The Western Maryland Coal Combustion By-Products/Acid Mine Drainage Initiative The Winding Ridge Demonstration Project

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ABSTRACT

The Maryland Department of Natural Resources Power Plant Research Program (PPRP) and the Maryland Department of the Environment Bureau of Mines (MDE) have undertaken the Western Maryland Coal Combustion By-products/Acid Mine Drainage (AMD) Initiative. The Initiative is a joint effort with private industry to demonstrate the beneficial application of alkaline coal combustion products (CCPs) to create flowable grouts for injection into abandoned, underground coal mines to reduce the formation of AMD. The Initiative is a key component of Maryland's overall ash utilization program to promote and expand the beneficial use of all CCPs. The purpose of this paper is to describe the key findings of the Winding Ridge Project, which was the Initiative's first demonstration of this technology. The Frazee Mine (a small “kitchen” mine), located in western Maryland, was used for the demonstration.

The CCP grout mixing and mine injection phase occurred from October through November 1996. Approximately 5,600 cubic yards of grout, consisting of 100 percent CCPs and virtually 100 percent mine water, were injected into the mine under dry and submerged conditions using conventional concrete mixing equipment. The grout formula was approximately 60 percent conditioned FBC by-product, 20 percent Class F fly ash and 20 percent FGD product. The lime for the CCP grout was provided by the FBC product, which contained about 5 percent free lime.

Since 1996, post-injection monitoring has included the collection of grout cores for laboratory testing, and water quality samples. Grout core samples from the mine 12 months after injection showed unconfined compressive strengths above 1,000 psi, with little evidence of weathering. Permeability measurements of the grout cores showed values of about 10^{-8} to 10^{-6} cm/sec. The post-injection water quality data show that there have not been any statistically significant increases (or decrease in the case of pH) in AMD-related parameters (total acidity, iron, sulfate) or trace elements (e.g., aluminum, cobalt, nickel, zinc) in the Frazee Mine water. There is also no evidence of adverse impacts to ground water or surface water from grouting.

INTRODUCTION AND PURPOSE

PPRP and MDE have undertaken the Western Maryland Coal Combustion By-Products /Acid Mine Drainage (AMD) Initiative, which is a joint effort with private industry to develop permanent solutions to AMD. The Initiative is a multi-year project that commenced in April 1995. The Initiative's goal is to demonstrate the beneficial application of alkaline CCPs generated by clean coal technologies, such as fluidized bed combustion (FBC) and flue gas desulfurization (FGD), to prevent the formation of AMD from abandoned, underground coal mines.

The purpose of this paper is to summarize the means and methods of the grout injection phase of the Winding Ridge Project, which is the Initiative's first demonstration project, and to present the results of more than two years of post-injection monitoring. The Frazee Mine, located atop of Winding Ridge in Garrett County, Maryland, was selected for this project. 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. AMD discharge was generally less than 5 gallons per minute, and occurred only through one mine opening. The water quality was typical of AMD, with a low pH (about 3 or lower), and high sulfate, iron and aluminum concentrations.

CCP GROUT FORMULATION

The CCP grout formula was developed by an iterative process that included both laboratory tests of candidate mixes and field adjustments. The grout was optimized for good flowability with minimum bleed and settlement. The grout tests were performed using potable spring and acidic mine waters from the site. The CCPs were FGD by-product and Class F fly ash from Virginia Power Company's Mt. Storm power plant (Mt. Storm, West Virginia), and FBC by-product from the Morgantown Energy Associates power plant (Morgantown, West Virginia).

The initial step was a laboratory study that evaluated different ratios of CCPs. Two different activators containing free lime were investigated: fresh, unconditioned FBC by-product, and commercially available quicklime. Using each activator, grout mixes were prepared with FGD by-product and fly ash. The fly ash provided pozzolan and the FGD by-product (consisting mostly of calcium sulfite and calcium sulfate with no free lime) was used to bulk the grout. The laboratory tested several grout formulae for key engineering parameters, including slump, modified flow, bleed, settlement, and unconfined compressive strength (UCS).

Table 1 summarizes the laboratory study results for measured grout characteristics. The tests showed that either FBC or quicklime could be used to prepare a CCP grout. Therefore, a grout mix consisting of FBC, FGD and fly ash was selected for advanced testing because of its relatively low cost compared to the quicklime mixes, and its use of 100% CCPs. In addition, the grout was also tested for metals using the Toxicity Characteristic Leaching Procedure (TCLP). The only two metals that were detected in the leachate were arsenic and barium at levels of 0.13 and 0.11 mg/L, respectively. The remaining six TCLP metals were not detected above the method detection limit, and none of the results exceeded their respective regulatory limits for characterization as a hazardous waste.

