Use of a CCP Grout to Reduce the Formation of Acid Mine Drainage: An Update on the Winding Ridge Project

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ABSTRACT

In 1995, the Maryland Department of Natural Resources Power Plant Research Program (PPRP) and the Maryland Department of the Environment (MDE) initiated the Western Maryland CCP/AMD Initiative. The Initiative is a joint effort with private industry to demonstrate the beneficial application of CCPs to create flowable grouts to abate AMD. The Initiative started with the Winding Ridge Project in 1996 with the injection of 5,600 cubic yards (yd³) (4,280 cubic meters (m³)) of CCP grout into a small, abandoned, deep coal mine in Garrett County, MD. Post-injection monitoring has continued since that time and included analysis of mine discharge water quality and grout core strength and permeability. This paper presents an update of more than eight years of post-injection monitoring, including water quality and grout core retrieval from the mine.

The results of post-injection monitoring indicate that placement of CCP grout into the mine has improved the quality of mine discharge. Concentrations of iron, sulfate, aluminum, manganese, zinc, cobalt, copper, nickel, and acidity in mine discharge have decreased below pre-injection concentrations. The pH of mine discharge has increased by one pH unit, and the estimated rate of acid production in the mine has decreased by approximately 80%.

Grout cores were collected in 1997 and 2004: one and seven years after injection. Testing of the cores has shown that, in general, the grout has maintained high strength and low permeability in the mine tunnels.

INTRODUCTION

The Maryland Department of Natural Resources Power Plant Research Program (PPRP) and the Maryland Department of the Environment Bureau of Mines (BOM) have undertaken the Western Maryland Coal Combustion Products (CCPs)/Acid Mine Drainage (AMD) Initiative. The Initiative is a joint effort with private industry to demonstrate the beneficial application of CCPs to create flowable grouts for placement
in underground coal mines to reduce acid formation. The Initiative is a key component of Maryland's overall ash utilization program to promote and expand the beneficial use of all CCPs on a massive scale. Ultimately, the Initiative is targeting significant acid reduction at large AMD sources in Maryland, such as the Kempton Mine Complex, which is Maryland's largest source of AMD, and mitigation of subsidence problems associated with both disturbed lands and natural karst topography.

The Initiative is a multi-year project that started in April 1995 with the Winding Ridge Project. This project involved the injection of a 100% CCP-based grout into the Frazee Mine, which is a small 10 acre (40,500 square meter (m²)) underground coal mine in Garrett County, Maryland (Figure 1). In 1999, the authors reported on the means and methods of the grout injection phase of the project, and presented post-injection water quality data for the first year following injection. In 2001, the authors presented an update on post-injection water quality monitoring including three years of post-injection water quality data. Since that time, additional water quality data has been collected, and monitoring is currently ongoing. As a result, an extensive database has been generated, including a total of eight years of post-injection water quality data. The purpose of this paper is to present the key findings to date regarding post-injection monitoring of grout stability and mine discharge water quality.

SETTING

The Frazee Mine is located atop of Winding Ridge in Garrett County, Maryland (Figure 1). The mine is a small, hand-dug, abandoned, underground coal mine that was used to mine coal from the Upper Freeport seam from the 1930s to circa 1960. The sulfur content measured in Upper Freeport coal samples from the project site ranged from 1.0% to 3.5%. Acid-base accounting performed on overburden samples indicates that a small, 6 - 18 inches (15 to 46 centimeters) thick, rider coal seam above the Frazee Mine is the only other potential source of acid producing rock besides the Upper Freeport. Total sulfur content of the rider coal seam is about 1.5% to 4.5%.

Investigative drilling at the site indicated that the mine consists of two main tunnels, a lower and an upper tunnel, connected by an unknown number of crosscuts (Figure 2). Downhole camera investigations of the mine indicated that the mine was in poor condition, the tunnels were poorly timbered and a number of roof falls and collapses were evident.

