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MINING ENGINEERING

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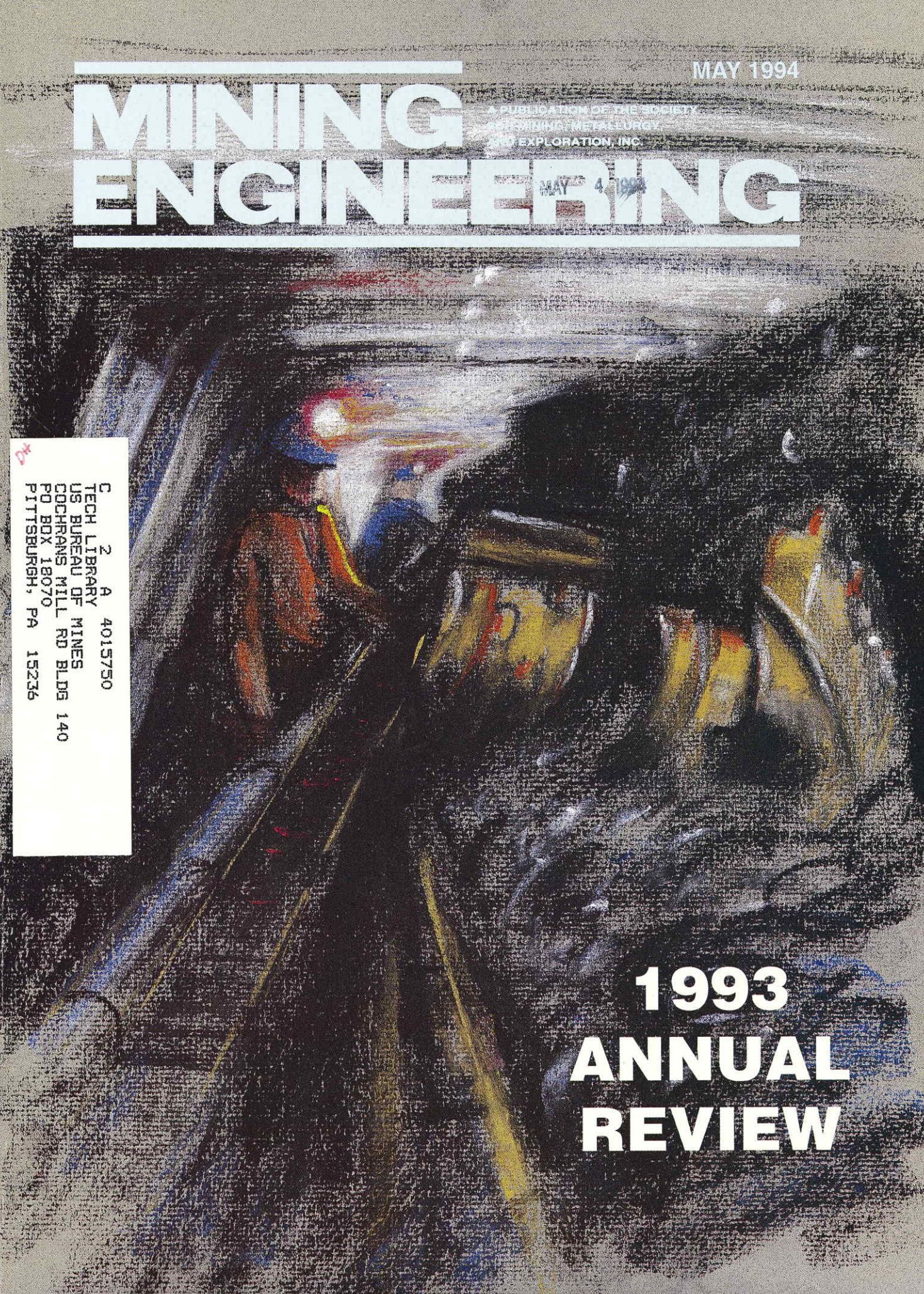

1993 ANNUAL REVIEW

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DEPARTMENTS

ANNUAL REVIEW

Each May, **MINING ENGINEERING** reviews what happened in the minerals industry the previous year. This year, that review begins on page 405 with the exploration section. In the June issue, we will profile industrial minerals activity in 1993.

