Lilian Velásquez, University of Talca, Chile

Abstract

It is well known that the copper oxides are running low due to the extraction through the years. Because of this, the main copper resources in the earth planet are copper sulphides in where chalcopyrite is one of the most difficult minerals to leach due to its passivation during the leaching process. In this paper work it was developed an electro reduction method based on the chalcopyrite surface reduction using a solution of 2 M NH_4Cl in presence of 0.5 g/L of cupric ions. First step to evaluate the feasibility of the research, were voltammetric tests at 0,3 mV/s with a chalcopyrite rotating working electrode, carried out to evaluate different parameters during the reduction process, in where it was found that the presence of copper improves the electro reduction kinetics. For the second step, were designed electrochemical chronopotentiometry-chronoamperometry tests, carried out with a potentiostat to simulate the electro reduction process, using 50, 90 and 180 A/m^2 during 5 hours (chronopotentiometry) and then leaching the phase formed during 5 hours more at 350 mV (chronoamperometry). The third step was to make a small scale of the system, using chalcopyrite concentrate (82.5% of purity) to electro reduce it in a electrodyalisis cell with an anionic membrane, setting all the parameters studied during the electrochemical tests in where it was demonstrated that the method improves the leaching kinetics of chalcopyrite.

Selective extraction of valuable metals from smelter slag by high-pressure oxidative acid leaching (HPOAL).

Labone L. Godirilwe, Graduate School of International Resource Sciences, Akita University, Japan

Kazutoshi Haga, Graduate School of International Resource Sciences, Akita University, Japan

Gwiranai Danha, Department of Chemical, Materials & Metallurgical Engineering, Botswana International University of Science & Technology, Botswana

Yasushi Takasaki, Graduate School of International Resource Sciences, Akita University, Japan

Atsushi Shibayama, Graduate School of International Resource Sciences, Akita University, Japan

Abstract

Recently, metallurgical waste is globally being explored as a potential secondary resource of valuable metals. High-pressure oxidative acid leaching (HPOAL) method was used to selectively extract nickel, copper, and cobalt from an amorphous smelter slag from Botswana. The slag sample is composed mainly of fayalite (Fe_2SiO_4), with a total entrapped metal sulfides content of about 1.0 wt.% occurring as fine inclusions in the fayalite phase. Experimental parameters such as sulfuric acid concentration, total pressure, and temperature were studied to achieve the maximum metal dissolution rate of Ni, Cu, and Co from the slag waste. The optimal Ni, Cu, Co extractions of 99.9%, 83.6%, and 99.9% respectively, were obtained under leaching conditions of 0.6 M H_2SO_4 , 1.0 MPa, and 150 °C. Substantially low Fe tenors of 1.13% to the pregnant leach solution (PLS) were obtained, the majority removed as jarosite in the solid residue.

Keywords: Fayalite slag, high-pressure oxidative leaching, leaching efficiency

Profile of solution potential within a diffusion pore in a cupric-chloride system

Luis Beiza, Universidad Católica del Norte, Chile

Jochen Petersen, University of Cape Town, South Africa

Lilian Velásquez-Yévenes, Universidad de Talca, Chile

Abstract

It is known that chalcopyrite dissolution depends on the redox potential, and it has been reported that chalcopyrite leaching has a rapid initial rate of dissolution. However, this process is affected by the formation of a product layer on the surface that inhibit its further dissolution. In the heap leaching context, a mineral grain inside a coarse particle may be in contact with solution only through the network of cracks and pores in the particle. It is believed that the redox potential might change within a pore when the reactions occur on the surface of a chalcopyrite grain occluded at the bottom of a diffusion pore due to the accumulation of reduced species close to the surface of the chalcopyrite.

In this study, two concentrations of chloride (20 and 150 g/L) were chosen to study the behaviour of the redox potential along a non-tortuous 1 mm diameter diffusion pore of 3 and 10 mm length. Electrochemical tests were implemented using an inert platinum (Pt-E) electrode to simulate the mineral grain surface. Chronoamperometry tests were carried out at a fixed reduction potential where Cu^+ ions were accumulated during 15 minutes on the surface of the Pt-E to consecutively measure the potential at different distances within the pore. Results showed that a drop in potential from the bulk solution is noted up to 3 mm away from the mineral independently of the pore length used (3 and 10 mm) at both chloride concentrations. This is taken as commensurate with the profiles of Cu(II) and Cu(I) as the potential of the system is governed by the Cu(II)/Cu(I) redox couple.

Operating a CuFeS_2 electrode occluded in a 10 mm pore immersed in bulk solution of 150 g/L Cl⁻ for 27 days at drop of the mixed potential from 540 mV to -131 mV (SHE) was noted. The surface of the mineral changed from metallic yellow to a metallic blue, which is believed to be associated with a reduced amount of Fe in the structure, usually bornite/covellite-like.

It is concluded that once the reaction of the mineral occluded in this pore occurs, there is an accumulation of reduced Cu(I) species close to the surface of the chalcopyrite, with a concomitant reduction of the oxidant Cu(II) species. The reducing environment in the presence of Cu(I) thus results in the formation of new mineral species which at those potentials will slow or even stop the dissolution.

The chemistry of the aqueous copper-ammonia system; implications for sustainable leaching recovery of copper.

Lilian Velásquez Yévenes, Universidad de Talca, Chile
Rahul Ram, Monash University, Australia

Abstract

The dissolution of copper during the leaching of chalcopyrite in ammonia solutions is an attractive alternative to acid sulfate leaching in the treatment of ores with high consumption of acid. Despite considerable research into this complex leaching system, a lack of understanding of the fundamental chemical drivers has delayed the implementation of the ammonia process. In the present study. Various ammonium salts solutions (chloride, sulfate, carbonate) have been used to study the effect of ion association on the dissociation constant of the ammonium ion at temperatures of 25 and 35 °C. Experimental and calculated solubilities of copper(II) have been obtained under different conditions and plotted in speciation distribution diagrams. The dissolution behavior of chalcopyrite concentrate were also investigated in oxidative ammonia/ammonium solutions at ambient conditions and temperatures below 35 °C.

Ion association was found to significantly affect the dissociation constant of the ammonium ion in solutions containing sulfate, chloride, and carbonate anions. Increasing temperature from 25 °C to 35 °C was found to decrease the dissociation constant of the ammonium ion. These findings highlight the importance of using the correct anionic ligands for the ammonium ions and temperature in order to obtain high dissolution of copper.

The NH₃ ligand forms strong coordination compounds with cupric or cuprous ions depending on the anionic ligand, generating an increase in solubility between pH 8.5 and 10.0.

The leaching results showed relatively rapid dissolution of chalcopyrite in ammonium chloride and ammonium carbonate but much slower dissolution in ammonium sulphate solution at the same total ammonium ion concentration.

The present study, therefore, identifies important constraints on the role of varying anion associated with ammonia, temperature, pH, and addition of chloride ions and the inter-dependence of these factors in controlling Cu(II) solubility in ammoniacal systems. The findings are directly beneficial to future commercial application employing effective ammonium-anion lixiviant strategies in the sustainable recovery of Cu.

Insights into dump bioleaching of low-grade chalcopyrite ores

Lilian Velásquez-Yévenes, Universidad de Talca, Chile
Sebastián Malverde Fernández, TresIn, Chile

Abstract

*Biorecovery of minerals is by now an established technological option to process refractory ores. The chemistry and biology of the process have been studied for decades; therefore, it can be considered a mature technique. However, the operation of bioleaching remains relatively difficult to control, in some cases causing operators to abandon it in pursuit of non-biological alternatives such as chloride leaching. This lack of success may be due to underestimating the limitations of bioleaching, which results in over-simplification of the related technology. This paper reports a study on inoculation of isolated *Acidiphilium*-microorganisms sequenced by a 16SrRNA amplicon on Illumina's Novaseq 6,000 platform. Column bioleaching tests also were performed with a low-grade chalcopyrite ore that currently is dump-leached under natural biological conditions without any control over microbial populations. The experimental methodology is based on managing the bacterial populations in a raffinate solution containing bacteria provided by a dump operation. Given the significant differences between laboratory and industrial applications, this study presents results from 0.45 m and 1.0 m height columns. The results show that the recovery of low-grade chalcopyrite ore is enhanced by increasing microorganism cell density in the dump. It was demonstrated that intermittent irrigation enhances the dissolution of chalcopyrite ore during column leaching. Still, excessively long rest periods can affect chemical and bacterial activity due to the shortage of oxidizing agents and or nutrients for microorganisms. In the column operated with intermittent irrigation cycles, no microorganism adaptation period is observed in the analysis of the solutions. The transition stage occurred during the rest period, allowing better management of the pH and redox potential to develop the bacterial activity. It is suggested that continuous irrigation constantly washes bacteria out of the column that needs to grow back, while the rest cycles allow better local accumulation of the bacteria. These results could reduce the leaching cycle with less irrigation, aiming to maintain the continuity of hydrometallurgy output (LIX-SX-EW) and would be more economical and eco-friendlier for natural microbe-assisted dump bioleaching. These results provide valuable insights for designing a sustainable controlled dump-based technology to bioprocess minerals.*



Chloride assisted sulfuric acid leaching of white metal using sea water or discard brine

Lilian Velásquez-Yévenes, Universidad de Talca, Chile

Sebastián Malverde Fernández, TresIn, Chile

Abstract

An experimental study of the kinetics of dissolution of white copper metal in chloride solutions using sea water and discard brine has been carried out at ambient temperatures. The dissolution of sized white copper metal particles was carried out in H_2SO_4 solutions containing known concentrations of chloride, copper(II) and iron(III) at controlled potentials. It will demonstrate that the rate of dissolution depends on the redox potentials. An increase in the potential will allow subsequent dissolution; this will explain the two-stage mechanism proposed for the leaching of white metal for other researchers. Test at different temperatures will show the rate-determining reaction. A mineralogical study of the residue after leaching will show unreacted species, their association and intermediate phase. These results will provide helpful information for the conditions that should be used for leaching copper from white metal as an alternative to pyrometallurgy.