Ground water monitoring wells installed at upgradient and downgradient locations showed that the Frazee Mine occurs in unsaturated bedrock, and that the regional ground water table is approximately 50 feet (15 meters) below the mine pavement. The cross section shown in Figure 3 shows the lithology of the Winding Ridge area and the relative elevations of the mine tunnel and mine pool.
Figure 2
Site Layout
Winding Ridge Project
Ferndale, Maryland

Figure 3
Cross Section Though Lower Tunnel of the Frazee Mine
The Winding Ridge Project
Ferndale, Maryland
Infiltrating precipitation impounded within the Frazee Mine created a pre-injection mine pool of at least 550,000 gallons (2,000,000 liters). This mine pool resided in the lower tunnel, while the upper tunnel was predominantly dry. Although there are four known mine entries, the only mine discharge is from Mine Opening No. 2 (MO2). At MO2, discharge occurs from a lower and upper seep. The elevation of the lower seep is about 9 feet (3 meters) below the mine pool elevation, and flow is continuous at about 2 gallons per minute (gpm) (0.12 liters per second (l/s)). Flow from the upper seep is intermittent and dependent upon the mine pool elevation. When the mine pool elevation is above the upper mine seep, flow occurs generally at about 3 to 5 gpm (0.19 to 0.32 l/s), although flash events of 20 to 30 gpm (1.3 to 1.9 l/s) have been recorded after rainfalls. Otherwise, the upper seep is dry.

The pre-injection water quality from MO2 was typical of AMD-quality water with an average pH of 2.8 and average total acidity of 1,300 mg/L. The average sulfate, iron, aluminum and total dissolved solids concentrations were 1,300 mg/l, 190 mg/l, 69 mg/l, and 2,100 mg/l, respectively.

**GROUT FORMULATION AND INJECTION**

The CCPs used for the Project were: fluidized bed combustion (FBC) by-product (commingled bed ash and fly ash), from the Morgantown Energy Associates power plant; Class F fly ash, from the Virginia Power Company’s Mt. Storm power plant; and flue gas desulfurization (FGD) by-product, also from the Mt. Storm power plant. The FBC provided the free lime, the fly ash provided pozzolan, and the FGD by-product (mostly calcium sulfite and calcium sulfate with no free lime) was used as a bulking agent.

The mix design consisted of 60% fresh (defined as less than 24 hours old) FBC ash, 20% FGD product, 20% fly ash, and virtually 100% mine water. The FBC was conditioned at the plant to contain about 15% moisture, which resulted in about 3% to 5% free lime content. The final grout moisture content was about 57% on a dry weight basis, and contained about 2% to 3% free lime. Grout samples collected during injection showed a spread of about 8 inches (20 centimeters), and a 28-day unconfined compressive strength of about 550 pounds per square inch (psi) (3.8 megapascals (MPa)).

Full-scale injection began on 7 October 1996 and ended on 8 November 1996. Approximately 5,600 yd³ (4,280 m³) of grout were injected into the Frazee Mine. The grout consisted of 3,800 tons (3,400 metric tons) of FBC ash, and 1,200 tons (1,100 metric tons) each of fly ash and FGD by-product. The project used 520,000 gallons (1,970,000 liters) of water, consisting of 449,000 gallons (1,700,000 liters) of untreated mine water (pH of about 3) and 71,000 gallons (270,000 liters) of river water. The river water was used at the end of injection when grouting precluded any further withdrawal of mine water.
POST-INJECTION MONITORING RESULTS

In-Situ Grout Sampling Results

Two sets of in-situ grout cores have been collected from Winding Ridge. The first set was collected in September 1997, approximately 1 year after grout injection. These coreholes targeted both wet and dry areas of the mine. Nine coreholes were drilled, grout was encountered in five coreholes, and samples from four coreholes were submitted for laboratory testing. Mine tunnel piezometers were constructed within four of the coreholes in order to monitor the presence and water quality of water within the mine tunnels.

The second set of grout samples was collected in July 2004, approximately 8 years after grout injection. These coreholes were located near the mine tunnel piezometers that were constructed in the 1997 coreholes. Three coreholes were drilled, grout was encountered in two coreholes. One sample was submitted for laboratory testing. The results of laboratory testing for all grout samples are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Location</th>
<th>Injection Samples</th>
<th>CH-3</th>
<th>P-1D</th>
<th>P-6</th>
<th>P-7</th>
<th>P-9</th>
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<tbody>
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<td>245 - 550</td>
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<td>773 / 644</td>
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<td>5.33 / 5.82</td>
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<tr>
<td>Permeability (cm/sec)</td>
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<td>—</td>
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<td>1.9E-06</td>
<td>5.1E-07 / 4.1E-07</td>
<td>1.29E-07</td>
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</tr>
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<td>Dry Density (pcf)</td>
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<td>70.8</td>
<td>80.1 / 62.7</td>
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<tr>
<td>Dry Density (kg/m³)</td>
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<td>1.23</td>
<td>1.13</td>
<td>1.28132</td>
<td>1.29</td>
<td>not suitable for testing</td>
</tr>
</tbody>
</table>

