EVALUATIONS OF ACID GENERATION PASSIVATION TECHNOLOGIES[1]

Suzzann Nordwick[2], Norma Lewis, Diane Jordan, and Diana Bless

Abstract. MSE Technology Applications has independently evaluated several technologies for eliminating acid rock drainage (ARD) from waste rock, under the Mine Waste Technology Program. Summary information and results from three individual and separate demonstration projects will be presented. This paper is an extended abstract with only cursory project details and is meant to serve as an additional information source to the poster presentation material. The first project was a laboratory-based weather accelerated evaluation of two commercial technologies applied to unoxidized material. Evaluated over a two-year period were treatment technologies from Klean Earth Environmental Company (KEECO) and Metals Treatment Technologies (MT^2). The second project was a field pilot-scale multi-cell evaluation of four technologies demonstrated at the Gilt Edge Mine Site. Treatment with lime was conducted along with treatment technologies from KEECO, University of Nevada, Reno (UNR), and MT^2. The level of contaminants of concern released over time was monitored to determine technology performance, as the project objective was to reduce the effluent of each treatment cell effluent. The third project was a field-based demonstration with application to prevent acid generation on open-pit highwalls. Four technologies were applied at the Golden Sunlight Mine in Montana. Two treatment technologies, potassium permanganate and magnesium oxide, were from UNR. MT^2 and Intermountain Polymers provided the third and fourth treatment technologies. The impact on total metals loading per unit area of each treated section was monitored. Results of the treatment effectiveness of the technologies tested in all three projects were obtained by comparison to control conditions by field monitoring and laboratory analysis. Results of the weather-accelerated project were most favorable to the KEECO technology. Results of the field multi-cell project were most favorable to the lime technology. Results from the highwall project indicated that all treatments reduced the concentrations of sulfate removed and reduced the mobility of metals from the highwall.

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[2] Suzzann Nordwick, Senior Engineer, and Diane Jordan, Process Engineer, MSE Technology Applications, Inc., Mike Mansfield Advanced Technology Center, 200 Technology Way, P.O. Box 4078, Butte, Montana 59702, USA; and Norma Lewis and Diana Bless, United States Environmental Protection Agency, NRMRL, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, USA.

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Introduction

The primary objective of the Mine Waste Technology Program (MWTP) is to advance the understanding of engineering solutions to national environmental issues resulting from the past practices in mining and smelting of metallic ores. Under this program, MSE Technology Applications, Inc. (MSE) has independently and comparatively evaluated several acid rock drainage (ARD) passivation or microencapsulation technologies. Specific evaluations and results from each of three separate demonstrations that have been conducted over the past four years will be presented.

The first evaluation to be presented was a laboratory-based weather accelerated evaluation of two commercial technologies provided by Klean Earth Environmental Company (KEECO) and Metals Treatment Technologies (MT^2). Results from the application of the KB-SEA technology and the EcoBond technology were documented over a two-year period using modified humidity cells. The KB-SEA technology employed a silica microencapsulation treatment to encapsulate solid media particles thereby stabilizing them to control future acid generation. The EcoBond technology created an impenetrable chemical bond with the solid media. The performance of the technologies was documented and the required field application rates were estimated. This research was jointly funded and conducted by the Minnesota Department of Natural Resources. Results are discussed and presented later in the paper.

The second evaluation was a field pilot-scale multi-cell evaluation at the Gilt Edge Mine site of four treatment technologies: Silica Micro Encapsulation (SME) Technology from KEECO, a potassium permanganate based Passivation Technology developed by DuPont and owned by the University of Nevada, Reno (UNR), EcoBond Technology from MT^2, and lime. Monitoring and quantifying the level of contaminants of concern documented the performance of each technology. The objective was to reduce the effluent of each treatment cell effluent. Following the evaluation, the integrity, feasibility, and cost of using each treatment technology was also determined. Results are discussed and presented later in the paper.

The third evaluation was the demonstration of four technologies with applicability to prevent ARD generation from open-pit mine highwalls. The four technologies, MT^2's EcoBond, Intermountain Polymers' modified furfuryl alcohol resin (FARS), UNR's potassium permanganate, and UNR's magnesium oxide, were applied on the highwall of the Golden Sunlight Mine. The impact on total metals loading per unit area of each treated section was compared to a control section of the highwall. All treatments reduced the concentrations of sulfate removed and reduced the mobility of metals from the highwall. In conjunction with the fieldwork, laboratory humidity cell testing was also conducted on rocks treated with each material.

