ASARCO

b.6.0K

Acid mine drainage

Acid drainage from underground workings (referred to as acid mine drainage or AMD) and surface operations and wastes (referred to as acid rock drainage or ARD) represent two of the most intractable issues faced by the non-ferrous metal and coal mining sectors. The recent creation of a number of high-level national and international initiatives clearly demonstrates the continuing concerns of industry, government and other stakeholder groups. Once initiated, the cycle of chemical and biological reactions that generates acidic, metal-contaminated waters, via the oxidation and leaching of sulphides, may be difficult or impossible to stop.

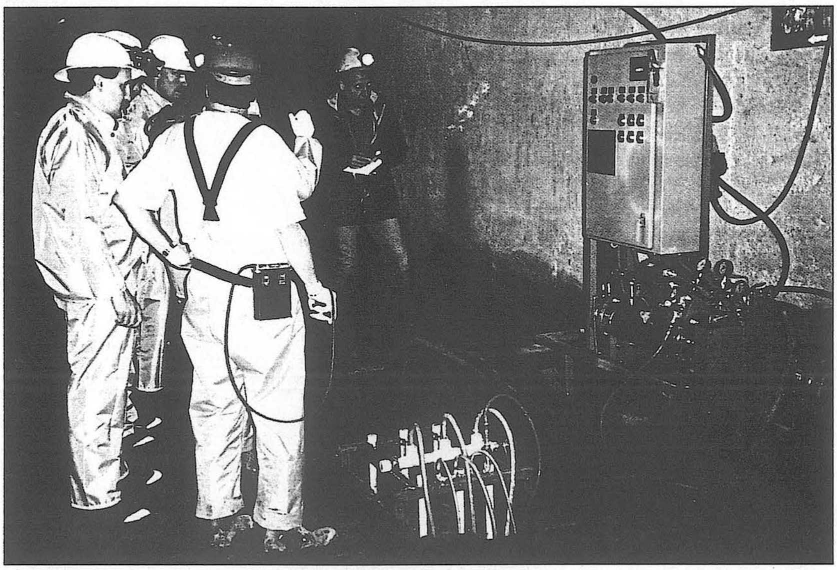
Although there is evidence to suggest that the degree of contamination in acid drainage will decrease rapidly within a relatively short time-frame, experience in historic mining regions of the world indicates that the problem may persist for centuries at certain sites. Add to this the global depletion of oxidised (non-acid generating) ore deposits and the increasing dominance of sulphide ores, and the potential for increasing acid drainage is clear. Indeed, acid drainage from mine workings and waste disposal is considered by many to be the most serious long-term and widespread environmental impact caused by mining and the industry's greatest environmental challenge.

Current best practice in dealing with acid drainage places the emphasis on prediction and prevention, planned from the outset of the operation and integrated with each phase of the mine site lifecycle. The elements that constitute best practice are becoming more clearly defined and as this process of clarification continues cutting edge companies will undoubtedly accelerate the process of best practice implementation, detaching themselves from the historic image of mining as a despoiler and polluter of landscapes.

However, it is equally clear that despite the best efforts of industry and regulators, acid drainage will continue to be an issue during operation and post-closure at many sites; a legacy derived from operational and strategic decisions made decades ago, before the risks and impacts of acid generation were properly understood. In addition, the generation of contaminated drainage from poorly managed operations and from historic and abandoned sites, and it seems certain that remedial treatment will be required for the foreseeable future to protect water quality, the ecosystem and human health.

LIME TREATMENT OF ARD

Despite the recent advances in predictive and preventative measures, treatment technologies have been static for several years, and remain dominated by the application of lime in a number of basic and more sophisticated guises. Although the drawbacks and deficiencies of lime-based systems are well known, the absence of cost-effective alternatives has ensured that it remains the treatment of choice at the majority of sites facing the issue of acid drainage. Although the negative aspects of lime-based systems vary according to site-specific factors, it is possible to draw up a generic list, which includes:



The K250 system in place at the treatment point.

- relatively high capital cost of the dosing system and ancillary equipment;
- chemical instability of treatment sludges leading to possible classification as hazardous wastes that require high-cost disposal at designated sites;
- poor handling characteristics of treatment sludges, which may require extensive land areas for disposal, or expensive mechanical dewatering;
- high pH required to remove metals such as manganese may in turn cause other metals (eg zinc and aluminium) to resolubilise, necessitating a multi-stage treatment to reduce all metals to acceptable concentrations;
- limited potential for resource recovery; treatment sludges normally have no commercial value and reprocessing to extract the metal content is uneconomic with existing technologies due to the large excesses of lime that are often used during treatment to ensure complete metal precipitation; and
- long-term liability associated with sludge disposal sites as a result of the potential for contaminant redissolution.