Notes:
Grout cores from P-7 in 1997 and P-6 in 2004 were too soft to be tested.
— - sample not analyzed for this parameter
ns - not applicable

In general, the grout cores were in very good shape, and had little evidence of in situ weathering caused by the mine environment. The grout cores showed good contact with the mine roof and pavement and showed that the grout was able to entrain mine debris and to fill vertical and horizontal cracks in the mine pavement (Figure 4).

In the 1997 samples, the measured permeabilities ranged from $10^{-8}$ to $10^{-6}$ centimeters per second (cm/sec). The unconfined compressive strengths ranged from about 560 to 1400 psi (3.9 to 9.8 MPa). The 2004 sample had a measured permeability of about $10^{-7}$ cm/sec and a compressive strength of 800 psi (5.5 MPa).

Two grout cores have shown possible evidence of in-situ weathering or poor grout curing. The samples from P-7 (collected in 1997) and from P-6 (collected in 2004) were
cohesive, but too soft for testing. Both of these sample locations are situated relatively close to MO2 and grout in these areas was injected in contact with water. Water has been present in the piezometers at these locations since they were constructed in 1997. These coreholes were also distant from the injection points and therefore the grout may have been excessively diluted by the mine pool prior to curing.

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Post-Injection Mine Hydrology

AMD continues to flow from the mine from ungrouted areas. Post-injection water level measurements from the mine tunnel piezometers show that the mine pool elevation is essentially the same as its elevation prior to injection, indicating that grout injection has not created new sub-pools or raised the water level to the point that it is contacting the rider coal seam. The seep characteristics have changed little since injection. The horizontal location of the lower seep has shifted a few feet, requiring the placement of a new pipe to facilitate sample collection, however, the rate of flow has stayed constant at about 2 gpm (0.12 l/s). The discharge from the upper seep remains intermittent, and dependent upon the mine pool elevation. The upper seep has been dry during approximately 25% of the post-injection monitoring events.
Post-Injection Water Quality Results

Mine discharge from the seeps at MO2 and ground water within the mine tunnels (mine tunnel piezometers) and within the bedrock outside of the mine (monitoring wells) have been monitored regularly since injection for AMD-related parameters (i.e. pH, total acidity, iron, sulfate, and aluminum), other major ions (i.e. calcium, potassium, sodium, and chloride), and for trace elements such as arsenic, copper, and chromium.

The lower seep is considered to be most representative of the long-term water quality conditions of the mine water in contact with the grout since its flow is continuous and independent of the mine pool elevation. In comparison, the upper seep is intermittent, and much more susceptible to water quality variation caused by repeated wetting and drying cycles of pyritic strata in the mine roof and ribs as the pool elevation fluctuates.

The mine tunnel piezometers were installed in 1997, approximately 1 year after injection, and water quality at these locations has been very similar to that observed at the lower seep. The monitoring wells were installed prior to injection, and water quality at these locations is essentially unchanged from pre-injection conditions.

AMD-Related Parameters and Other Major Ions

Table 2 summarizes the pre and post-injection water quality results for AMD-related parameters and other major ions for the lower and upper seeps at MO2, as well as the mine tunnel piezometers and ground water monitoring wells. The results show that there have been no significant increases (or decreases in the case of pH) in AMD-related parameters in the mine water discharging from the seeps. The results also show that there have been no adverse impacts to ground water quality.

At the lower seep, pH fluctuated within the historically observed range of values during and immediately after grout injection (Figure 5). Since injection, however, pH has exhibited a beneficially upward trend at the lower seep. Overall, the pH of water discharging from the lower seep has increased by about 1 pH unit above pre-injection conditions. Conversely, the upper seep has not shown any appreciable change in pH since injection. This observation is attributed to the recharge of hydrogen ions to the mine water as the mine pool rises and falls, exposing pyritic strata to wetting and drying cycles.