Laboratory Weather Accelerated Evaluation

The first project to be presented was a laboratory accelerated weathering demonstration project, which was conducted on a cost-share basis with the Minnesota Department of Natural Resources. The objectives of this laboratory study were to evaluate the success of preventing ARD and to estimate field application requirements for two technologies. Samples of unoxidized sulfidic rock material were tested using three application levels of two commercially available microencapsulation technologies: KEECO's KB-SEA and MT^2's EcoBond. The samples were evaluated in comparative laboratory studies using modified humidity cell operation (Fig. 1).

Figure 1. Laboratory humidity chamber and test cells.

Microencapsulation is the isolation of sulfide minerals by precipitating a chemical coating on unoxidized pyrite or where the material is reacted with an oxidizing agent to produce ferric ions.

KEECO's KB-SEA technology uses a soluble silica to produce an insoluble ferric silicate precipitate that encapsulates solid media particles. The materials become stabilized as this silica coating helps to control future acid generation. MT^2's EcoBond technology uses a soluble phosphate to form a ferric phosphate precipitate that prevents the leaching of metal contaminates by creating an impenetrable chemical bond. Humidity cells containing three application rates (high, medium, and low) with duplicates for each along with control cells were tested and leached weekly.The drainage collected from the control reactors had a pH > 6 after 1 week and a pH = 3.3 at 60 weeks. After 60 weeks of testing, the KB-SEA treatment was successful in preventing acid drainage; however, it must be noted that initially very high pHs were generated in comparison to the controls (Fig. 2). The EcoBond treatment delayed the onset of acidification, but was not successful in preventing acid drainage (Eger and Antonson, 2004; and Nordwick and Lewis, 2006).

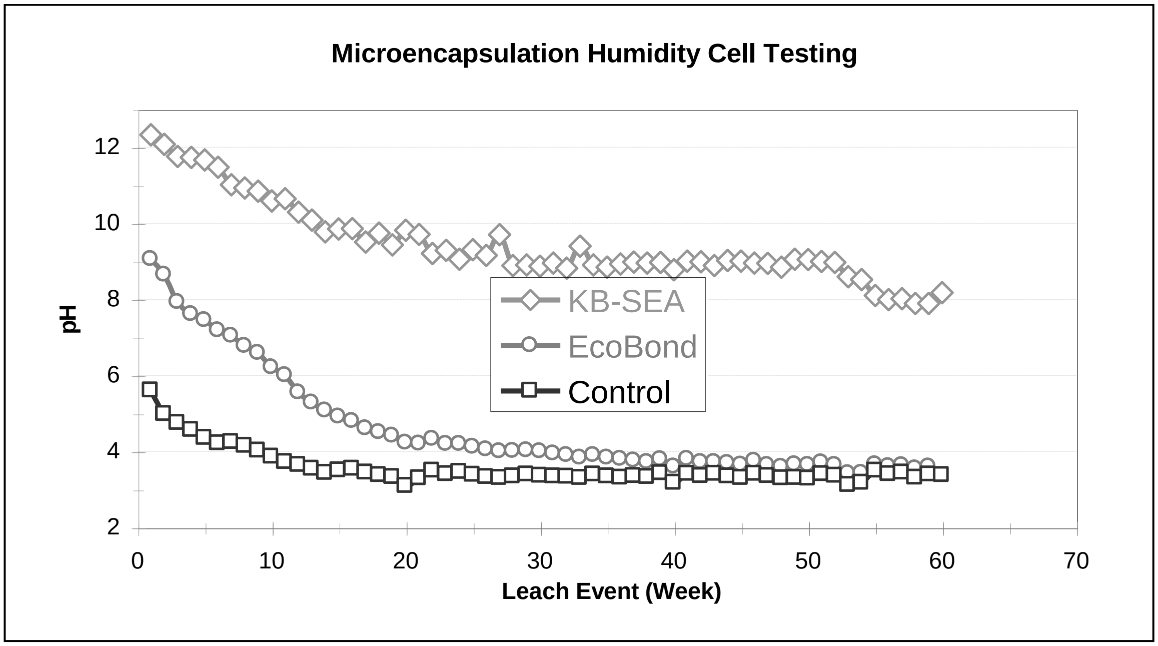

Figure 2. pH vs. time for modified humidity cell tests.