THANK YOU

ME editors thank the authors and contributors who make possible this May annual review issue. We appreciate your help. **ME** readers should benefit from your efforts. Cover artwork courtesy of Bonnie Wiebmer.

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BPA

SPECIAL ISSUE: 1993 ANNUAL REVIEW

ate complex was observed, which depended on the surface area to a lesser degree.

A review of flotation of carbonates from phosphates led to a demonstration of depression of fluoroapatite using H_3P0_4-$H_2C_20_4$ at pH 5.5-6 while floating the calcite (Elgillani and Abuzeid, *International Journal of Mineral Processing*, Vol. 38, pp 235-256). Hanna and Anazia reported a new process for direct phosphate flotation from US siliceous ores (*Mining Engineering*, Vol. 45 No. 2, p.184). ♦

Flotation process analysis

R.A. Seltz, *Unimin Corp.*
C.E. Jordan, *US Bureau of Mines*

The flotation process involves complex interaction among the physicochemical characteristics of the particle species involved and the hydrodynamic and chemical environment in flotation cells. Considerable research into many of these areas took place in 1993.

Conference proceedings were published with many references to flotation: Beneficiation of Phosphate — Theory and Practice (BPTP), SME; Emerging Computer Techniques for the Minerals Industry (ECTMI), SME; CIM - Mill Operators Conference (CMP); Flotation Circuits: Are They Optimized? (FCAO), SME: and the 18th International Mineral Processing Conference (IMPC) held in Sydney, Australia.

Process mechanisms

Pulp phase

There are still many conventional flotation cells being used and selected for use. Research continues, to understand the mechanisms responsible for flotation in these cells. Nguyen Van (*International Journal of Mineral Processing*) developed a fundamental analysis of phenomena occurring during the sliding interaction of bubbles and particles, to calculate induction time and to model the adhesion process. Predictions agreed with experimental observations.

Lu et al. (SME Annual Meeting, February 1993) reported on the kinetics of particle-bubble aggregation in the cell. Most of the bubble-particle attachment takes place in a small region near the impeller where the mixing energy is high. The theoretical mechanism for bubble-particle detachment was also investigated and related to the Weber number at various locations in the cell. Bubble-particle detachment only takes place in the small region near the impeller where the mixing energy is high.

Optimization and control

Flotation is notorious for process upsets and resulting poor performance. So control offers a potential for improving process performance. Control is a difficult task because the process is subject to unmeasurable disturbances and because of the inconsistent response to a given disturbance. In addition, considerable confusion arises even when deciding upon control objectives.

The benefits are recognized of monitoring and control of chemical environment in flotation pulps. Zhou and Chander (ECTMI) reviewed the advantages and disadvantages of various techniques available for controlling reagent additions, emphasizing potentiometric and voltammetric sensors. Potentiometric sensors are simple to use but are limited by the availability of an electrode reversible to the species to be monitored. In some cases, the response signal could be unreliable due to the presence of interfering species. Voltametric sensors require a higher degree of instrumentation. However, that provides an opportunity to decrease interferences and increase levels of detection.

Richardson et al. (ECTMI) discussed an electrochemical probe developed by the Bureau of Mines, plant testing in copper-moly flotation circuits, and the interpretation of chemical and electrochemical processes that determine the potential of various sensor electrodes.

Use of visually-derived information has accelerated for the control of flotation circuits. Poirier et al. (CMP) reported on the development of an advisory expert system for copper flotation operations at Highland Valley Copper. The system is used to help operators identify froth types and troubleshoot corrective action.

Fonseca et al. (*Coal Preparation*) and Meenan and Oblad (ECTMI) reported the development of novel optoelectronic sensors for the online measurement of ash and solids percentages. They also reported on successful applications in CONSOL preparation plants.

To improve process monitoring and control, the coherence of information from sensors must be assured. Erroneous values must be identified and corrected. Hodouin et al. (ECTMI) reviewed methods for online data reconciliation and missing-values estimation.