Chemical pretreatment of primary copper sulfide ores

Jorge Ipinza, Universidad Técnica Federico Santa María, Chile

Juan Patricio Ibáñez, Universidad Técnica Federico Santa María, Chile

Abstract

Chemical pretreatment, a stage that precedes heap leaching, allows the mineral to be mixed with defined dosages of a chloride salt, a raffinate solution and concentrated sulfuric acid, to promote the formation of HCl gas in situ. A fraction of this gas diffuses through microcracks and solubilizes in the refining solution surrounding the ore particles. The exothermic reactions that occur in the formation of HCl and this with copper and iron sulfides, allow its transformation into more soluble compounds in chlorinated acid solutions.

It has been experimentally found that primary copper sulfides can reach a copper extraction of the order of 50% at room temperature and increase rapidly as a function of temperature, reaching values of 80% when the raffinate solution enters with a temperature above 40 °C. Under these conditions, the chlorinated leaching kinetics proceeds in a similar way to that observed with a secondary copper sulfide ore.

Mass and Thermal Balance METSIM Modeling of a Copper Sulphide Heap Leaching.

Marcelo Jo. Jo y Loyola Process Consultants, Chile

Luis Bondis, Jo y Loyola Process Consultants, Chile

Daniel Eyzaguirre, Jo y Loyola Process Consultants, Chile

Emmanuel Herrera, Jo y Loyola Process Consultants, Chile

Felipe Lagno, Codelco Chile

Héctor Carreño, Codelco Chile

M. Carolina Salhe, Codelco Chile

Abstract

The need to advance in the improvement of the leaching processes of primary and secondary copper sulfides minerals is well recognized. In particular, the advantages to apply external heat to a chloride heap leaching of copper sulfides and its potential application at Codelco Radomiro Tomic Division is presented. To better define the leaching process, the heap design criteria and its operation, it was decided to model the energy balance for the sulphide ore heap leaching.

Is expected that the ore heap under leaching conditions exchanges energy - in the form of heat- by the following mechanisms: convection (surface with the environment), adsorption of solar radiation, emission of energy by nocturnal radiation, conduction through the ore bed and with the heap's platform, energy exchange between the ore bed and the liquid and gaseous fluids, energy generation/consumption by chemical reactions and the mechanisms of water evaporation and condensation.

To integrate these mass and heat transfer mechanisms, a dynamic METSIM model was made to analyze the complete leaching cycle in time intervals of one hour and estimate the evolution of the temperature profiles in the ore bed.

METSIM® is a metallurgical process modeling and simulation software, designed to calculate material and energy balances in the different unit operations in a metallurgical process plant. In addition, it has a complete thermodynamic database for the most common compounds that are considered in metallurgical plants, it also allows programming in APL language and allows creating interfaces with other programs such as Microsoft Excel.

In this work, the stages of construction of the model and the results obtained will be presented.

Marimaca Project: Process Design and Optimization assisted by METSIM simulation.

Marcelo Jo, Jo y Loyola Process Consultants, Chile

Luis Bondis, Jo y Loyola Process Consultants, Chile

Rodrigo Yunge, Jo y Loyola Process Consultants, Chile

Gustavo Cabello, Jo y Loyola Process Consultants, Chile

Luis Tondo, Marimaca Copper Corp., Brazil

Eduardo Yung, Marimaca Copper Corp., Chile

Abstract

Marimaca is one of the most attractive copper oxide mineral projects discovered in recent years in Chile with a projected cathode production of 40,000 tpy operating with sea water without desalination.

Resource is characterized by the predominant presence of green copper like atacamite, chrysocolla and brochantite, as well as black coppers, mainly in the form of copper wad and iron oxides. Carbonate and FeT grades around 1% and 8% respectively are estimated, both impacting the acid consumption.

During 2020 the Preliminary Economic Assessment study (PEA) was carried out, completing the first plant design using the metallurgical tests results available at that time. This work was assisted by METSIM simulation and industrial operating conditions like height, irrigation rates, acid addition strategy and others were established based on smaller scale tests results.

In the year 2021, the Geomet V metallurgical testing program was developed using 5 representative samples to test the ore response under the operating conditions theoretically defined for the PEA and to make an additional effort to optimize the acid consumption.

This optimization was done once again through METSIM modeling and the experimental results corroborate prior metallurgical analysis used to define the process conditions. These optimized conditions achieved a lower consumption of acid without compromising copper recovery.

In the present work, the support of the plant design, tests and results obtained are presented.

Copper extraction from leaching solutions of Chilean tailings reprocessing, using IX

Malte Drobe, Federal Institute for Geosciences and Natural Resources (BGR), Germany

Frank Haubrich, G.E.O.S. Ingenieurgesellschaft mbH, Germany

Herwig Marbler, German Mineral Resources Agency (DERA) at the Federal Institute for Geosciences and Natural Resources (BGR), Germany

Oswaldo Ramírez, Servicio Nacional de Geología y Minería (SERNAGEOMIN), Chile

Abstract

After sampling of a tailing, in the region of Taltal, adjusted cost models to the specific framework of the tailings, were discussed based on lab to semi-technical scale processing tests in a former paper. Magnetic separation, followed by leaching was most promising for an economic success. Here, we will discuss acid grade and acid consumption and challenges and possible hurdles, concerning the economic extraction of copper from the resulting relatively low-grade leaching solution (700 mg/l). Possible extraction steps, combined with a rough economic assessment, to find out the most adequate technique, to extract copper from the solution and transfer the leached material into a (semi)final product that has a commercial market, will also be discussed. The basis material for leaching are copper mine tailings with a copper grade of 0.5 %. As possible extraction techniques, solvent extraction, cementation and ion exchange are tested. Final product would be sponge copper for cementation and cathode copper for solvent extraction and ion exchange. The leaching recovery using agitation leaching with dilute sulphuric acid was around 80 % due to a high content of copper oxides and chlorides. Ion exchange proofed most promising to recover copper. Final recovery was 80 % for leaching and 90 % for the extraction from the solution (in total 72 %). The recovery from the solution to the final product of 90 % could be improved by optimizing the process, when applying larger sample volumes.

Quantifying mass transport and leaching variability at the particle and grain scale in agglomerated ores

Luis Salinas-Farran, Imperial College London, United Kingdom

Stephen J. Neethling, Imperial College London, United Kingdom

Abstract

A key factor in heap leach performance is the apparent leaching kinetic. This apparent kinetic is a complex function of mass transfer through the particle and the reaction kinetics at the mineral surface, with this relationship being strongly influenced by the mineralogical texture, variability in the mineralogy, as well as the size and spatial distribution of the mineral grains. Most leaching studies, though, have generally focused either on the macroscopic relationship between lixiviant properties and leach or have carried out idealised experiments to determine the surface reaction kinetics. The important mass transport processes occurring within individual ore particles or agglomerates have received less attention than they deserve given their importance to the overall leaching behaviour.

In this paper, a methodology for assessing the leaching variability at the particle and grain scale in agglomerated ores is presented. Two different agglomeration and leaching solution recipes were used to also assess the impact of chloride ions in the leaching of chalcopyrite ores. Samples were leached and periodically scanned using X-ray Microtomography (XMT) over a period of 46 days, obtaining a set of 3D time-resolved representations of the internal changes in the sample structure. Approximately two million mineral particles were tracked over the full leaching process and their individual leaching kinetics was estimated. By studying how the leach kinetics varied with respect to both the grain's position within the particle and the size of the grain, the relative contribution of the mass transport and surface kinetic effects and how they varied both spatially and temporally could be assessed. By incorporating this data into particle scale and, ultimately, heap scale leach models, improved predictions and optimisation of leach performance can be made.



Recovery of Copper and Cobalt from Complex and Refractory Ores in Congo through an Integrated Beneficiation and Hydrometallurgy Approach

Jinghe Chen, Zijin Mining Group Co. Ltd., China
Chaoyang Que, Zijin Mining Group Co. Ltd., China
Xingxun Zhang, Zijin Mining Group Co. Ltd., China
Hongzhen Xie, Zijin Mining Group Co. Ltd., China
Qiankun Wang, Zijin Mining Group Co. Ltd., China, State Key Laboratory of Comprehensive Utilization of Low-Grade Refractory Gold Ores, China.

Abstract

The copper-cobalt resource in Kolwezi, Congo, has the following characteristics: various ore types, complex gangue minerals, broad varieties in copper mineral types, grades and oxidation extents, high clay content in rocks, as well as low cobalt content and high manganese content in the run-of-mine ore. In consideration of the distinctive geological characteristics of the resources, a comprehensive approach was taken to develop a combined technology which integrated different beneficiation and hydrometallurgy processes for recovery of copper and cobalt from the complex and refractory ores. The results from commercial application of the combined technology in the past few years have indicated significant social and economic benefits: improved resources utilization and metal recovery, reduced production costs, and minimized environmental impact.