Figure 6 summarizes the loadings of AMD-related parameters (acidity, iron, aluminum, and sulfate) and calcium discharging from the lower seep over time. The results show a transient condition of mine water quality during the first year (November 1996 to September 1997) after grout injection. During this time period, the concentrations and loadings for AMD-related parameters increased significantly compared to pre-injection conditions. After that period, the concentrations and loadings gradually decreased to below pre-injection levels.
### Table 2 - Summary of Water Quality Results

#### Winding Ridge Site, Friendship, Maryland

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<tr>
<th>Parameter</th>
<th>1/30-2/9/06</th>
<th>3/30-4/29/06</th>
<th>5/30-6/29/06</th>
<th>8/30-9/29/06</th>
<th>11/30-12/29/06</th>
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#### C & D Deep Water Quality Data Summary

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#### General Water Monitoring Wells Data Summary

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### Notes
- N/A: No sample available for this parameter during the year.
- ND: Not detected
- MD: Missing data
- MFR: Maximum feasible range
- CR: Corrected range
- NA: Not applicable
- NR: Not reported
- LO: Limit of detection
- LOQ: Limit of quantitation
- MDL: Method detection limit
- LOQ: Limit of quantitation
- MDL: Method detection limit
- LOQ: Limit of quantitation
- MDL: Method detection limit
Figure 5
pH Results for Upper and Lower Seep at Mine Opening Number 2

L-2 Lower Seep

C-2 Upper Seep

Legend
- Pre-Injection
- Injection
- Post-Injection
Figure 6
Loading Ranges and Averages for AMD Parameters and Calcium for the Lower Seep at Mine Opening Number 2

Legend
- = Average loading in kg/day
- = Range of loadings in kg/day
The transient condition is probably due to a combination of factors. One contributing factor is that the grout injection phase could have indirectly caused an increase in acidity when the mine pool was lowered as a result of pumping mine water for grout mixing. The lowering of the mine pool would have exposed previously submerged mine areas to oxidizing conditions, which would have created acid weathering products available for mobilization once the mine pool rose to pre-injection levels. Another contributing factor could have been the re-routing of mine water through previously isolated mine workings. Nonetheless, the water quality data show that the transient condition was a relatively short occurrence.

Co-plotting pre and post-injection concentrations against mine discharge flow rates provided for further evaluation of the difference between the pre and post-injection water quality for AMD-related parameters. This method was selected to allow a direct comparison of pre and post-injection concentration data under normalized flow conditions. Accordingly, Figure 7 shows that the post-injection concentrations for total acidity, iron, and aluminum at the lower seep fall within or below the pre-injection concentrations. The results for the upper seep show some post-injection concentrations above pre-injection concentrations for similar flows. This is not considered significant as the upper seep has been dry for many monitoring events after grout injection, and is affected by repeated drying/wetting cycles of pyritic strata.

The post-injection loadings of calcium, potassium, sodium, and chloride remain elevated compared to pre-injection levels (Figure 6 and Figure 8). These are non-toxic elements, and the post-injection concentrations for each of these elements in the mine discharge (Table 2) fall well below their average concentrations in sea water. The post-injection concentration of calcium is less than half of that in sea water (which contains about 400 mg/l calcium). The post injection concentrations of potassium, sodium, and chloride are one or more orders of magnitude below those in sea water (which contains about 400 mg/l potassium, 10,000 mg/l sodium, and 19,000 mg/l chloride).

Calcium, potassium, sodium, and chloride are most likely dissolving from the grout into the mine water. Part of the increase in sulfate loading observed during the transition period may also have been due to dissolution of grout components. However, since the grout cores from the mine show that the grout is strong, intact, and competent, it is reasoned that dissolution is most likely localized to grout surfaces that are exposed to or in contact with acidic mine waters. In addition, though the levels of these major ions remain elevated relative to pre-grouting levels, their concentrations in the mine discharge have gradually decreased in the eight years since injection. This suggests that dissolution rates are slowing. A reduction in the dissolution rate could be due to the formation of a low-solubility surface layer on the grout surface. Such a layer could be formed by the rapid dissolution more soluble grout components from the grout surface, leaving a layer of less soluble grout components which acts as a sort of crust, preventing water from reaching the rest of the grout. Another contributing factor could be precipitation and coating by secondary minerals (i.e. iron and aluminum hydroxides) on the grout surface as the chemical conditions within the mine tunnel change.
Figure 7
Comparison of Pre-Injection and Post-Injection Results for Total Acidity, Iron, and Aluminum for the Lower Seep at Mine Opening 2