Multi-Cell Field Evaluation

The second comparative evaluation project for technologies to eliminate ARD from waste rock was a multi-cell field demonstration, which was part of the Remediation Technology Evaluation Project, completed in collaboration with the U.S. Environmental Protection Agency (EPA) Region VIII. This field demonstration evaluated three acidic waste rock stabilization technologies and compared the technologies to the presumptive remedy of lime treatment. The objective of EPA Region VIII was to conduct a treatability study as part of the remedial investigation/feasibility study process for the Gilt Edge Mine near Lead, South Dakota, providing data to help in the decision-making process supporting the record of decision for the site. The objective of the MWTP was to evaluate promising new technologies for preventing the oxidation of sulfide waste rock, which may be applicable to a large number of mine waste sites.

The four technologies tested in the Multi-Cell Field Evaluation were lime addition; the SME Technology from KEECO; the potassium permanganate based Passivation Technology from the UNR; and EcoBond Technology from MT^2. The three technology vendors also provided a cost estimate to treat a hypothetical 500,000-cubic yard (yd^3) waste rock pile at the Gilt Edge Mine using the pilot-scale data as a guideline (Fig. 3).

Figure 3. Multi-Cell Demonstration Site.

Multiple waste-rock samples were collected from each cell while the cells were being filled and analyzed for acid-base accounting parameters. Five field duplicates were collected from the waste rock as well. The acid-base accounting results show that the acid-base potential [megagrams (tons) of calcium carbonate (limestone)/907 megagrams (1,000 tons) of waste rock] ranges from -21 to -130 with an average of -48, and the paste pH of all the waste rock samples ranged from 2.1 to 5.3 with an average of 2.75. Waste rock with an acid-base potential of less than -20 is considered to be acid producing; therefore, the waste rock used for this technology demonstration is considered acid producing.

The performance of each technology was evaluated during a pilot-scale demonstration. Treated waste rock was placed into isolated cells and the leachate from each cell was collected. The leachate was monitored from the spring of 2001 to the fall of 2002. The performance objective of the treatments was to reduce the contaminants of concern by at least 90% or to South Dakota water discharge limits.

By evaluating the leachate parameters of pH, total dissolved solids (TDS), dissolved As, Al, Fe, Zn, and SO_4^{2-}, it was possible to compare how each technology performed. Table 1 summarizes the effectiveness of each technology in reducing the relevant contaminants by at least 90% or achieving the South Dakota discharge limits for the Gilt Edge site.

The lime treatment performed well; however, the high pH may indicate the waste rock was overdosed, and the calcium oxide (CaO) does have a limited life. Once the CaO is exhausted, it may need to be reapplied, depending on the circumstance.

EcoBond from MT^2 did reduce some contaminants; however, the fact that it increased concentrations of arsenic, TDS, and sulfate cannot be ignored. Also, the approach by MT^2 of treating only the top 2 inches of each layer of the hypothetical waste rock for the cost estimate is uncertain since each lift is made of sulfidic waste rock through the whole thickness not just the top 2 inches. If MT^2 were to treat the whole thickness of each lift, the cost would increase substantially.

Table 1. Performance evaluation summary for Multi-Cell Demonstration.

Technology	Achieve 90% Reduction?			Achieve SD Discharge Limits?				Cost to Treat 382,275 m^3 (500,000 yd^3) of Waste Rock	Comments
	Al	Fe	Sulfate	pH	TDS	As	Zn		
Lime	Yes	Yes	Yes	No	Yes	Yes	Yes	$4,774,438	Effective, but pH was elevated above 8.8 and will fail once lime is exhausted
MT^2	Yes	Yes	No	Yes	No	No	Yes	$4,034,750	Actually increased TDS, sulfate, and arsenic concentrations
UNR	Yes	Yes	No	Yes	Yes	Yes	Yes	$3,241,408	Effective and has longer life than lime treatment
KEECO	No	Yes	No	No	No	No	No	$12,682,998	Expensive and failed during second field season

UNR's permanganate based Passivation Treatment performed well, and it is cost effective compared to the other treatments. The advantage of this Passivation Treatment is that, in theory, it will not degrade over time and a one-time application is all that is required.

The treatment by KEECO did not perform well past the first field season. Increasing the treatment dosage may solve this problem; however, it will add to the cost and make it more expensive compared to the other treatments.