Copper Solvent Extraction: 2022 Global Survey of Operating Practice and Performance

Kathryn C. Sole, Sole Consulting, South Africa

John Parker, Process Ideas, South Africa

Timothy G. Robinson, Metso Outotec, USA

Jacklyn Steeples, Freeport McMoRan, USA

J.J. Taute, BASF, USA

Owen S. Tinkler, Solvay, USA

Yi Zhou, BASF, Canada

Abstract

Global surveys of operating practice in copper solvent extraction have been regularly carried out since 1997. This paper reports and evaluates the outcomes of the seventh survey in this series, based on individual plant operating data for 2021. Trends in feed and electrolyte compositions and extractant and diluent selection are reviewed, with their impact on copper recovery and operating costs. Strategies for optimisation and maximising copper transfer and copper production with changing feed compositions during life of mine are discussed. The evolution of equipment design trends in recently commissioned operations is assessed. Differences in operating practices in different parts of the world are compared.

Thermochemical database and copper mineral solubilities in process waters using PHREEQC

Aldo Fuentes, Departamento de Ingeniería Metalúrgica y de Materiales, Universidad Técnica Federico Santa María, Chile.

Sergio Ojeda, Departamento de Ingeniería Metalúrgica y de Materiales, Universidad Técnica Federico Santa María, Chile.

Francisca Justel, Departamento de Ingeniería Metalúrgica y de Materiales, Universidad Técnica Federico Santa María, Chile.

José Contreras, Departamento de Informática, Universidad Técnica Federico Santa María, Chile.

Pía Hernández, Departamento de Ingeniería Química y Procesos de Minerales, Universidad de Antofagasta, Chile.

Yecid Jiménez, Departamento de Ingeniería Química y Procesos de Minerales, Universidad de Antofagasta, Chile.

Jesús M Casas, Departamento de Ingeniería Metalúrgica y de Materiales, Universidad Técnica Federico Santa María, Chile.

Abstract

This work presents a thermochemical database for copper aqueous speciation and solubility using industrial conditions of metallurgical plants. The cases studied were the solubilities of copper salts in process waters, solutions from heap leaching operations and electrolytes from electrowinning plants. The simulations were carried out in different conditions of temperature and ionic strength, considering diluted waters to saturated industrial solutions. The applied methodology included copper mineral solubility simulations with selection of balanced ionic waters, leaching solutions and electrolytes. Then, a compilation of thermochemical properties of copper, iron, aluminium, magnesium, sodium, sulphate, and chloride solutes, among others, was performed. The activities of water and the dissolved solutes were estimated using the extended Debye-Hückel model (EDH), the specific ion theory (SIT) and Pitzer's ion interaction model. Finally, the collected data were included into the respective databases of the geo-hydro-chemical software PHREEQC to simulate the "Study Cases" defined in the present work.

The results indicated that the metal solubilities were strongly dependent on the temperatures and salinities or concentrations of the solution for the cases studied. Under certain operational conditions, saline solutions improved the solubility of copper in contrast to their respective sulphate salts.

Study of the kinetics of electrochlorination of rhodium obtained from copper-nickel sulfide ores

Evgeniy Kuzas, Laboratory of Advanced Technologies in Non-ferrous and Ferrous Metals Raw Materials Processing, Ural Federal University, Russia

Abstract

Due to the tightening of environmental regulations, there is an explosive increase in demand for rhodium. Rhodium is used in the production of automotive catalysts. In 2021, the price of rhodium was approaching \$30,000 per troy ounce. At the same time, there is a depletion of rich deposits of platinum placer. It is the main raw material for the rhodium production. The restoration of the balance of supply and demand is facilitated by companies that simultaneously extract rhodium during the processing of copper-nickel sulfide ores. As of 2020, the Russian company Norilsk Nickel ranks eleventh in the world in copper mining (487,000 tons, 2%), the first place in the production of refined nickel (236,000 tons, 22%) and the fourth place in the production of rhodium (3.6 tons, 12%).

Copper-nickel ores are subjected to enrichment. The copper and nickel concentrates are processed using traditional methods: melting, converting, electrolysis, etc. During electrolysis, sludges are formed. They are processed to extract precious metals. Collective concentrates are obtained from sludges. They contain up to 0.4% rhodium. During refining, rhodium is extracted from collective concentrates in the form of powder.

Large refining plants obtain rhodium compounds from production solutions. Small plants use rhodium powder as a raw material. Due to the low chemical activity of rhodium, special methods of oxidation and leaching are used. One of these methods is sintering rhodium with barium peroxide. The sinter is dissolved in nitric acid. However, this method does not allow obtaining a high purity rhodium nitrate solution.

To obtain a precursor (a rhodium chloride solution), an electrochlorination method has been developed. The oxidation of rhodium occurs with atomic chlorine. It is formed by passing a periodic current with a duration of its passage in forward and reverse pulses of 1/1 min/min through a hydrochloric acid solution in an electrolyzer. Rhodium hydroxide is precipitated from the solution. It is dissolved in nitric acid and a high-quality solution of rhodium nitrate is obtained.

In this work, the kinetics of electrochlorination of rhodium is studied. The influence of various types of electric current on the rate of rhodium ionization is determined. The mechanisms of dissolution and passivation of rhodium under the action of an electric current in hydrochloric acid are established.

Mineral colonization by Epifluorescence Microscopy to enhance chalcopyrite bioleaching with meso- and thermophile microbial communities

Julián Casas-Vargas, Departamento de Ingeniería Hidráulica y Ambiental. Escuela de Ingeniería. Pontificia Universidad Católica de Chile, Chile

Cristóbal Martínez, Departamento de Ingeniería de Minería. Escuela de Ingeniería. Pontificia Universidad Católica de Chile, Chile

Diego von Bernath, Departamento de Ingeniería de Minería. Escuela de Ingeniería. Pontificia Universidad Católica de Chile, Chile

Álvaro Videla, Departamento de Ingeniería de Minería. Escuela de Ingeniería. Pontificia Universidad Católica de Chile, Chile

Mario Vera, Departamento de Ingeniería Hidráulica y Ambiental. Escuela de Ingeniería. Pontificia Universidad Católica de Chile, Instituto de Ingeniería Biológica y Médica. Facultades de Ingeniería, Medicina y Ciencias Biológicas. Pontificia Universidad Católica de Chile, Chile.

Abstract

Bioremediation is an economically and ecofriendly alternative to extract copper using acidophilic microorganisms as catalysts. However, chalcopyrite, the main copper source used for bioleaching, suffers passivation, hindering copper release. It has been suggested biofilm formation of microbial communities might induce mineral passivation. Hence, it is important to select microbial consortia that could overcome this challenge for enhancing copper bioleaching rates. The research's aim is to evaluate the chalcopyrite bioleaching potential and the biofilm formation capacity of mesophilic and thermophilic consortia obtained from a Copiapo mine's samples. For this purpose, samples from an oxide-leaching heap were cultured in Mackintosh media pH 2.5, supplemented with pyrite 1% and yeast extract 0.02% at different temperatures. The consortia's diversity was determined by next generation sequencing. The bioleaching potential of enrichment cultures was tested by cultivation with chalcopyrite 2% at flask and/or column scale. The planktonic growth, pH and ORP were measured daily, and iron and copper release were determined. The mineral colonization was quantified by Epifluorescence Microscopy. As results, it is expected that at least one enrichment from each temperature shows remarkable copper bioleaching rates and how these results might be associated with higher or lower mineral colonization levels. These enrichments could be applied to upscaling to improve copper extraction efficiency.



The use of Albion Process™ to produce Copper Sulphate reagent for use in Zinc flotation (Case Study)

Kelvin Roche, Glencore Technology, Australia

Rebecca Mckechnie, Glencore Technology, Australia

Abstract

Glencore Technology's Albion Process™ is a combination of ultrafine grinding and oxidative leaching at atmospheric pressure, providing a proven, effective, safe, and robust approach for oxidizing sulphidic materials. This paper describes an innovative application of the Albion Process™ in an existing zinc flotation operation, who had approached Glencore Technology to design and commission an Oxidative Copper Leach plant to produce a suitable Copper Sulphate reagent from refinery generated Copper Cementation Cake (Copper Mud). The site had previously operated a copper sulphate crystal reagent mixing and dosing system, however it was found that the purchasing and transportation of copper sulphate crystal resulted in unacceptably high operating costs. The Albion Process™ plant supplied by Glencore Technology successfully produces the required reagent on site at a fraction of the cost and provides flexibility in both potential feed sources and production rate to suit site requirements.



Improvement of Hydrometallurgical Process for Copper-Anode Slime Treatment at Saganoseki Smelter and Refinery

Kodai Nagata, JX Metals Smelting Co., Ltd., Japan
Yuya Matsuda, JX Metals Smelting Co., Ltd., Japan
Yosuke Yamaguchi, JX Metals Smelting Co., Ltd., Japan
Toshinori Ishii, JX Metals Smelting Co., Ltd., Japan

Abstract

Saganoseki Smelter & Refinery of JX Metals Smelting Co., Ltd., has been operating a hydrometallurgical process to recover precious metals and rare metals from copper-anode slime since 1997. The adoption of this process brought many operational advantages including higher product quality, higher productivity, and reduction in environmental load. In recent years, the Smelter is promoting to increase the treatment of secondary materials. Owing to the rise, impurities such as antimony in the secondary materials transfer more to the copper-anode slime. The antimony causes several undesirable phenomena in the electrorefining process. In order to prevent this influence, the Smelter improved the distribution ratio of antimony. In addition, this paper also describes recent improvements of recovering selenium and tellurium in the anode slime treatment plant.