Legend
- = Pre Injection Concentration
- = Injection Concentration
X = Post Injection Concentration (Transition Period)
= Post-Injection Concentration (Post-Transition Period)
Figure 8
Loading Ranges of Potassium, Sodium, and Chloride for the Lower Seep at Mine Opening 2

Legend
■ = Average loading in kg/day
= Range in loading in kg/day
Trace Elements

Table 2 also summarizes the results of the trace element analyses for mine water samples collected from the lower and upper seeps at MO2, the mine tunnel piezometers, and the ground water monitoring wells. The only trace elements that were routinely detected during pre and post-injection monitoring were cobalt, copper, manganese, nickel, and zinc. The water quality data show that there have not been any significant increases in trace element concentrations in the discharge from the Frazee Mine and no trace elements have been detected in the mine discharge that were not present in the pre-injection samples. Similarly, the results from the ground water monitoring wells show that there have been no increases in trace element concentrations in the ground water since the grout injection.

Figure 9 summarizes the loading data for copper, cobalt, nickel, manganese, and zinc. As with the AMD-related parameters, the plots show a period of transition during the first year following grout injection. Since the second year after grout injection, however, the trace elements have consistently been detected at concentrations within or below those prior to injection.

The difference between the pre and post-injection water quality for the trace elements was evaluated in the same manner described above for the AMD-related parameters. Figure 10 was prepared by co-plotting pre and post-injection concentrations for copper, manganese and nickel (the results were similar for cobalt and zinc), against the mine discharge rate from MO2. For the lower seep, the analyses show that the post-injection concentrations for these trace metals all fall within or below their pre-injection concentrations. The results for the upper seep show some post-injection values above per-injection concentrations for similar flows. As mentioned earlier, this is not considered significant as the upper seep has been dry for many monitoring events after grout injection.

Ground Water

Ground water quality outside of the mine pool has been monitored at several ground water monitoring wells at the site. Essentially, there is no evidence of AMD at these monitoring locations, and grout injection has not altered this condition or introduced any new dissolved constituents at these monitoring locations.
Figure 9
Loading Ranges and Averages for Trace Metals
For the Lower Seep at Mine Opening 2

Legend
- = Average loading in kg/day
- = Range of loading in kg/day
DISCUSSION

Mechanisms for Water Quality Change

The goal of the grout injection at the Winding Ridge site was to reduce the formation of AMD within the mine by covering and trapping pyritic mine debris and exposed mine walls with grout, thereby preventing the interactions between water, oxygen, and pyrite, which produce AMD. The changes in water quality observed during post injection monitoring (increased pH, decreased acidity, and decreased concentrations of AMD parameters and trace metals) are consistent with reduced AMD formation within the mine; however, other possible processes which could account for the changes are considered as follows.

Alkalinity Provided by Grout

One possible contributing process is dissolution of alkalinity-producing components (i.e. lime) from the grout. This process would raise the pH and decrease the acidity of the mine water, which in turn, would cause precipitation of iron and aluminum hydroxides.
Trace metals may co-precipitate with metal hydroxides or adsorb to their surfaces, reducing their concentrations in solution as well.

In order to investigate this possibility, speciation and saturation index calculations were performed using the geochemical modeling program PHREEQC. Saturation indices for amorphous iron and aluminum hydroxides at the upper seep are plotted in Figure 11 (while trace metals were included in the calculations, they are not present in high enough concentrations to form secondary minerals). The graphs show that the mine discharge was undersaturated with respect to these phases prior to injection and that status has not changed significantly during the post-injection period. Although not shown in Figure 11, the same calculations were performed for samples collected from the upper seep and mine tunnel piezometers and the results show the same pattern. The calculations indicate that iron and aluminum hydroxides have not been precipitating from the mine water during any part of the study (pre, or post injection). Therefore, the decreasing concentrations of these parameters (and trace metals) observed since injection must be due either to adsorption of these elements to the grout surface or to a decreasing source of the elements (i.e. a reduction in the rate of acid production in the mine.)

Sorption onto Grout

A second process that could explain the observed reductions in iron, aluminum, and trace metals in the mine discharge is adsorption of these constituents to the grout surface. In this scenario, metal cations adsorb to the predominantly negatively charged grout surface. Because iron and aluminum contribute to total acidity, removing them from solution could lower the acidity of the mine discharge somewhat and lead to some increase in pH. This process alone does not account for significant decreases in sulfate concentration in the mine discharge.