Table 1
Winding Ridge Grout Formulation

Parameter/Lime Source	Initial Laboratory Study FBC	Initial Laboratory Study Lime Based(b)	FBC-Based Grout Mixes (c)	During Injection
FBC/FGD/fly ash ratio (a)	30/32/38	NA	60/20/20	60/20/20
Lime/FGD/fly ash ratio	NA	10/40/50	NA	NA
Target Water Content (%)	38	40	47	46 - 57
Slump (inches)	8.5 - 9.0	8.1 - 8.2	NM	7 - 8
Spread (inches)	NM	NM	8	6.5 - 9.5
Bleed (%)	0.9 - 1.8	1.0	NM	NM
UCS (psi)				
7-day	294 - 319	192 - 213	142	30 - 77
28-day	711 - 735	1,095-1,134	520	245 - 560

(a) Expressed as percentages of total solids by weight. (b) Not carried forward into subsequent testing. (c) Second iteration of laboratory testing after selecting the FBC as the free lime component of the grout. NM - Not measured; NA - Not applicable.

The next step was to transition the FBC-based grout mix from the laboratory to field conditions, which entailed evaluating the heterogeneity of the FBC by-product to account for "as-delivered" conditions (e.g., free lime and moisture content). FBC by-product samples were collected from the Stack's Run FBC disposal site near Kingwood, West Virginia, which receives MEA's FBC by-product. As expected, the test results showed a wide range of values depending on the age of the sample. Moisture content ranged from <1% to 58%, free lime content (measured by the ASTM C25 method) ranged from <1% to 10%, and pH varied between 9.3 and 11.6. Fresher samples generally had higher free lime content and pH, and lower moisture content. As a result, the final grout mix design consisted of 60% fresh (defined as less than 24 hours old) FBC by-product, 20% FGD by-product, and 20% fly ash. The FBC was conditioned at the plant to contain about 15% moisture, which resulted in about 3% to 5% free lime content, for a grout mix total of about 3% free lime. During injection, the moisture content was increased to 57% on a dry weight basis to achieve the desired grout workability for full scale equipment.

CCP GROUT INJECTION PHASE

CCP grout injection commenced on 30 September 1996 with the mobilization of construction equipment for grout handling, mixing and injection. Full-scale injection began on 7 October 1996 and ended on 8 November 1996. The grout mix consisted of 100% CCPs and virtually 100% mine water pumped from the Frazee Mine. More than 5,600 cubic yards (cy) of grout were injected into the Frazee Mine under dry and submerged conditions, and consisted of 3,800 tons of FBC ash, and 1,200 tons each of fly ash and FGD by-product. The project used 520,000 gallons of water, consisting of 449,000 gallons of untreated mine water (pH of about 3) and 71,000 gallons of river water. About 471,000 gallons were used for grout mixing, and 49,000 gallons were used for equipment washing.

The CCPs were stored in separate holding bins prior to mixing. A front-end loader was used to load the segregated CCPs into a Maxon MC-1-10 mixer at the appropriate proportions by weight. The mix water was incrementally added to the mixer from water storage tanks. The grout was pumped to the injection boreholes using a Schwing trailer-mounted concrete pump. At the injection boreholes, the grout entered the mine voids by gravity until refusal. The average daily injection rate was about 220 cy over a 10-hour injection work day (additional time was needed daily for set up and take down). Hourly injection rates ranged from about 20 cy to as much as 60 cy. The higher hourly injection rates could not be sustained due to equipment sizing, workability of the CCPs, and injection pipe setup. However, the equipment could be sized for scale-up projects to attain higher sustained grout injections.

The CCP grout was injected into the mine under both dry and submerged conditions, and exhibited flow characteristics very similar to that of flowable fill. Although direct measurements of grout flow in the mine tunnels were not practicable, observations from borehole camera logging indicated that the grout was capable of flowing at least 100 feet along the mine pavement.

POST-INJECTION MONITORING RESULTS

Flow from the Frazee Mine

Seepage continues to flow from the Frazee Mine due to ungrouted areas of the mine and other unknown mine voids. The flow rates from the mine are comparable to pre-injection flows. Specifically, flow occurs through a lower and an upper seep at mine opening 2 (all other mine openings have always been dry). Flow through the lower seep is continuous at a rate of about 1 to 2 gallons per minute (gpm). Flow through the upper seep is intermittent, and depends upon the mine pool elevation. After precipitation events, flow occurs through the upper seep, otherwise it is dry.

Grout Cores

Grout cores were collected from the mine one and two years after injection, and show that the grout remains competent and intact in the mine. Testing of the first-year cores showed compressive strengths of over 1,000 pounds psi, which was an approximate two-fold increase in strength compared to the those measured in samples collected during injection. Permeability tests of the grout cores showed values ranging from 6.02×10^{-8} to 1.89×10^{-6} cm/sec.