A novel process for the value recovery from borras

Ricardo Pezoa, EcoMetales Limited, Chile
Nelson Parra, EcoMetales Limited, Chile
Marcelo Acuña, EcoMetales Limited, Chile

Abstract

Human activities are depleting our planet resources at a high rate raising concerns about the development of our society in the long term. Circular economy is a must in order to obtain as much as possible from our resources, thus minimizing the generation of waste. EcoMetales is a company that operates an industrial plant where processes flue dust recovering copper and removing arsenic in the form of scorodite. However, the leaching residue so called "borras" has a remaining of metals such as copper, iron, germanium and silver which are of significant value for the market. Our company has developed a process for the recovery of said elements in a series of step by step processing that find synergies with our current industrial operation. With this process copper is recovered in a pregnant leaching solution comprising iron which is used for the removal of arsenic in the form of scorodite in our patented abatement of arsenic and antimony process. The leaching residue of copper recovery is then sent to a cleaning stage where lead is removed in a specific way to generate a lead concentrate. The leaching residue from lead removal is sent to an alkaline leaching operation where germanium is recovered and further purified using ionic exchange and distillation operations for obtaining a germanium concentrate. Eventually the alkaline leaching residue is sent to a chloride leaching stage where silver among other elements are recovered to obtain a PLS with copper and iron values and a silver concentrate. In this work results of laboratory and pilot scale test are presented which were the basis for the definition of a process that is currently under evaluation in engineering studies for the determination of investment and operational costs.



Chalcopyrite leaching with iodine (JX Iodine Process) for various ore types

Asaka Nakamura, JX Nippon Mining & Metals Corporation, Japan

Yuken Fukano, JX Nippon Mining & Metals Corporation, Japan

Akira Miura, JX Nippon Mining & Metals Corporation, Japan

Abstract

JX Nippon Mining and Metals Corporation has developed and patented the JX Iodine Process which is an innovative copper-leaching method for low-grade primary sulfide ores. The process itself is comprised of the irrigation of ferric iron and low-concentration iodide solutions. The test was carried out on a one-meter column with various types of ore. Compared to the conventional ferric leaching method, the Cu recovery rate has been improved for most ores in the case of the JX Iodine Process. However, the efficiency of the JX Iodine Process has decreased when the ore that implies a likely high resistance to leachate. Those ores can be expected to improve the Cu recovery rate by granulating them.

To make this process economical in actual operation, it is necessary to regenerate ferric from ferrous in the pregnant leach solution (PLS) and to reuse iodine in the PLS. Therefore, we designed a process including recovery of iodine which inhibits bio-oxidation, bio-oxidation of iron, and copper recovery by SX-EW. In order to demonstrate the process, closed-circuit tests were conducted using a column and a mini-heap both with a six-meter height. As a result, iodine recovery and bio-oxidation of iron were performed as expected, and a higher Cu recovery with the JX Iodine Process than the conventional method was confirmed.

Chalcopyrite leaching with hydrogen peroxide and iodine species in chloride–acid media at room temperature: Technical and economic

German Moraga, Universidad de Antofagasta, Chile

Pía C. Hernández, Universidad de Antofagasta, Chile

Teófilo A. Graber, Universidad de Antofagasta, Chile

Nathalie E. Jamett, Universidad de Antofagasta, Chile

María E. Taboada, Universidad de Antofagasta, Chile

Abstract

Because of the depletion of available copper oxide ores and the abundance of copper sulfide ores, hydrometallurgical copper production is predicted to decrease by almost 50% by 2029, with reference to the production in 2018. The impending disuse of hydrometallurgical plants has necessitated research into heap leaching, an economical extraction technology, for copper sulfide ore processing. Leaching solutions combining iodine-based oxidants and hydrogen peroxide in a chloride–acid medium, at room temperature, were studied in an effort to obtain suitably pregnant leaching solutions for solvent extraction. Experiments were performed to determine the effect of hydrogen peroxide on the leaching process; subsequent factorial experiments were conducted to evaluate the effects of the different leaching solution reagents (KI, NaIO₃, NaCl, H₂O₂, and H₂SO₄). The results showed that the most influential variable is the H₂O₂ concentration; increasing the concentration from 3 g/L to 15 g/L increased the copper extraction percentage by ~25%. In decreasing order of importance, the factorial experimental results showed that the H₂O₂, H₂SO₄, NaCl, NaIO₃, and KI concentrations affect the copper extraction percentage. The highest copper extraction percentage (i.e., 60.6%) was obtained using a leaching solution containing the highest reagent concentrations. An economic evaluation of the laboratory-scale leaching experiments showed an increase in the unit cost (USD/Ton Cu) for experiments involving leaching solutions without H₂O₂ because of low copper extraction percentages. As the concentrations of the reagents, NaIO₃ and KI, increase, the unit cost increases because the reagents are relatively expensive and have limited effect on the copper extraction percentage.

The estimation of microgram powder electrode system on sulfide mineral oxidation for mineral processing

Hajime Miki, Kyushu University, Japan
Hiroki Fukuda, Kyushu University, Japan
Berdakh Daniyarov, Kyushu University, Japan
Gde Pandhe Wisnu Suyantara, Kyushu University, Japan
Tsuyoshi Hirajima, Sumitomo metal mining Co.,LTD, Japan
Keiko Sasaki, Kyushu University, Japan

Abstract

Electrochemistry with powder sample is essential for hydrometallurgy since in many case sample can obtain only with powder form such as ground mineral or precipitations. However, powder electrode system is not well developed since it is difficult to obtain reproducibility and sensitivity with current carbon paste electrode. Authors has developed its well sensitivity and reproducibility with relative simple method for powder sample electrode. This system yields highly reproducible results and is sensitive compared with conventional electrode systems for various sulfide minerals. Authors estimate this method to apply oxidation behavior on various sulfide minerals. These results can be utilized with sulfide oxidation leaching or mineral processing method. From this method, results of various primary copper sulfide and secondary sulfide minerals will be indicated and reaction model will be discussed on this research.



The nature of the passivation layer on chalcopyrite formed during leaching

Zihe Ren, Jetti Services Canada, Canada
Nelson Mora, Jetti Services Canada, Canada

Abstract

The problem of chalcopyrite's slow dissolution has challenged the copper industry for more than half a century. This challenge is becoming more pressing as copper ore grades decline globally and as demand for copper grows exponentially. For example, it is projected that 500 million tonnes of copper alone will be needed for the wiring in renewable technologies by 2050. This is 25 times the current annual global production of copper, and more copper than has been mined over the last 5,000 years. To address the issue of slow chalcopyrite dissolution, most of the previous research has tried to tie the observed "passive" behavior, i.e. slow dissolution, of the mineral to a single mechanism and has attempted to provide a solution accordingly. However, although extensive research has been carried out, chalcopyrite is still considered "unleachable" under ambient conditions with no conclusive explanation being proffered. In this paper, we use a variety of analytical methods to make an important discovery and propose the passivation mechanism from a new angle. Using bioleaching reactors, electrochemical, TOFSIMS and ex-situ I-V analysis, we find that chalcopyrite's semiconductor properties change as it undergoes oxidative dissolution. We also clarify several major misunderstandings about this mineral and provide unambiguous evidence to support a novel passivation mechanism.

Copper-zinc separation from electric arc furnace leachate by solvent extraction using fatty acid derived extractant and diluent

Erik Prasetyo, National Research and Innovation Agency, Indonesia

Widya Aryani, National Research and Innovation Agency, Indonesia

Astria Gesta Anggraini, National Research and Innovation Agency, Indonesia

Abstract

Copper was separated from zinc from a pregnant leach solution (PLS) as product of alkaline leaching of electric arc furnace using monosodium glutamate as a lixiviant. Due to high concentration of zinc in PLS, first Zn was selectively precipitated by acidifying the PLS to pH 6 using sulfuric acid. The precipitation decreased Zn concentration from 17 g/L to 1 g/L, while Cu concentration remained constant at 0.3 g/L. Green chemicals were synthesized from fatty acid i.e oleate hydroxamate and ethyl laurate, which were then used as extractant and diluent, respectively. The effect of initial pH on metal extraction showed that 50% of Cu was extracted at pH 3 (distribution coefficient 142), while Zn at pH 5.5 (distribution coefficient 672). The best pH for both metal separations occurred at pH 3 (separation factor 1422). The study on the effect of organic-aqueous volume ratio resulted in maximum organic capacity for Cu was 5.7 g/L (oleate hydroxamate 5% v/v in ethyl laurate at pH 3). Stripping test using mineral acid demonstrated that 5 M sulfuric acid was required for quantitative removal of Cu (93%) from organic phase.

A two-step methodology to generate an optimal irrigation plan for heap leaching operations

Andrés Araya, AMTC & Universidad de Antofagasta, Chile

Ignacia Contreras, AMTC & Universidad Federico Santa María, Chile

Joaquín Silva, AMTC & Universidad Federico Santa María, Chile

Simón Díaz, AMTC – Universidad de Chile, Chile

José Espinoza, AMTC – Universidad de Chile, Chile

Nelson Morales, Polytechnique Montreal, Canada

Tomás Vargas, AMTC – Universidad de Chile, Chile

Enrique Jélvez, AMTC – Universidad de Chile, Chile

Humberto Estay, AMTC – Universidad de Chile, Chile

Abstract

In this paper we focus on the problem of finding an irrigation strategy for operating in heap leaching, with the aim of optimizing the recovery and/or the economic benefit, taking into account a series of operational considerations. For this purpose, the approach proposed includes two steps: (i) a dynamic mass balance of the heap with description of leaching kinetics at particle level, and (ii) an optimization model to define an optimal irrigation plan based on the information from the first step. This methodology was implemented in a case study and compared with a simulation of the operation dynamics: the results showed only 5% deviation between what is predicted by the proposed methodology and the simulated results.