Figure 12 shows a typical curve for the concentrations of a sorbing dissolved parameter after the solution reacts with an exchange surface. An influent solution of constant composition (i.e. water flowing from the mine pool out to the MO2 discharge) interacts with an exchange surface having a finite number of exchange sites (i.e. the grout surface). The initial effluent solution would be expected to have very low concentrations of the sorbing constituents (i.e. iron, aluminum, and trace metals). Over time, as the influent solution continues to flow past and interact with the exchange surface, the exchange sites are filled and the concentration of sorbing constituents (iron, aluminum, and trace metals) in the effluent gradually increases. At some point, the exchange sites may be completely filled and the concentration of sorbing constituents in the effluent quickly rebounds to match the influent concentration (i.e. “breakthrough”) because the exchange surface can no longer adsorb any more ions. The concentrations of iron, aluminum and trace metals observed at Winding Ridge during the last eight years of post-injection monitoring do not match this pattern. Rather than a sharp initial decrease in iron, aluminum, and trace metal concentrations, the Winding Ridge seep samples show a steady gradual decrease in iron, aluminum, and trace metal concentrations, which has remained consistent since the second year of post-injection monitoring.
Figure 11
Saturation Indices for Amorphous Aluminum and Iron Hydroxides
For Lower Seep at Mine Opening 2

Al(OH)₃(a) SI vs Time

SI for Al(OH)₃(a)

SI > 0 (Al(OH)₃(a) precipitates)
SI = 0 (Al(OH)₃(a) precipitation = dissolution)
SI < 0 (Al(OH)₃(a) dissolves, if present)

Fe(OH)₃(a) SI vs Time

SI for Fe(OH)₃(a)

SI > 0 (Fe(OH)₃(a) precipitates)
SI = 0 (Fe(OH)₃(a) precipitation = dissolution)
SI < 0 (Fe(OH)₃(a) dissolves, if present)
Even if the grout at Winding Ridge may not have been in place long enough for the exchange sites on the grout to reach saturation ("breakthrough"), the pattern of gradually decreasing concentrations of iron, aluminum, and trace metals, do not match the early part of the sorption curve either. Therefore, sorption processes alone do not readily explain the water quality patterns observed at Winding Ridge.

Thus, analyses of the water quality data and trends from Winding Ridge suggest that the changes in water quality observed since injection are due, in large part, to reduced AMD formation within the mine as a result of reduced contact between water and pyrite-containing mine debris.

**Grout Dissolution**

As mentioned previously, the concentrations of some major ions (sodium, potassium, and chloride) increased significantly after injection and remain at or above their pre-injection levels. It is assumed that these constituents, along with calcium and sulfate, have been dissolving from the grout. Speciation calculations were also used to evaluate the dissolution of the grout.

Due to the composition of the CCPs used in the grout, calcium sulfate (i.e. gypsum or anhydrite, which are relatively soluble minerals), is expected to make up a significant
portion of the grout. Saturation indices for gypsum in mine discharge samples from the lower seep. These are plotted in Figure 13. The graph shows that the mine discharge was unsaturated with respect to gypsum phase prior to injection. During the injection period, the discharge was saturated with respect to gypsum, presumably due to dissolution of calcium sulfate minerals present in the fly ash. During the post-injection period, the discharge remained near saturation with respect to gypsum, but over the last few years, the gypsum saturation index of the mine discharge has gradually decreased. This suggests that dissolution of calcium sulfate from the grout has slowed, possibly due to the formation of a residual crust of less soluble grout components, or precipitate coating at the grout surface. Although not shown in Figure 13, the same calculations were performed for samples collected from the upper seep and mine tunnel piezometers; the results show the same pattern.

In general, the concentrations of the major ions that appear to indicate dissolution of the grout (calcium, sulfate, potassium, sodium, and chloride) have progressively decreased over the long term monitoring and appear to be asymptotically approaching their pre-injection levels. This also suggests that dissolution of the grout is slowing and may be limited due to the formation of a residual low solubility layer or precipitate coatings at the grout surface.
Grout Injection vs Traditional Treatment Methods

Figure 14 shows a comparison of the changes in water quality observed at Winding Ridge compared with the changes in water quality observed at several sites using anoxic limestone drains (ALDs), which are a commonly used passive treatment method for AMD. While the Winding Ridge project did not achieve the increases in pH or alkalinity observed with most of the ALD systems, the Winding Ridge project achieved much more significant reductions in acidity, sulfate, iron and aluminum. It should be noted that high concentrations of aluminum, such as those observed at the Winding Ridge site are problematic for ALD systems, because as the system increases the pH of the AMD, aluminum hydroxides precipitate on the limestone surfaces, preventing contact between the mine water and the limestone, eventually causing failure of the system. The grouting approach used at Winding Ridge avoids this problem.