Although lime is widely accepted at present on the basis of operational costs and its capacity to treat acid drainage, it is becoming apparent that these and other drawbacks will continue to undermine its dominant position in the next century and help overturn industry hesitance towards alternative innovative techniques.

SILICA MICRO ENCAPSULATION

The Klean Earth Environmental Company (KEECO) has been aware of the drawbacks of lime-based treatment systems for a number of years. In response the company has been developing an innovative, cost-effective and high-performance treatment system that has the positive characteristics of lime-based systems (eg responsive to variations in flow and degree of contamination, capacity to treat highly acidic waters, and performance that is independent of temperature), but none of the drawbacks. The KEECO Silica Micro Encapsulation (SME) system is based on a range of unique and proprietary calcium/silica-based reagents. To date, these have been applied in the treatment of acid drainage, industrial effluents, tailings and mine waste, brownfield sites and the removal of radioisotopes from mixed and aqueous wastes, and the list of potential applications continues to grow.

The reagent optimised for such applications as removal of heavy metals from acid drainage and industrial effluents is KB-1™ which contains three major components: a pH adjuster to initiate the precipitation of heavy metals; a polymerising component that traps the precipitated metals in a three-dimensional structure, or matrix, composed primarily of silica; and a support component that carries the pH adjuster and polymeriser, increasing the available surface area and minimising reaction times.

Together, the three components cause the silica micro encapsulation of dissolved contaminants, producing decontaminated water and silica encapsulated metal precipitates in the form of a fast-settling, sand-like product, which is environmentally benign, non-hazardous and resistant to degradation under naturally occurring conditions. Due to the coarse size and high density of the encapsulated particles (relative to precipitates resulting from liming), no flocculent is required to induce settling, which occurs naturally at a high rate. As solid-liquid separation rapidly occurs, high-cost dewatering techniques are not necessary and the land sterilised by sediment disposal is also dramatically reduced. The photograph shows the encapsulation of a copper arsenate precipitate.

KB-1 may be applied in dry or slurried form, depending on the dosing system required. For continuous high flow regimes, the K500 is used. The K500 is a self-modulating and compact plant that achieves rapid and economic removal of heavy metals. The system can treat in excess of 40 litres/s in a single pass and the entire mixing process is achieved by air, directed dry KB-1 powder and controlled turbulent effluent flow without any form of mechanical stirring, with an energy requirement of little over 3 kW.

For lower flows, irregular flow scenarios, or sites where the space is at a premium (eg underground treatment stations), KEECO developed the K250 shear-mixing unit. This machine utilises a system that blends KB-1 powder with a bleed stream from the main acid flow. Efficient mixing is accomplished through the blending action of a high shear mixer to homogenise the KB-1 slurry and maximise its chemical reactivity. Compressed air is then used to assist the injection of slurry into the main waste stream. As the sheared KB-1 slurry is extremely reactive it is dispersed through a chemically resistant, ventilated plastic manifold to facilitate rapid dispersion of the reagent throughout the stream. This process results in rapid reaction between dissolved metals and the KB-1. As the unit is designed to inject slurry directly into the water stream, it is capable of treating highly variable flows up to or in excess of 150 litres/s. This significantly reduces the capital outlay that is often associated with systems that must respond to seasonal or production-related changes in flow.

KEECO believes that KB-1, the K500 and K250 represent the first serious alternative to lime treatment that delivers reliable performance, a high level of environmental protection and is a waste management tool that meets the wider requirements of sustainable development at low capital and operating cost. Its application as a dry powder or as a slurry means that there is no need for major reinvestment in terms of ancillary equipment for sites already using lime, removing one very significant obstacle often seen in the introduction of innovative technologies. Its position as a serious contender with lime is being confirmed by an upsurge in field trials and commercial contracts in the last twelve months, of which one of the first was the treatment of an acid stream emanating from the Kellogg tunnel of the Bunker Hill mine.

Table 1 Water quality analyses (µg/litre)

Parameter	Untreated water	Treated water	US Drinking Water Standard
pH	2.0	9.0†	6.5 - 8.5
As	585	27	50
Cd	401	<1	5
Cu	555	2	150
Fe	146,029	<1	-
Pb	1,291	4	15
Zn	199,645	<1	5,000

† Following liquid-solid separation, the supernatant water pH returns to approximately 7.

Silica micro encapsulation of copper arsenate precipitates.