Efficacy of Nanocoatings in Reducing pH Sensor Maintenance in Froth Flotation Cells

Mark Fitzpatrick, IC Controls, Canada

Abstract

Industrial online pH sensors are used to monitor and control pH in froth flotation cells to establish and maintain the desired surface chemistry for the particles in the pulp. The minerals and chemicals present in the froth flotation process eventually cause sensor failure in some manner. Common modes of failure include the poisoning of the reference cell via process penetration through the reference junction and fouling of the reference junction surface to the extent that the ionic connection with the process is lost. This paper explores the benefits of modifying the surface characteristics of the reference junction using nanocoatings to mitigate these failures and prolong useful sensor life. The various constituents of the pulp such as collectors, frothers and clay minerals each have their own surface characteristics and as a result, have varying affinities for pH sensor surfaces. Accordingly, different coating types are investigated to determine the best surface properties (e.g., hydrophobic) for a particular froth flotation process.

Improvement of chalcopyrite dissolution in sulphate media by organic additives : an initial study

Jordy Dinga, University of Cape town, South Africa

Jochen Petersen, University of Cape town, South Africa

Thandazile Moyo, University of Cape town, South Africa

Abstract

Chalcopyrite, which is by far the most abundant copper mineral, representing 70 % of the copper lithosphere reserve, is not easily amenable to hydrometallurgical processing. This is particularly true in the context of the most studied leaching system, ferric sulfate media. This study investigated the potential of four organic compounds: ethanol, 2-propanol, acetic acid and acetonitrile to improve the dissolution of chalcopyrite in sulphate media. In presence of hydrogen peroxide as oxidant, all the additives improved the extraction of copper with 2-propanol being the most efficient. 2-propanol, and acetonitrile also enhanced copper recovery in presence of oxygen as oxidant. The results suggest difference in mechanism between leaching with oxygen and leaching with hydrogen peroxide. They also showed that the enhancing effect of the organic additives on the leaching does not necessarily result from the stabilization of hydrogen peroxide as proposed by some authors. More probable is a correlation between the effect of the additive and its ability to stabilize cuprous ion or to affect the surface product.

A novel hydrometallurgical method for chalcopyrite treatment using organic aqua regia

Yasunari Matsuno, Chiba University, Japan
Shunya Fujisaki, Chiba University, Japan
Akihiro Yoshimura, Chiba University, Japan

Abstract

Chalcopyrite (CuFeS_2) is one of the most copper-abundant minerals. However, its refractory nature when treated using conventional sulfate media leaching systems hinders its industrial applications. Owing to the continuous depletion of high-grade ores, hydrometallurgical alternatives for chalcopyrite treatment have received attention.

We developed a novel method for leaching of chalcopyrite using organic aqua regia, e.g. dimethyl sulfoxide (DMSO) solutions of copper chloride (CuCl_2) and chloride salt (NaCl). The high boiling point of DMSO enables the use of a high operating temperature at ambient pressure, leading to a high dissolution rate of chalcopyrite. In addition, organic aqua regia can selectively dissolve valuable metals, i.e. Cu and Au, from chalcopyrite, leaving minerals with little economic value, e.g., pyrite (FeS_2) or penalty elements, e.g., As in the residues. The recovery of Cu from the leachate was investigated by solvent extraction using commercial extractants such as LIX 860N-IC and PC-88A. All the Cu can be extracted by using LIX-860N together with Na_2CO_3 and H_2O . However, all the Fe in the leachate also settled in the extractant layer; hence, further separation of Fe and Cu is required. On the other hand, the Cu extraction fraction is approximately 40% when using PC-88A, whereas all the Fe remained in the leachate layer. Process optimization will be investigated from the view point of leaching, recovery of Cu, Au, and regeneration of organic aqua regia.



Udokan Project

Marko Lampi, Metso:Outotec Oyj, Finland

Kaarlo Haavanlammi, Metso:Outotec Oyj, Finland

First Name Last name, Company or University, Country

First Name Last name, Company or University, Country

Abstract

Udokan deposit is third largest copper deposit in the world and known since 1950's. Copper content in ore is 1,25%. The Udokansky field is located in 30 kilometers to the south of the railway station New Chara of Zabaykalsky Krai of Russia on Ridge Udokan. Three dominant copper minerals on Udokan copper field are - chalcocite-bornite; - brochantite - malachite; - chalcopyrite-pyrite. Ores are characterized by preferential average oxidation level, and among the oxidized minerals of copper prevail hardly removable hydroxyl sulfates that is unique feature of the Udokan copper deposit. Brochantite belongs to such minerals.

Udokan Copper together with their partners has developed a process treat Udokan ore recover copper as copper cathodes and sulfide copper concentrate and is now implementing the project. Metso: Outotec is the main technology supplier for this project. Process consist of crushing, grinding and bulk flotation. Oxide coper from bulk concentrate is leached, leaching solution id purified with solvent extraction and copper is recovered as copper cathodes. Leach residue slurry is washed in CCD circuit and, neutralized before slurry continues through regrinding step to sulfide flotation circuit, where sulfide concentrate is produced.



An investigation into the leaching behavior of tenorite in aqueous alkaline monosodium glutamate solutions

Carlos Perea, University of Chile, Chile

Christian Ihle, University of Chile, Chile

Humberto Estay, Advance Mining Technology Center (AMTC), Chile

Laurence Dyer, Curtin University, Australia

Abstract

Tenorite is commonly extracted by acidic leaching, using acids such as H_2SO_4 , HCl , and HNO_3 . These strong acids are the most widely used because of their high dissolution kinetics. However, their main problem is the high acid consumption due to the fact that copper oxide deposits contain large amounts of acid consumable gangue. Besides, when the acid interacts with silicate minerals, it can induce silica gel formation that could affect the copper extraction. On the other hand, they can cause a high environmental impact due to their toxicity and potentially improper handling during transport, storage, and use in the leaching process. In this study, the use of aqueous alkaline monosodium glutamate system is proposed as an alternative for the batch leaching of tenorite. Studying the effects of glutamate concentration, temperature, and Eh will be investigated at a pH of 9.4 and atmospheric pressure, using high purity synthetic mineral.



Atmospheric oxidation-leaching of a chalcopyrite concentrate with activated carbon catalysis

Himesh Patel, McClelland Laboratories, Inc., USA

Jared Olson, McClelland Laboratories, Inc., USA

Steve Dixon, SND Consulting, USA

Abstract

Chalcopyrite is the most abundant copper mineral, but it is resistant to hydrometallurgical processing at atmospheric pressure. An oxidative leaching method is proposed in this paper for extracting copper from a chalcopyrite concentrate. The effects of varying leach time, grind size, slurry density, ferric iron addition, and activated carbon addition were evaluated in this study. Adding activated carbon catalyzed the leaching process and resulted in an improvement in extraction. A higher copper extraction was achieved under optimum conditions. This extraction was achieved after 96 hours of leaching at ambient pressure with air-sparging.

Co-processing of High Impurity Copper Concentrates and Nickel Laterite Ores

Preston Holloway, Sherritt International, Technologies Division, Canada

Jan Smit, Sherritt International, Technologies Division, Canada

Cory Kosinski, Sherritt International, Technologies Division, Canada

Jay Mahal, Sherritt International, Technologies Division, Canada

Abstract

Copper sulphide deposits with high levels of arsenic, antimony and/or bismuth are underutilized resources, due to the difficulties in treating copper concentrates with these impurities in copper smelters. Nickel laterite ores are another underutilized resource, due to the low grade of these materials (1 to 2 wt% Ni) and high capital intensity of conventional laterite processing technologies.

Sherritt has developed the Chimera Process in an effort to unlock the value of both resources by coprocessing these materials a single autoclave step. Oxidation of the sulphides in the copper concentrate provides the heat and acid for the leaching reactions, while the limonite or transition laterite ore consumes acid and provides a source of iron to form highly stable leach residues (<0.02 mg/L As in TCLP Leachate). This approach allows for over 97% copper extraction from concentrates with up to 5 wt% As, 8 wt% Sb and 5 wt% Bi. Gold and/or silver can be recovered from the leach residue by cyanidation of the leach residue.

Copper, nickel and cobalt from both feed materials are leached into a common solution. Copper is recovered as copper cathode using solvent extraction and electrowinning. Nickel and cobalt are then recovered from the solvent extraction raffinate as mixed hydroxide or mixed sulphide intermediates, both of which can be refined to produce Class I nickel products or can be used as precursors for battery production.

VALUE RECOVERY AND WASTE MANAGEMENT USING ADVANCED ION EXCHANGE

**Les-Lee Thompson, Chimerical Technology, South Africa.
Matthew Darwood, Ecovyst, United Kingdom.**

Abstract

Ecovyst Alpha select advanced resins for copper, arsenic and iron have been applied to three streams of aggressive mining solutions to specifically target value recovery and reduce, reuse and manage the waste produced from these streams.

As-Select was evaluated on an acidic copper waste stream with concentrations exceeding 1 g/L As. The objective was to reduce As content to < 50 mg/L in order to reuse the contained sulfuric acid and reduce the environmental impact of As from precipitation.