Mineralogy

Filho et al. (*Minerals Engineering*) and Qi (*International Journal of Mineral Processing*) discussed process mineralogy as an integral part of studies for optimizing flotation performance for two different phosphate ores. For one ore, surface heterogeneity, collector response and solubility determinations were correlated with flotation performance. In the latter case, QEM*SEM was used to assess the flotabilities and intergrowth and association characteristics of major minerals. In both cases, specific reagent regimes and flowsheets were picked based on information from both sources.

Heinrich (CMP) combined size-by-size metallurgical information and pentlandite liberation data to ascertain the mechanisms responsible for process selectivity. With this information, Heinrich was able to better identify a means for process improvement. These studies illustrate how basic process mineralogy can be studied in conjunction with flotation performance to identify causes of refractory behavior.

Modeling and kinetics

Reuter and Bernhard (*Minerals Engineering*) and Van Der Walt et al. (*Minerals Engineering*) reported on the application of a generalized neural net kinetic equation to simulate and identify ill-defined kinetic processes, such as flotation, where existing approaches fail due to their lack of generality or their complexity.

Tikhonov and Kavetsky (*Proceedings*, Australasian Institute of Mining and Metallurgy) presented a new flotation model for analysis and circuit simulation. The model allows predictive calculations of total solids flows and metal grades and recoveries to be made for industrial flowsheets. The model also includes the effect of cell aeration rate on performance. The authors discussed the problems of determining sufficient flotation characteristics from a circuit feed sample, to predict the behavior of a specific ore in a specific circuit. Some suggestions for solution are made. Data from the Kambalda Nickel circuit is used to illustrate the approach.

Circuit design

Most flotation circuits combine a variety of rougher, cleaner and scavenger banks arranged with recirculating loads to deliver "optimum" grade-recovery performance. Yingling (*International Journal of Mineral Process-*

ing) reviewed prior work on configuration and parameter optimization of flotation circuits, pointing out their advantages and disadvantages. He also presented a new approach for optimization based on analyzing the effects of circuit configuration. But Yingling was forced to conclude that while a drastic improvement, the shortcomings of existing models limits the potential for an integrated assessment of circuit structure and factors that influence the circuit's pulp environment.

Column flotation

Column flotation continues to show its advantages over conventional mechanical cells in many applications. Raju et al. (*Transactions*, Institute of Mining and Metallurgy, C) reported that column flotation performed better than conventional mechanical cells to separate fine silica particles from iron oxide particles. In lab and pilot plant studies, the column recovered more iron and had a higher separation efficiency than the mechanical cells. The separation efficiency of the column increased as the fineness of the grind increased. However, Wyslouzil et al. (SME Annual Meeting, February 1993) reported that with column flotation there was better flotation of the coarse silica from the iron ore. This probably shows the effects of the operating regime on process performance.

Aliaga and Soto (*Transactions*, Institute of Mining and Metallurgy, C). reported better performance of coarse potash particles in column vs. mechanical cell flotation. In both lab and pilot plant studies, they observed success in all applications (roughing, scavenging and cleaning). Most notable was the separation of coarse potash 1.2 mm (0.05 in.) size, where a positive bias of brine injected at the bottom of the column aid in coarse particle recovery.

tiple applications of column flotation, from ore processing to waste water processing. These include applications in electrolytic cleaning of organics from SX solutions and removal of oil and

Design

The axial dispersion model depicts the residence-time distribution within a column flotation cell. However, correlations to determine the extent of axial dispersion are still being developed. Mavros (*Minerals Engineering*) derived a simple correlation in terms of the column diameter and superficial gas velocity.

The behavior of bubble-particle aggregates in the froth phase is poorly understood. The behavior is likely governed by operating parameters such as gas and wash water flow rates and the depth of the cleaning zone.

Comparison of the predicted axial dispersion number with various literature sources indicates good correlation. The primary parameter affecting axial dispersion is the column diameter. Large columns have large amounts of axial dispersion with resulting backflow circulation of the pulp. Most of the backflow is caused by the pulp feed. Only a minor amount of the backflow is caused by the rising air flow.