Table 2 Sediment analysis by SEM-EDS (Wt%)

Element	Primary stage	Secondary stage
Al	2.48	2.09
Ca	9.10	6.16
Fe	31.07	3.60
Mg	1.40	3.68
Mn	1.36	7.72
O	37.98	32.47
S	4.80	6.58
Si	3.94	4.38
Zn	7.44	33.05
Total	99.56	99.72

BUNKER HILL MINE

The Bunker Hill mine (part of the Bunker Hill mining and metallurgical complex) was one of the largest lead and zinc mines in the US and has been in virtually continuous operation for over 100 years. It has 31 levels, over 240 km of drifts, and nearly 10 km of major inclined shafts. Researchers have estimated that the total volume of disturbed ground associated with mining activity is 20 km3. The sulphide mineralogy of the mine is complex and gives rise to a broad range of metals and metalloids in the acid discharge, including lead, zinc, iron, copper and manganese. The mine is an archetypal example of the chronic problems associated with acid drainage that are so often seen in historic underground sulphide mine workings. Preventative measures have been hindered by the infiltration and percolation of incipient rainfall through several thousand feet of sulphide-bearing rock overlying the mine workings.

The main entrance to the mine is at Level 9 (the Kellogg tunnel); a 3 km drift that terminates in the heart of the mountain overlying the mine. The tunnel is the main haulage route into, and out of, the mine and is the level at which water percolating down through overlying sulphide-bearing strata is combined with water pumped from the lower levels and discharged.

Until relatively recently the mine was under a care-and-maintenance regime and its acid discharge was treated in a lime-based system that dealt centrally with effluents from the whole area. This was built in the early 1970s, after federal law made it illegal to discharge untreated mine waste waters directly to surface waters, and is now overseen by the US EPA. Much of the remedial work in the area has been funded through the Superfund and, after its purchase in 1991 by the New Bunker Hill Mining Co., liability for the part of the mine's acid discharge was transferred to the new owners. At the time of the field trials, the company mine was under pressure to improve the quality of water being dis-

AGRA
ENGINEERING GLOBAL SOLUTIONS

GLOBAL MINING SOLUTIONS

- Geotechnical Engineering
- Rock Mechanics
- Water Resources
- Environmental Impact & Permitting
- Materials Engineering
- Construction and Field Services
- Hydrogeology
- Tailings & Waste Management
- Heap Leach Design

AGRA Earth & Environmental Limited

We provide engineering and environmental services to mining through its 1,300 employees in 55 offices throughout Canada and Western U.S.A., as well as offices in Russia, Indonesia and Latin America.

NEW OFFICE IN LIMA, PERU

VANCOUVER ..... (604) 294-3811
CALGARY .... (403) 248-4331
EDMONTON ...... (403) 436-2152
SASKATOON ..... (306) 975-0444
TORONTO .... (905) 568-2929
PHOENIX .... (602) 272-6848
RENO .... (702) 331-2375
ANCHORAGE .... (907) 276-6480
DENVER .... (303) 277-9988
LIMA .... (511) 422-2241

charged from the mine and thereby reduce the load on the central treatment facility. Standard treatment processes had proved unsuccessful or uneconomic (including the use of lime-based systems) and subsequently KEECO was invited to undertake trials at the mine. At the time an acid stream of approximately 40 litres/s at a pH of 1.96 was emanating from a large underground working and this discharge was chosen as the most appropriate for the trial.

To accommodate underground treatment a K250 system was chosen in preference to the K500. The compact nature of the K250 is displayed in the photograph on page 7, which shows the control and shearing system in the background and the plastic manifold delivery system in the foreground, discharging KB-1 slurry into a trench carrying the water from its source to the portal of Level 9, 3 km away. The only additional space required beyond that shown is for the reagent feed hopper and reagent storage (relative to lime the latter is lower per tonne due to the higher bulk density of KB-1).

Results of the trials were exceptional. The K250 treatment system was assembled and running within hours of its arrival at the mine site. Previous laboratory tests had indicated that a dose rate of 3-4 g KB-1/litre would be required to reduce metal concentrations to acceptable levels. However, the high efficiency of the K250 reduced this to 2.0 g/litre under field conditions, at a cost of under one-tenth of US$0.01/litre. At this dose rate the treated waters achieved discharge criteria and in fact were sufficiently clean to satisfy US drinking water criteria for arsenic, cadmium, chromium, lead and zinc (see Table 1). The silica-encapsulated sediments also passed the US EPA Toxicity Characteristic Leaching Procedure (TCLP), confirming the non-hazardous nature of the waste and eliminating the expense of hazardous waste disposal. It would therefore be feasible to return the encapsulated sediments to worked-out areas of the mine, removing the need for a surface disposal site, with the decanted clean water discharged directly to surface waters.