Cu-Select was evaluated on an acidic cobalt sulfate waste stream to recover the entrained copper value and reduce the waste production as well as improve the product purity from the battery grade cobalt plant.

Fe-Select was evaluated on an acidic copper solution to selectively remove iron from the copper liquor prior to copper sulfate precipitation. Iron is considered a major contaminant in the purification process and requires multi-stage precipitation with tight control to manage Fe levels.

This paper covers the case studies for the 3 streams with results and performance drivers through the implementation of silica-based ion exchange resins.



Implementation of Jetti Resources Catalytic Technology at Pinto Valley Mine to Leach Low-Grade Chalcopyrite Ore

David Castro, Jetti Resources, United States

Paul Thomas, Capstone Mining, United States

Ross Cooper, Worley Engineering, United States

Monse Rebolledo, Jetti Resources, United States

Abstract

Low-grade chalcopyrite ore represents 70% of the remaining known global copper reserves, but the formation of a passivating layer on the mineral surface during conventional leaching inhibits further copper extraction. Jetti Resources has developed a catalytic technology that disrupts existing passivating layers and prevents their formation, thus extending the leaching reaction and increasing overall recovery. Testwork on a sample from the leach pad at Pinto Valley Mine began in April 2017 to demonstrate Jetti's technology performance, determine optimum leaching parameters using column tests, and identify any effect of the catalyst on downstream processes. Based on successful leach testing results, a catalyst addition facility was built and seamlessly integrated into the existing Pinto Valley solvent extraction/electrowinning operation. Copper production per unit area irrigated has increased more than 2-fold since implementation in May 2019, with no reported effects on cathode quality. An independent analysis by Worley of results from Pinto Valley between May 2019 and May 2020 for an array of contributing factors (oxidation potential, pH/acid concentration, temperature, irrigation area and flow rate) concluded that the Jetti technology was responsible for the increase in copper production.

Keywords: Chalcopyrite, Copper, Leaching



Kazakhstan's first Cu Leach-SX-EW facility. Ten years of operations at Central Asia Metals' Kounrad plant.

Phil Crane, Director, PCMETS Consulting Pty Ltd, Australia

Howard Nicholson, Australia

Barrie O'Connell, Australia

Aung Moe, Australia

Vladimir Vanner, Australia

Ivan Zhuravlev, Australia

Abstract

Previous mining operations dating back over 75 years had deposited more than 650 million tonnes of low-grade copper bearing stockpiles around the Kounrad open pit. Central Asia Metals Ltd. recognized the value in this resource and in 2012 commissioned Kazakhstan's first leach-SX-EW facility to recover copper at a design capacity of 10,000tpa Cu.

With no mining expenditure, the project has consistently been placed in the lower quartile of production costs at around 50-60 US cents per lb and has exceeded the original production target by more than 25%. Copper quality is usually around the "five-9's" expected of the best performing operations.

During its operational life the project has experienced an unusual combination of challenges including sub-zero leaching temperatures, high PLS chloride concentrations, high PLS iron levels, and extremely high PLS ferric to ferrous ratios; along with the environmental challenges that come from leaching ore historically placed over unprepared ground.

The effects of these and other challenges are discussed, along with the management practices developed to successfully alleviate their impacts upon operational efficiency.

Evaluation of the Toowong process for the pre-treatment of high arsenic containing copper concentrates

Rakan Rahbani, Aurubis Ag, Germany
Leslie Bryson, Aurubis Ag, Germany
Lachlan Macdonald, Core Group, Australia

Abstract

With major cities pledging to become carbon neutral in the next decades, the demand for metals such as copper is forecast to increase. Consequently, there is also an increased need to manage associated impurities, such as arsenic, in concentrates being shipped from mines to smelters all over the world.

Aurubis, Europe's largest copper producer and the world's largest copper recycler, partnered between 2019 and 2020 with the Core Group, a global leader in the development and commercialization of process technologies for the mining industry. The aim was to conduct a technical evaluation of Core's proprietary Toowong Process, a hydrometallurgical flowsheet for removing arsenic from copper concentrates. The study processed 350 kg of high arsenic and gold rich copper containing concentrate through the entire Toowong flowsheet, enabling the evaluation of all output products and the determination of key reagent consumption rates. The study showed that over 98% of the arsenic could be extracted from the concentrate along with high gold recovery. A calcium arsenate intermediate for further processing into scorodite or encapsulated glass was produced along with saleable sodium sulphate. The study optimized the process to produce products which can be integrated into Aurubis's existing flowsheet.

This paper will highlight the collaboration between industry and technology providers to solve problems faced by the non-ferrous industry as well as raise open points that still need to be addressed.



Copper-Cobalt Hydrometallurgy Projects in DRC

Zhang Haibao, Huang Jianfei, China Nerin Engineering Co., Ltd., China
Chen Yanjie, China Nerin Engineering Co., Ltd., China
Meng Xianglon, China Nerin Engineering Co., Ltd., China
Fu Xiaodan, China Nerin Engineering Co., Ltd., China

Abstract

In this paper, are investigated, the resource characteristics, raw material composition, experimental study, technological scheme, main technical parameters and main problems in operation of Mining projects are analyzed and summarized, such as Deziwa Mining, Shituru Cobalt Project, RTR Mining, Tenke Fungurume Mining and Kamoya Mining. In order to propose a technological scheme more suitable for resource characteristics and raw material change of similar projects in DRC. In addition, it is found in practice that removing iron and manganese with low concentration SO₂ and replacing second-stage cobalt precipitation are effective ways to improve the cobalt recovery rate of such projects.

Keywords: Copper Oxide, Cobalt Ore; Copper Sulfide and Cobalt Ore Concentrate; Removal of Iron and Manganese By Low Concentration So₂; Second-Stage Cobalt Precipitation

Cuprochlor In Zaldivar Mining Company

María de la Luz Osses Klein, Compañía Minera Zaldívar, Chile

Abstract

The evolution of mineralogy in Zaldívar deposit has led to the need to add new processes for the metallurgical processing of copper.

These processes consider higher levels of metallurgical requirements based on the fact that the depletion of copper oxides reserves and the massive mining of the underlying secondary enrichment challenge us with the need to install metallurgical processes capable of solubilizing mineral species with higher refractoriness levels.

The secondary copper sulphides currently being mined in Zaldívar deposit are predominantly characterized by covelline and chalcocite mineralogical species.

In this context, Compañía Minera Zaldívar in 2017 made the decision to industrially incorporate the Cuprochlor process whose previous experimental stage allowed to show a high performance in its application for this type of minerals (10 - 15 pp higher Cu extraction versus the conventional acid leaching process).

The Cuprochlor process, currently in its industrial implementation stage, includes significant levels of chlorides in the curing and irrigation stages of heap leaching pads. The presence of this element (Cl) in solution, together with a moderate content of copper and iron, in addition to the simultaneous application of aeration and temperature, allows activating the Ferric ion regeneration mechanisms, which is the copper leaching agent present in secondary sulphide ores.

There is no doubt that the presence of chlorides in the leaching stage has required important adjustments in the various unit operations that make up the processing chain in order to protect the safety of people and the environment, the sustainability of the assets of our production plants, as well as guaranteeing the quality of the finished products.

These challenges have been faced mainly with three modifications to the production process: i) installation of a brine plant, which considers a robust hydrochloric gas capturing and washing stage, guaranteeing emissions well below what is established in the standards, ii) change in the materials of the SX trains and iii) incorporation of additional washing stages in the four SX plant trains.

Currently, CMZ is beginning the brine plant start-up and the capturing and scrubbing of hydrochloric gases and in the final stage of the modifications to the Solvent Extraction process, in addition to the implementation of additional operational practices, whose integrated purpose aims to maintain an adequate control of chlorides sent to the Electrowinning Process.

Leaching and electrowinning in methanesulfonic acid - An alternative method of raw silver refining.

Johannes Hopf, TU Freiberg, Germany

Abstract

The traditional way of silver refining consists of an electrolytic refining process of raw silver anodes in a nitric acid-based silver electrolyte (Moebius-electrolysis). However, this process is associated with several technological and ecological disadvantages, like the re-dissolution of deposited silver and the evolution of toxic nitrous gases. Thus, there is an interest in developing an alternative refining technology for raw silver. A possible base chemical for this alternative process could be methanesulfonic acid (MSA), which is less environmentally hazardous than nitric acid. The work presented in this paper shows the suitability of MSA for the design of an alternative raw silver refining process consisting of a leaching step and electrowinning. Raw silver granules with a silver concentration of approx. 93 % were leached with MSA and the silver-rich leaching liquor underwent an electrowinning-process to obtain fine silver. The influence of fundamental leaching parameters like the solid concentration, the temperature, the hydrogen peroxide dosage and the influence of impurities in the leaching solution have been investigated. Furthermore, electrolysis parameters for the deposition of a smooth and pure silver cathode have been identified.

Evaluation of various SX formulations for high chloride conditions

Juan Carlos Sánchez, SOLVAY LATAM, Chile

Rodrigo Zambra, SOLVAY LATAM, Chile

Tyler Mccallum, SOLVAY USA, USA

Abstract

The depletion of copper oxide minerals is a constant concern of metallurgists and other experts in the hydrometallurgical industry, which has led to the study of new leaching techniques for copper sulphide minerals. The technology that appears to be one of the most successful is chloride assisted leaching. In several practical industry cases, the addition of chloride salts (either sodium or potassium) has resulted in chloride concentrations up to 60-90 gpl in the PLS. These chloride levels are seen to improve leach kinetics and help overcome passivation and encapsulation of copper sulfides.