In large columns, the rising air bubbles expand on their path upward as the head pressure decreases. Zhou and Egiebor (*Minerals Engineering*) developed a model to predict this phenomena. The model had good agreement with existing literature. Del Villar et al. (*CIM Bulletin*) presented a novel alternative measurement of the carrying capacity of the air bubbles. Their values were considered more realistic for designing column capacity.

The use of baffles is an important consideration for many column scale-ups. Moys et al. (*CIM Bulletin*) reported on a study of column cell baffles to reduce axial mixing and improve separation efficiency. In large columns, reduced efficiency was due to unequal feed and air distribution resulting in dead zones within the column. For best results, individual feed ports should be used to distribute the feed equally inside each baffled zone. The baffle should extend into the froth zone at the top. At the bottom, the baffle should be high enough above the air spargers to provide uniform air dispersion throughout the column cross-section before entering the baffled zone.

The flotation rate depends on the availability of bubble surface. Thus, the maximum gas velocity is important in column's design and operation. Excessive air flows cause transformation from a bubbly flow to a churning, turbulent-flow regime.

Ityokumbul (*Minerals Engineering*) developed a technique to measure this transformation point in a column and relate it to column diameter. This relationship was compared with results for successful column operations as reported in the literature.

Froth phase

Froth characteristics in a flotation cell often tell the operator how well a circuit is performing. Several studies were directed at increasing the knowledge of flotation froths. Zhou et al. (*Minerals Engineering*) discussed the effect of frother concentration on bubble size estimation in a column. Unlike single bubble systems, the solution's surface tension cannot be used as a criterion to predict the average bubble size produced in the column in the presence of different frothers. Based on bubble flow characteristics in the system, a new method was developed to estimate the average bubble size in the column. Contrary to popular belief, higher gas holdups in the column do not necessarily mean that smaller bubbles were produced.

The behavior of bubble-particle aggregates in the froth phase is poorly understood. The behavior is likely governed by operating parameters such as gas and wash-water flow rates, the wash-water addition point and the depth of the cleaning zone. Choung et al. (*International Journal of Mineral Processing*) reported significant and interactive effects of both the wash water addition point and the flowrate. Optimum grade-recovery performance is achieved only by considering both factors.

Control

Only level control is needed to operate a column. To achieve reasonable results requires an appropriate gas holdup in the collection zone and some desirable residence time and mixing pattern in the froth zone. Using conventional instrumentation, it is possible to measure and regulate froth depth, gas holdup and a relative bias. But large errors are frequently present. In practice, only rough stabilizing control is achieved most of the time. Movement to improve stabilizing or optimizing control holds considerable potential for

improving performance. Bergh and Yianatos (*International Journal of Mineral Processing*) reviewed recent work in this area on measurements, dynamic and functional models, control strategies and control algorithms.

Novel flotation devices

Trembley et al. (CMP) provided an overview on the plant installation, commissioning and evaluation of two Jameson cells at Kidd Creek. The work involved understanding the cell operation and design constraints and developing a flowsheet to replace three divisions of copper cleaner flotation. Fine particle (-44 μm or -325 mesh) recovery was improved, while recovery of coarser particles (+44 μm or +325 mesh) dropped.

Gas hold-up is a potential control variable in flotation. Summers et al. (*Transactions,* Institute of Mining and Metallurgy, C) reported on a sensor for estimating gas hold-up and identifing process disturbances in Jameson cell downcomers.

Conditioning

Although most researchers focused on the separation part of flotation, several aspects of reagent conditioning were reported upon. Davis and Hood (*Mining Engineering*, BPTP) reported improved selectivity in phosphate flotation with longer conditioning times and/or increased agitation. Laskowski and Nyamekye (SME Annual Meeting, February 1993) also reported improved flotation response with longer conditioning times for a fatty acid flotation system. The authors attributed this to increasing the number of collisions between the particles and the slightly soluble fatty acid emulsion droplets. ♦

Hydrometallurgy

P. Thompson,
Dawson Metallurgical Laboratories Inc.

In 1993, several important developments occurred in the field hydrometallurgy. Salt Lake City, UT hosted the SME Fourth International Symposium on Hydrometallurgy. This symposium honored Milton E. Wadsworth for contributions to hydrometallurgy during the past 40 years.