Grout injections, like the one at Winding Ridge, could also be viewed as pre-treatment approaches to reduce the load of acidity or other dissolved constituents that must be addressed by additional treatment systems. For example, the computer program AMDTreat was used to calculate the chemical costs to actively treat pre and post-injection discharge at Winding Ridge.

The average flow rate from both seeps was used to calculate the annual volume of water discharging from the mine. The annual cost of chemicals needed to treat this volume of water with hydrated lime was calculated (only the annual cost of chemicals required for treatment was calculated as it was assumed that the costs to construct the treatment system would not change for pre-injection vs. post-injection conditions). The cost of hydrated lime was assumed to be $0.022 per kilogram, transportation costs are not included in the analysis. Based on these assumptions, the annual cost to treat the pre-injection discharge using hydrated lime was estimated at $3,500 per year, while the annual cost to treat the post-injection discharge using the same treatment method was estimated at $430 per year. This represents a significant reduction in long-term maintenance costs if an active treatment system were to be installed at this site. While active treatment may not be a likely option at a small site, like Winding Ridge, lowering the levels of metals and acidity in mine discharge could significantly reduce the costs of treatment systems at larger sites.
CONCLUSIONS

The CCP grout placed in the Frazee Mine remains stable eight years after injection. Acid discharge from the mine has not been eliminated. However, significant improvements in the water quality of the mine discharge have been achieved. The average pH of the discharge has increased by approximately 1 pH unit and the average acidity of the mine discharge has decreased by more than 80%. The concentrations of other AMD-related parameters (Fe, Al, and sulfate) have also decreased relative to their pre-injection levels. The concentration of trace metals (Co, Cu, Mn, Ni, and Zn) has also decreased since injection.

Some dissolution of the grout has occurred, as indicated by concentrations of nontoxic major ions (Ca, K, Na, and Cl) that increased during injection and remain at or above...
pre-injection levels. The concentrations of these parameters in the mine discharge have decreased steadily over the past eight years since injection, indicating that dissolution of the grout is slowing. Trace metals do not appear to be leaching from the grout into the mine water. No trace metals have been detected in the mine discharge that were not detected prior to injection (in other words, no new trace metals have been detected since injection) and the concentrations of trace metals that were detected prior to injection are currently below their pre-injection levels, and in some cases are regularly below detection. Analysis of samples from ground water monitoring wells at the site show that ground water outside of the mine has not been impacted by the grout.

The results of the Winding Ridge Project show that CCPs can be used to create a grout for mine backfilling, which both reduces the volume of CCPs that must be placed in landfills and mitigates the environmental impacts associated with acid mine drainage.

Building upon the success of the Winding Ridge Project, the Initiative is planning to implement CCP-grout injection projects at the Kempton Mine Complex (Kempton Complex). The Kempton Mine Complex is Maryland’s largest source of AMD as it discharges thousands of pounds (thousands of kilograms) of acidity per day into Laurel Run. Through the Initiative, PPRP is working jointly with the Kempton Work Group, which includes MDE and private industry, to fund, design and implement AMD abatement projects at Kempton. The Kempton Complex consists of nine interconnected mines, and covers twelve square miles (thirty one square kilometers). As such, the Kempton Complex provides an enormous opportunity to beneficially use millions of tons of CCPs for the betterment of Maryland’s terrestrial and aquatic resources, and to demonstrate CCP use under various conditions.

In 2003, a CCP grout was used to construct a seepage barrier at the Kempton Manshaft, a former mine shaft, which acts as a conduit directing good quality ground water into the Kempton mine pool. Future projects which are planned at the Kempton Complex include the use of a CCP grout to coat acid-producing mine pavement at a small section of the Kempton Complex known as Siege of Acre. In addition, the Initiative has initiated a cost optimization study to evaluate the use of CCPs for deep mine restoration. Specifically, the Cost Optimization Study will consider the means, methods, and associated costs to use CCPs from the AES Warrior Run power plant for deep mine restoration in the nearby Georges Creek Basin.

REFERENCES