Although higher concentrations of chloride aids leach performance, it creates a challenge for solvent extraction (SX). Increased chloride concentrations in the PLS lead to a reduction in pH due to a greater activity of the hydrogen ion. Lower pH makes Cu extraction more difficult for the SX operation. In addition, PLS viscosity increases due to the dissolution of other metals in the gangue such as aluminum and magnesium. Higher viscosity can lead to increased entrainment and negatively impact stage efficiency resulting in higher operating costs or reduced copper recovery.

To optimize copper transfer in the SX circuit, typically a modified aldoxime extractant shows stronger performance at lower pH and higher kinetics and stage efficiency over a ketoxime extractant. However, Solvay has studied and presented previously that with higher chloride concentrations, stage efficiency concerns with ketoxime can be overcome. As the hydrometallurgical industry in LATAM specifically is seen to be moving to more aggressive chloride leach conditions, a review of the optimal reagent selection is presented. The present study compares a range of aldoxime and ketoxime extractant formulations and evaluates their performance over a wide range of PLS chloride concentrations that can be found in current operations or projects that consider a chloride assisted leach.

The relationship of silica and chloride on nitration in solvent extraction

Juan Carlos Sánchez, Solvay Latam, Chile

Rodrigo Zambra, Solvay Latam, Chile

Tyler Mccallum, Solvay Usa, Usa

Abstract

Nitration in solvent extraction is a well-known phenomenon and has been a focus of study by Solvay for many years. The potential to form nitrating conditions is dependent on the nitrate content in solution but is also catalyzed by acid and potential. This typically translates to more likely chances of nitronium formation in electrolytes over PLS. Generating nitronium can nitrate the oxime when the aqueous phase contacts the organic phase in the solvent extraction plant. Nitrated oxime stabilizes the copper-oxime complex (either aldoxime or ketoxime) making it impossible to strip the loaded copper under normal stripping conditions. Because of the higher acidity and potential in electrolyte, nitration typically occurs in the strip section of the SX circuit.

However, in recent times, nitration has occurred in operations where these conditions are not typical (in the extraction stage). In the investigations carried out at different sites, it has been identified that aqueous entrainment (which carry electrolyte with a high acid concentration to the extraction stages) generates nitration points or "hot spots" leading to increased formation of nitronium.

To a lesser extent, it has been suggested that the presence of colloidal silica in solution generates a catalytic effect on the formation of nitronium and promotion of nitration. Additionally, the presence of chloride (whether due to the use of seawater, the addition of chlorinated salt or present in the mineral) generates an ordered pair together with the nitrate but has not been studied in depth. The interaction between silica, chloride and nitrate remains an interesting area to expand on the industries understanding of nitration.

In the present study, a deep investigation has been developed using a Matrix type experimental design to understand the relationship between colloidal silica and chloride (along with the REDOX potential and acid concentration) and their effect on nitration. As a measurement method, the TAP Test methodology was used to quantify the amount of nitronium ion formed for each condition.

Sulphurised chalcopyrite leaching process Optimisation

Virginia Quiroga, Universidad Nacional de San Juan, Argentina

Ivana Orozco, Universidad Nacional de San Juan, Argentina

Vanesa Bazán, Universidad Nacional de San Juan-CONICET, Argentina

Abstract

In Argentina, the most common sulphide copper ores are the primary ones, such as chalcopyrite -which is currently treated by means of pyrometallurgy- but due to environmental restrictions, alternatives techniques such as hydrometallurgical procedures have been used. In spite of this, this method has not found widespread acceptance for chalcopyrite, since the refractory nature of this mineral phase does not permit leaching under ambient conditions. Moderately high temperatures and pressures are required to break down a protective passivation layer formed by intermediate oxidation products. As an alternative, the use of polar aqueous solvents, such as acetone, methanol and ethylene glycol, together with hydrogen peroxide and sulphuric acid solutions, has been proven to increase chalcopyrite dissolution, which is not entirely successful technologically. Por lo tanto, surgen diferentes estudios como la adición de catalizadores, como pirita y/o iones de plata, utilizadas durante la lixiviación para modificar esta película pasivante formada. Sin embargo, las mejoras no han sido económicamente atractivas y aún requieren un procesamiento prolongado durante sus tiempos de lixiviación, al encontrar las variables de operación óptimas que hagan este procesamiento rentable.

Therefore, several studies have emerged, such as the addition of catalysts, like pyrite and/or silver ions, used during leaching to modify this formed passivating film. Nevertheless, the improvements have not been economically attractive and still require prolonged processing during their leaching times to find the optimal operating variables in order to make this processing profitable.

Based on the above, the aim is to use the combination of pyrometallurgical and hydrometallurgical methods, and obtain a favourable synergy in regards to the combination of both processes, in order to optimise the copper obtainment from the sulphide ore. Thus, in this research, the optimisation of global leaching process of previously sulphurised chalcopyrite is studied so as to determine the optimal operational variables for each aforementioned process.

Oxidative roasting at relatively low temperatures and short roasting times in the presence of elemental sulphur are used for chalcopyrite sulphidation. The studied parameters are: roasting temperature at 300°C, 350°C and 400°C, reaction time of 20 min, 30 min and 45 min and elemental sulphur concentrations from 2 to 6%. It should be noted that work was carried out with different molar ratios and by analysing the results of the variation of the Cu and Fe concentration for different temperatures and sulphurisation times, the best response was obtained for the Cu:Fe:S=1:1:1 conditions. The transformation of mineral chalcopyrite (CuFeS₂) into a mixture of covellite (CuS) and pyrite (FeS₂) was successfully accomplished.

The feasibility of obtaining the mentioned phases was estimated by performing a thermodynamic analysis of the possible prevailing reactions during roasting in a controlled atmosphere and in the presence of sulphur. On the other hand, the designed experimental tests are studied under a response surface system obtaining the operating parameters from different response surfaces.

The recovery of copper from chalcopyrite without sulphurisation makes this process complex, mainly due to the dissolution kinetics slowness for most extraction ways. In contrast, leaching of sulphidised chalcopyrite to produce copper is a very attractive process as it exhibits fast kinetics and is very selective in chloride environment. Therefore, leaching solutions such as H_2SO_4 -NaCl can be used in hydrometallurgical process for chloride leaching, showing much faster dissolution kinetics for this leaching medium by modifying its mineralogical phase. At this stage, a thermodynamic analysis for the applied leaching is also outlined, taking into account the most feasible Eh-pH values for the dissolution of copper and iron respectively.

Since the objective is to determine the optimum conditions to selectively dissolve copper contained in the ore, the respective lixiviation process response surfaces are analysed, taking into account the previous thermodynamic study, yielding the conditions for the following operational parameters: concentration of the leaching solution, leaching temperatures and times, pH conditions and agitation speed. Then, the leaching is performed in Bach processes with different concentrations of H_2SO_4 -NaCl solutions. The concentrations of the leaching agent for the different tests are: 0.2M, 0.4M, 0.6M, with the enriched solution sampled every one hour. The leaching temperature range is from 25°C to 90°C, the leaching times are from the very beginning to 4 hrs; for the analysis of the leaching pH, the values of pH:1 and pH:2 are used; and finally, for the variation in the agitation speeds, a range from 380 to 680 rpm is studied. In conclusion, experimentally it is obtained that the optimal operational variables found are the following: leaching solution concentration $[H_2SO_4/NaCl] = 0.2M$; leaching temperature $T = 80^\circ C$; leaching pH = 1; leaching time = 3 and 4 h, coinciding with the parameters obtained from the response surface analysis and the thermodynamic analysis. Thus, the optimum conditions for a Cu recovery of 94% are determined, such that no dissolution of the iron present in the mineralogical phases obtained is observed.



Investigation into counter current leaching for copper bearing printed circuit boards with ammoniacal lixivants utilizing Cu(I) and Cu(II) complexes

Peijia Lin, University of Kentucky, United States of America

Joshua Werner, University of Kentucky, United States of America

Abstract

The complexes of Cu(I) and Cu(II) in ammoniacal systems allow for the possibility of a closed loop coupled leaching-electrowinning system when Cu(II) is utilized as an oxidizer and regenerated at the anode. To understand the feasibility of such a system, leaching experiments were conducted to determine the efficacy of reaction kinetics under various leaching extents and oxidizer concentrations to evaluate the suitability of counter current leaching with a consumable oxidizer for efficient leaching. This work will evaluate the experimental framework to approximate a counter current system and the results obtained.



Investigations into solvent extraction for electrolyte purification in ammoniacal systems

Joshua Werner, University of Kentucky, United States of America

Lucas Bertucci, University of Kentucky, United States of America

Abstract

In order to mitigate metallic contaminants due to leaching in a coupled ammonia based leaching-electrowinning system, a study was conducted into the suitability of solvent extraction of metals as a means of electrolyte purification. This work will discuss extractant selection, equilibrium determination between metals in aqueous and organic systems, and a model framework to evaluate performance. The intent of this work is to provide an initial evaluation of solvent extraction for the purpose of electrolyte purification for a closed loop copper ammonia coupled leaching and electrowinning system.