LOOKING TO THE FUTURE

KEECO and Bunker Hill mine evaluated the possibility of recovering a zinc product from the contaminated water as an integral part of the treatment process. Preliminary tests were very promising. Using a primary treatment step with the addition of KB-1 to raise the pH to 5.5, and a secondary step where further KB-1 is added to bring the pH to 8.5, zinc-depleted and zinc-rich sediments can be separated. A typical analysis of the primary and secondary stage sediments is shown in Table 2. The primary stage sediment passed the TCLP, while the secondary stage sediment was comprised of approximately one-third zinc, with the other major components being calcium, iron and manganese. KEECO is now exploring processing options for the economic recovery of the zinc; based on the chemical stability of the sediment, it is likely that a pyrometallurgical process will be the most appropriate route. While this approach would not be suitable for every operation, the fact that no additional KB-1 is required offers a tremendous potential at certain sites to generate additional revenue to offset the cost of treatment.

CONCLUSIONS

It is certainly worthy of note that the mine owner has stated that the KEECO process represented a substantial reduction in the capital expenditure required for water treatment and was unmatched by anything he was aware of, while still providing the desired water quality results. The ability to implement a consistent treatment programme that can adequately address any requirements for both present and future regulatory criteria was the primary reason for the mine owner's decision to evaluate the KEECO process. Understandably, the mining industry is relatively conservative when investing its funds in new technologies or approaches. This reflects in part the low profit margin of many companies. However, new technology must be incorporated into mine design and closure plans as it becomes available. So far, it appears that the project at the Bunker Hill mine was a success, and a substantive stepping-stone on the way to the increased implementation of the SME process, and the next generation of environmental technologies for water and waste treatment in the mining industry.

With a number of full-scale contracts underway or completed, and rapidly expanding interest, the credibility of the SME process has been firmly established; something that KEECO has worked hard to achieve against a background of financial troughs and peaks in the mining industry. KEECO is, however, keen to ensure that it continues to contribute to the safe and clean development of the mining industry. It is, therefore, working to develop techniques to specifically target and encapsulate pyritic materials to prevent acid generation from existing, new and planned mine wastes. Resource recovery from metal-contaminated waters via control of the SME process is also being examined further at specific sites. Conscious of the financial pressures under which most, if not all, mining companies operate, KEECO will continue to work with clients to find ways to drive costs down and move from waste management to pollution prevention via integration of the SME process with mine development and plant design.

By Dr Paul Mitchell[1] and Amy Wheaton[2]

1 Technical Director, KEECO (UK) Limited, Rosemanowes, Herniss, Penryn, Cornwall, TR10 9DU, UK. Tel: (+44 1209) 861585. Fax: 861564. E-mail: paul-mitchell@keeco-uk.demon.co.uk
2 Manager - Project Operations, KEECO Inc., 19023 36th Ave. W., Suite E, Lynnwood, Washington 98036, US. Tel: (+1 425) 778 7165. Fax: 778 7564.

Knight Piésold
CONSULTING

Knight Piésold provides a wide range of quality services to the international mining industry covering resource development, planning and design, economics, engineering and environmental matters for both surface and underground mining.

Services

- ***Planning & Feasibility Studies***
- ***Environmental Assessment***
- ***Mine Design & Permitting***
- ***Construction Quality Control***
- ***Tailings Facilities & Heap Leaching***
- ***Geomechanics & Geochemistry***
- ***Water Resources & Hydrogeology***
- ***Civil Engineering Design***
- ***Mine Closure & Rehabilitation***

Offices	Telephone	Fax
Ashford, Kent, UK	+44 1233 658200	+44 1233 658299
Denver, CO, USA	+1 303 629 8788	+1 303 629 8789
Vancouver, Canada	+1 604 685 0543	+1 604 685 0147
Sydney, Australia	+61 2 9482 1644	+61 2 9482 1542
Perth, Australia	+61 8 9481 1266	+61 8 9481 1399
Rivonia, South Africa	+27 11 806 7111	+27 11 806 7100
Elko, NV, USA	+1 702 738 2265	+1 702 738 3321
Santiago, Chile	+56 2 341 7627	+56 2 341 7628
Lima, Peru	+51 1 422 0844	+51 1 422 0331
North Bay, Canada	+1 705 476 2165	+1 705 474 8095
Kumasi, Ghana	+233 51 33194	+233 51 28741
Buenos Aires, Argentina	+54 1 394 5559	+54 1 322 4756
Manila, Philippines	+63 2 752 7006	+63 2 752 7003
Kitwe, Zambia	+260 2 228 466	+260 2 223 649
Harare, Zimbabwe	+263 4 882 732	+263 4 882 367

UK: *Derby, Truro* **Overseas:** *Nairobi, Singapore, Gaborone, Mbabane, Sao Paulo*

www.knightpiesold.com