The UNR and lime treatment technologies were able to achieve seven of the eight objectives (Table 1). However, the treatment by lime application will be exhausted over time because the lime is soluble and will eventually be consumed.

The KEECO and MT^2 technologies may be able to produce favorable results by making dosage adjustments and/or using different mixing or application approaches. Additional treatment past the second field season was beyond the scope of this technology demonstration. To confirm if the modified KEECO and MT^2 treatments would be effective, another technology demonstration would need to be performed (Trudnowski and Lewis, 2004).

Open-Pit Highwall Evaluation

Prevention of ARD from open-pit highwalls was the focus of a third MWTP project. By reducing the potential for ARD generation from a mine highwall, reclamation costs for mining companies and regulatory agencies could be minimized. The intent of this project was to obtain performance data on the ability of several application technologies to prevent ARD on open-pit highwalls. The four applied technologies were: Ecobond developed by MT^2; a magnesium oxide passivation technology developed by UNR; a potassium permanganate technology applied by UNR; and a furfuryl alcohol resin sealant developed by Intermountain Polymers. Each of the four technologies inhibits ARD differently, dependent upon chemistry of the treatment formulation, rock sulfide content, morphology, pH of waste material, weather conditions, and the amount of water draining from the highwall.

The demonstration was conducted at an active open-pit gold mine, the Golden Sunlight Mine in Montana. The four technology providers applied their technologies to a designated area on the highwall with the objective of comparing the effectiveness of each treatment to an untreated area on the highwall. Also, during application of the technologies, each technology provider was required to apply their technology to separate, specially prepared samples that underwent humidity cell testing.

The open-pit benches at the project site were 50 feet high and had near vertical slopes. Each technology was spray applied to a 50-foot high by 50-foot wide highwall area by the technology provider with oversight by MSE. A total of five test plots were located on the highwall, which included one plot for each of the four technologies and an additional plot designated for background and control (Fig. 4 and 5).

Figure 4. Highwall demonstration site.

Prior to the demonstration, background data on the highwall of concern was obtained for the project by monitoring for dissolved metal constituents. This data was compared to the National Primary and Secondary Drinking Water regulations for copper, iron, manganese, nickel, and zinc concentration and pH (Table 2). After the technologies were applied, a mine wall/residual wash water sampling method, developed from the Canadian Mine Environment Neutral Drainage (MEND) Program and the Minesite Drainage Assessment Group (MDAG) was completed to determine the total metals loading per unit area (Morin and Hutt, 1997). The run-off pH of the highwall was also recorded. This method provided a standardization, which allowed the technologies to be evaluated under field conditions and with field designed application rates.