Several new precious metals projects started up in 1993, mostly overseas. One exception was the Lone Tree pressure oxidation plant near Winnemucca, NV. This plant, owned by Santa Fe Pacific Gold Mining, is treating gold-bearing pyrite ore by using a relatively low temperature of 160° C (320° F) acid autoclave process before cyanidation.

Newmont started up Yanacocha heap leach facility in northern Peru. The company expects annual gold production to reach 7.8 t (250,000 oz) in 1994. Newmont also broke ground on the Muruntau gold heap leach facility in Uzbekistan.

Several other projects using US developed cyanidation heap leach technology are being developed in Kazakhstan and Kyrgyzstan.

Hydrometallurgical treatment of copper ores continues to be the focus of considerable research and development.

The minerals laboratory of BHP-Utah International developed the Escondida process for treating copper sulfide flotation concentrates containing chalcocite and bornite. The process uses ammonia-ammonium sulfate leaching followed by solvent extraction-electrowinning (SX-EW).

A plant that will produce 80 kt/a (88,000 stpy) of copper cathodes is being built at the port of Coloso. Hydrometals Joint Venture completed development of the ferric-chloride-based Cuprex process for treating low-grade copper concentrates. The process has been piloted and feasibility studies completed.

The use of leaching aids in copper dump leaching continued to attract attention. Fluorad FC-1129 is a fluorochemical surfactant developed by 3M Co. It is being used at Magma Copper's San Manuel leach operation. A 5% increase in copper recovery has been reported.

The use of biohydrometallurgy as a pretreatment for refractory gold ores has yet to be demonstrated commercially in the United States. Although a bacterial leaching facility is operating in Brazil at the Sao Bento Mineracao operation, a domestic plant using this technology has not been built.

Newmont has developed a biooxidation process for treating low-grade refractory sulfidic gold ores that uses heap leach technology. Biooxidation is accomplished using a mixed culture of acidophilic, iron oxidizing bacteria. The heap is actually the bioreactor. After biooxidation, the heap is rinsed with fresh water, dismantled and reconstructed in preparation for conventional cyanide heap leaching. This concept has been demonstrated on a pilot scale in the field.

Considerable research is being directed toward biological remediation of acid mine drainage and cyanide effluents. Biooxidation of pyrite using heap leach techniques is being considered to reduce the sulfur content of slate, which is used as portland cement kiln feed. ♦

Industrial waste processing

S.K. Mishra,
Tetra Technologies, Inc.

In 1993, waste treatment technology receive much attention. Metals and organic contaminants were the major interests.

In this review, attention is paid to the processes for the treatment of metals and organics contaminated liquid and solid wastes.

Inorganic contaminated effluents

While conventional hydroxide precipitation is still a widely used method of removing heavy metals from the acidic waste streams.

Foreman, however (*Process Industry Journal*, Vol. 8, No.4, 1993, pp. 18-19), discussed how magnesium hydroxide as a precipitant can produce relatively fast settling and easy to dewater sludge when compared to the sludge generated with other alkalis.

Various adsorbents have been used to remove trace amounts of metal contaminants from industrial effluents. Heavy metal ions, such as Cr, Ni, Cu, Cd and Zn have been removed from electroplating wastes using Fe (III) hydroxide as the adsorbent (Ajmal et al., *Water, Air and Soil Pollution*, Vol. 68, Nos. 3-4, June 1993, pp. 485-492). The maximum removal of these metals occurred at a pH of 8 to 9.

Low et al. (*Bioresource Technology: Biomass, Bioenergy, Biowastes, Conversion Technologies, Biotransformations, Production Technologies*, Vol. 44, No. 2, 1993, pp. 109-112) used dye-treated and natural oil-palm fibers from a palm-oil mill to remove copper and other heavy metal cations from solutions. Test data show that dye coating had a pronounced effect on the adsorption of metal species.

Using ion exchange and electrowinning technologies, Fries and Chew (*CHEMTECH*, Vol. 23, No. 2, 1993, pp. 32-35) treated copper ion containing waste waters to reduce the copper levels to below 1 ppm, and recovered copper in a salable metallic form.