Arsenic containing intermediate materials processing from copper smelting production

Kirill Karimov, Ural Federal University, Russia

Maksim Tretiak, Ural Federal University, Russia

Abstract

The need to increase the production of copper and other non-ferrous metals compels the industry to engage various primary and man-made low-grade polymetallic materials such as copper–zinc, copper–lead–zinc, poor arsenic-containing copper concentrates, enrichment products, etc. The overall decrease in the quality of mineral raw materials, combined with the use of arsenic-containing ores, results in large amounts of various intermediate products containing this highly toxic element.

The current technologies for processing copper concentrates are mainly pyrometallurgical, resulting in the formation of a large amount of waste gases and dusts. Arsenic is a harmful impurity contained in recovered non-ferrous metals, which determines the importance of its removal from technological processes

Autoclave leaching of cake after atmospheric leaching of fine dust makes it possible to break down copper and zinc sulfides and ferrites at 160°C. The overall extraction achieved into solution for the atmospheric and autoclave stages is 93% Cu, 96% Zn, 99% Cd, 99 % As.

Considering the high environmental hazard of arsenic, its precipitation from solution to low-soluble, low-toxic compounds is important. Ferric arsenates obtained through hydrothermal precipitation are the least soluble and most stable form of arsenic. As temperature increases and pH decreases, the crystalline structure of the precipitate improves at 150–200 °C and at a Fe:As ratio of 1.5 and higher. The hydrothermal interaction affords $FeAsO_4 \cdot H_2O$, $Fe_3(AsO_4)_2SO_4OH$, $FeSO_4OH$, and $Fe_2(HAsO_4)_3 \cdot xH_2O$. At temperatures of 180 C and above, over 95% of arsenic is removed.

Hydrothermal enrichment of chalcopyrite concentrates: kinetics aspects and process efficiency

Aleksei Kritskii, Ural Federal University, Russia

Denis Rogozhnikov, Ural Federal University, Russia

Stanislav Naboichenko, Ural Federal University, Russia

Abstract

Hydrothermal treatment of copper concentrates and associated minerals with copper sulfate solutions is currently in the area of interest of modern research laboratories. The hydrometallurgical approach allows to enrich typical copper concentrates (16–22% Cu) and simultaneously purify from a number of impurities such as Fe, Zn, Mo, As and others. Recent improvements of the process are mostly related to the increase in temperature, since it allows to raise the reactivity of the mineral particles.

Current paper is devoted to optimizing the process parameters for chalcopyrite concentrate treatment in sulfuric acid media. At optimal conditions (230 °C; 20–40 g/L H₂SO₄; Cu_{CuSO_4}/Cu_{CuFeS_2} ratio = 1.8–1.9; 160 g/L solids; 60–100 min) a higher-grade concentrate of 50–55% Cu was obtained. Effect of initial copper and sulfuric acid concentrations, temperature, pulp density and process duration is discussed. As the result of the investigation, a parametric model was created, which allows to select parameters for producing the Cu-rich concentrate (40–55%) and final solution with low copper content (0.05–0.25 g/L).

A special attention attended to a behavior of the secondary minerals such as ZnS, FeS and FeAsS. The Shrinking core model (SCM) was applied for describing kinetics of the hydrothermal treatment of the minerals with copper sulfate solutions in temperature range of 170–250 °C. The apparent activation energy and reaction orders with respect to the reagents were calculated and semi-empirical expression describing reaction rate was suggested.

The results show high-efficiency of this approach for copper concentrates enrichment, however, the conversion rate of the secondary minerals remain insignificant in the studied parameters range. A strategy for further improvement of the process is proposed.

Evaluating pre-treatment methods to maximize copper recovery from printed circuit boards

Moyo, T., Minerals-to-Metals Signature Theme, Department of Chemical Engineering, University of Cape Town, South Africa

Prestele, M.P., Minerals-to-Metals Signature Theme, Department of Chemical Engineering, University of Cape Town, South Africa

Kondo T., Minerals-to-Metals Signature Theme, Department of Chemical Engineering, University of Cape Town, South Africa

Petersen, J., Minerals-to-Metals Signature Theme, Department of Chemical Engineering, University of Cape Town, South Africa

Abstract

Waste Printed Circuit Boards (PCBs) are a valuable-metals rich fraction of the electronic waste (e-waste) stream. Copper is the most abundant metal on the PCBs, found on the surface of the boards, on the vias that connect copper layers and on the inner copper layers in the now common but more complex multilayered PCBs. Liberation of the inner copper layers presents significant challenges in the hydrometallurgical processing of the PCBs due to the impervious tight lamination of the multilayers rendering lixiviant-metal contact impossible. The inaccessible copper is found in alternating layers of copper sheets and glass- reinforced epoxy laminate. Current practice employs pyrometallurgy and/or energy extensive size reduction to liberate the copper. This has the disadvantages of high energy costs, loss of materials in the extensive size reduction steps and the potential to emit toxic gases if furnaces are not equipped with advanced gas scrubbers. This study investigates and compares the effectiveness of chemical pre-treatment methods, i.e. organic solvent swelling, sodium hydroxide soaking and physical pre-treatment i.e. shredding the PCBs using an industrial grab shredder as well as an integration of the chemical and physical pre-treatment methods. The study employs ammonia-based copper leaching to evaluate the effectiveness of each pre-treatment method, using copper extractions as a proxy for assessing effective copper liberation in the precursor step. The cost implications and environmental footprint of each processing route is also discussed.



Effectiveness of 4-contact hydro-metallurgical insulators in improving the current balance and reducing the energy consumption of copper refineries

Robert Dufresne, P.Eng, Pultrusion Technique, Canada

Hamid Arabzadeh, PhD, P.Eng, Pultrusion Technique, Canada

Abstract

The current study investigates the effectiveness of an innovative insulator system for copper refineries with a built-in short-circuit bypass element that can significantly contribute to a more uniform electric density within the circuits in each cell, as well as throughout the entire electric distribution in the cell house. The new design uses multiple loop backup pieces to compensate for degradation in the contact points between the contact bar and electrodes. In this work, a brief theoretical analysis of the problem is presented, and the methodology is supported by results of tests on small-scale specimens to prove the efficiency of the proposed design. Results have shown a reduction in the quantity of the short-circuits up to %80, combined with a noticeable reduction in their magnitude. Also, the higher uniformity of electric density in the system can result in up to %15 reductions in electric consumption.

Application of nitric acid leaching for refractory sulfide materials processing

Denis Rogozhnikov, Ural Federal University, Russia

Kirill Karimov, Ural Federal University, Russia

Oleg Dizer, Ural Federal University, Russia

Abstract

Due to the depletion of high-grade deposits and an increase in the share of polymetallic sulfide raw materials used, the issue on the involvement of low-grade and refractory sulfide materials in industrial processing is becoming highly actual. The efficiency and the features of nitric acid leaching in an application for refractory sulfide materials are discussed in this article.

The most common refractory sulfide minerals to hydrometallurgical treatment such as CuFeS_2 , FeS_2 , FeAsS and $\text{Cu}_{12}\text{As}_4\text{S}_{13}$ were used to study the kinetics and the thermodynamics of dissolution in nitric acid media. The main kinetic characteristics are determined, semiempirical equations and mechanisms of the dissolution are proposed.

Based on the kinetics studies, the optimal conditions of nitric-acid leaching for sulfide Cu-containing and precious metals containing materials were proposed. The decomposition degree of refractory sulfide minerals in the materials was more than 98%, which allowed the extraction of more than 95% of base metals, iron, and arsenic into the solution.

Pilot testing of the suggested method confirmed the high efficiency of base metals leaching, a gold recovery at the level of 90 %, nitrous gases utilization at the level of 99 %, and a "green" pathway in waste disposal.

A new method to irrigate heap leach using stakes for an underground irrigation.

Rodrigo Villarroel, ASComposites, Chile

Fernando Penna, ASComposites, Chile

Abstract

Heap leaching is the most used method in Chile in copper hydrometallurgy and irrigation is a preponderant stage in the process, since an adequate calculation allows determining parameters for the leaching solution such as flow, pressure, amount of acid and others. Also, those associated with the conformation of the heap (height, granulometry, compaction, agglomeration), all to achieve a better mineral recovery. However, there are factors both in the formation of the heap or in the environment where they are located, which can affect the process in unexpected ways. An excess of wind and heat can generate high rates of water evaporation with the consequent economic loss of this input, as well as an increase in the acid concentration of the leaching solution, which moves it away from the calculated conditions, as well as the loss of heat from the surface of the heap. The type of agglomeration or the granulometric characteristics of the mineral can affect the permeability and generate areas of surface settlement, which can generate destabilization of the pile. A technological proposal to minimize these unwanted effects is the application of underground irrigation (under the surface) of the heap using a network of buried perforated stakes connected to the irrigation line, joined to a roof scheme supported by the same stakes. it will allow greater penetration of the solution and less heat loss and evaporation through the surface.



DEM Analysis of an Agglomeration Drum with Liquid Spray Addition Phenomenology

José Arraztio, Syntec, Chile

Máximo León, Syntec, Chile

Abstract

In this paper the analysis of an agglomeration drum is presented using the discrete element method (DEM), with a focus on the prevention of material ring formation, material load distribution and process flowability. We consider an inlet of dry material to the drum which is impacted with tiny particles carrying a large liquid film, emulating the liquid sprayed inside the drum. The simulation interactions consider the cohesive properties of the material, in conjunction with the viscous forces generated by the liquid bridge between particle-particle and particle-boundary. From the study, a parametric analysis is carried out between the RPM and the angle of inclination of the drum, with the respective pros and cons, as a guide for the operator. In addition, some potential uses of this study for agglomeration drum design are discussed.