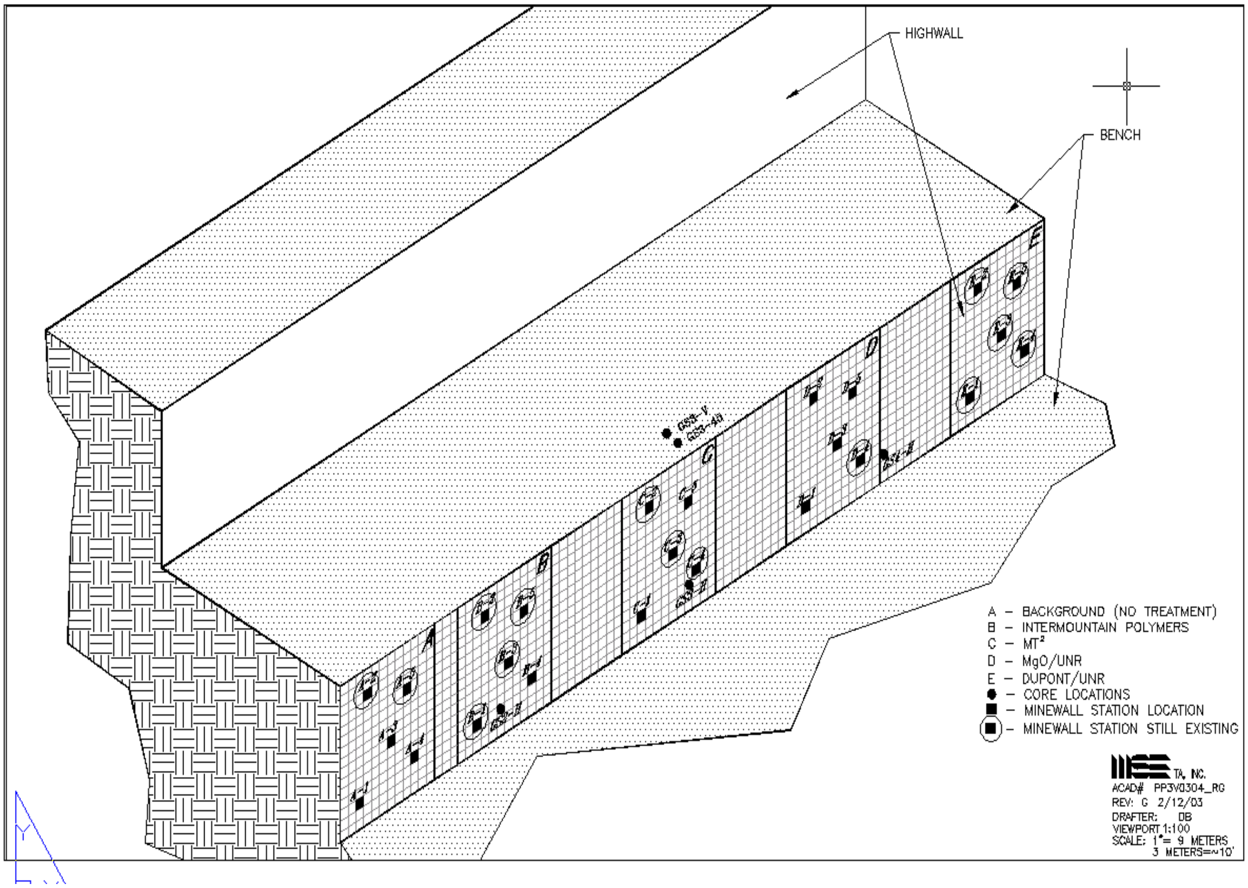

Figure 5. Highwall test plots.

Table 2. Highwall monitoring well data.

Analytical Parameter	Analytical Result [milligrams per liter (mg/L) unless otherwise indicated]	Primary and Secondary National Drinking Water Standards
pH	4.35 s.u.	6.5 to 9
Sulfate	4,773	250
Aluminum	Data not available	0.05 – 2.0
Iron	1,042	0.3
Manganese	18.9	0.05
Nickel	3.15	0.1
Zinc	29.3	2.1
Copper	Data not available	1.3

Note: The analytical results listed above are for the dissolved metal concentrations.

Field sampling results for pH and relative metals loading are summarized in Table 3 and Fig. 6, respectively. The pH results show that after approximately 10 months, the EcoBond, UNR/MgO, and UNR/KP plots had a pH of less than 4, as low as the background plot. The range of the average percent metals reduction was between -211% and 82% (Table 3). The pH for the Intermountain Polymers application was steady at pH 4 to 4.5 and held constant for the full duration of the demonstration project, with metals reduction ranging from 75% to 91% when compared to the background results. A large negative number for the percent metals reduction indicates high metals mobility, and a high positive number indicates low mobility.

Table 3. Percent reduction of total metals from treated technology plots vs. untreated plot.

Plot vs. Background	Percent Reduction			
	Intermountain Polymers	EcoBond	UNR/MgO	UNR/KP
Aluminum	75	20	38	62
Copper	85	-211	26	76
Iron	85	24	-16	30
Manganese	84	49	82	51
Nickel	90	48	50	72
Zinc	91	-40	75	76

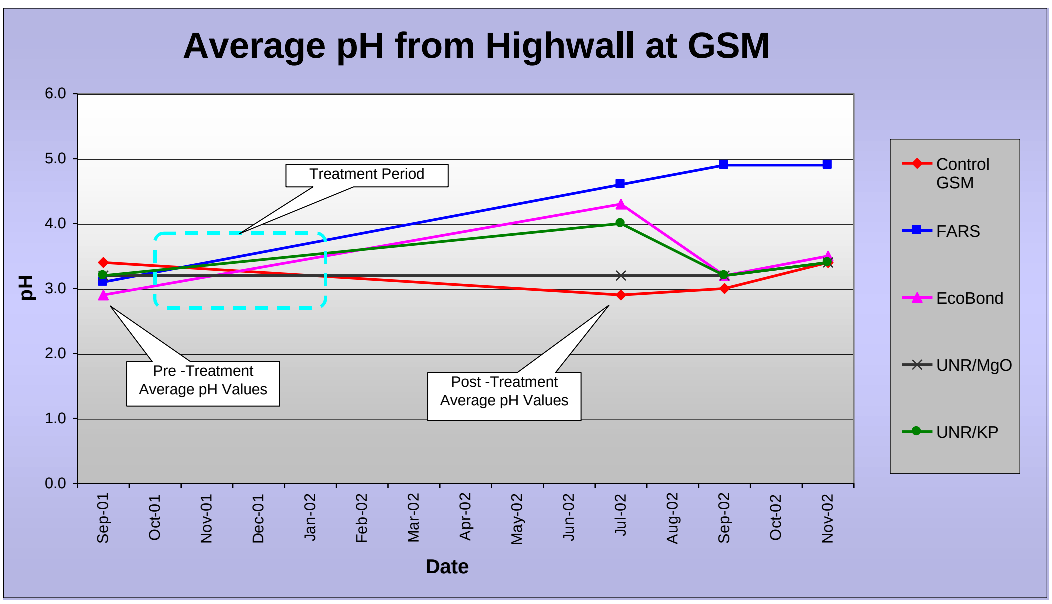

Figure 6. Average pH from highwall at Golden Sunlight Mine.

In the field, physical stabilization of the highwall was only observed on the Intermountain Polymers technology plot. The other three technologies provided chemical passivation of the wall, but not physical stabilization.

Test results, from both the field and the humidity cell tests, indicate that all of the treatment technologies (to some degree) controlled the acid generation potential of a mine highwall. The results from the highwall residual wash sampling indicate that in the field, the technologies did not perform as well as the samples analyzed in the laboratory (humidity cell testing) in a controlled environment. If these technologies were to be applied at another site, a small-scale field application should be performed to evaluate the full effectiveness of the technology before investing in a full-scale technology application (McCloskey and Bless, 2005).

Summary

MSE is working to advance the understanding of engineering solutions to environmental issues from past mining practices. Under EPA's Mine Waste Technology Program, MSE has conducted three comparative evaluation studies to evaluate several ARD passivation and microencapsulation technologies. Laboratory-based weather accelerated conditions were studied for two commercial technologies. This work indicated that the KEECO treatment was successful in preventing or delaying ARD with the initial consequence of generating very high pHs. This work also indicated that the MT^2 EcoBond treatment delayed the onset of ARD. A field multi-cell evaluation of four treatment technologies (KEECO, potassium permanganate, EcoBond, and lime) indicated that the UNR and lime technologies were able to prevent or delay ARD formation. An evaluation demonstration of four technologies on an open-pit mine highwall indicated that all treatments reduced the concentrations of sulfate removed and reduced the mobility of metals from the highwall.

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Literature Cited

Eger, P., and D Antonson. 2004. Use of Microencapsulation to Prevent Acid Rock Drainage, Final report to MSE Technology Applications, September 2004. Minnesota Department of Natural Resources, Division of Lands and Minerals.

McCloskey, A. L. and D. R. Bless. 2005. "Final Report — Prevention of Acid Mine Drainage Generation From Open-Pit Highwalls, Mine Waste Technology Program Activity III, Project 26." Published by the Mine Waste Technology Program by MSE Technology Applications, Inc. and the U.S. Environmental Protection Agency. (July 2005). http://www.epa.gov/ORD/NRMRL/pubs/600r05060/600r05060.pdf

Morin, K.A. and N.M. Hutt. 1997. Environmental Geochemistry Of Minesite Drainage*; Appendix D, Minewall Methods.*

Nordwick, S. and N. Lewis. 2006. "Final Report — Microencapsulation to Prevent Acid Mine Drainage, Mine Waste Technology Program, Activity III, Project 33." Published by the Mine Waste Technology Program by MSE Technology Applications, Inc. and the U.S. Environmental Protection Agency.

Trudnowski, J. and N. Lewis. 2005. "Final Report — Remediation Technology Evaluation at the Gilt Edge Mine, South Dakota, Mine Waste Technology Program, Activity III, Project 29." Published by the Mine Waste Technology Program by MSE Technology Applications, Inc. and the U.S. Environmental Protection Agency. (November 2004).

http://www.epa.gov/ORD/NRMRL/pubs/600r05002/600r05002.pdf