Water Quality Data

Table 2 summarizes the results of pre and post-injection water quality monitoring for the Frazee Mine. The post-injection water quality data show that there have not been any statistically significant increases (or decrease in the case of pH) in AMD-related parameters (total acidity, iron, sulfate) or trace elements (e.g., aluminum, cobalt, nickel, zinc) in the Frazee Mine water.

Table 2
Summary of Frazee Mine Water Quality
The Winding Ridge Project

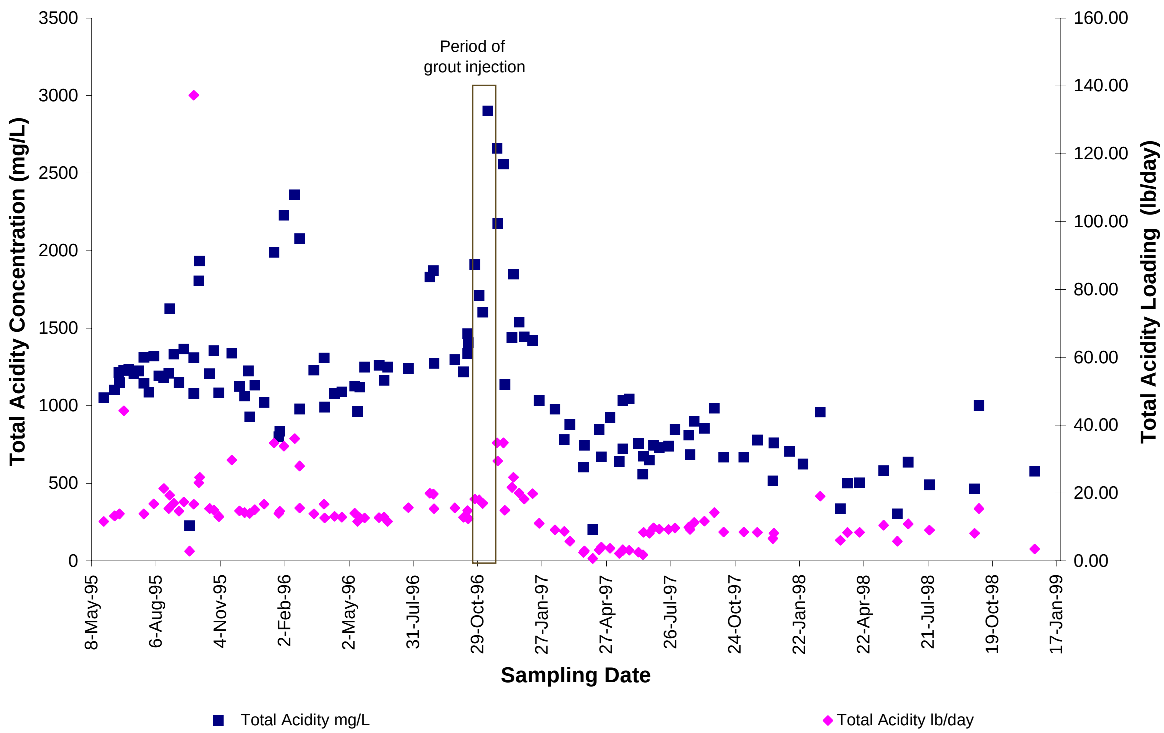
Parameter	Range of Values for Lower Seep			Range of Values for Upper Seep			Mine Piezometers
	Pre-Injection	Post-Injection		Pre-Injection	Post-Injection		Post-Injection
	1/95 - 9/96	10/96 - 9/97	10/97 - 3/99	1/95 - 9/96	10/96 - 9/97	10/97 - 3/99	10/97 - 3/99
pH	2.50 - 3.04	2.5 - 3.37	2.92 - 3.53	2.77 - 3.45	2.5 - 3.3	2.84 - 3.34	3.6 - 6
Acidity, mg/L	227 - 2,361	204 - 2,902	304 - 1,002	50 - 681	128 - 2,519	167 - 630	90 - 438
Major Ions, mg/L							
Iron	35 - 329	42 - 322	6 - 130	3 - 151	8 - 320	13 - 95	28 - 92
Calcium	<1 - 67	3 - 490	70 - 418	1 - 36	7 - 520	112 - 309	183 - 489
Magnesium	13 - 97	21 - 69	23 - 52	3 - 47	12 - 76	14 - 44	17 - 48
Potassium	<1 - 3	<1 - 22	11 - 27	<1 - 3	1.5 - 17	8 - 15	20 - 74
Sodium	<1 - 3	1 - 22	5 - 15	<1 - 3	<1 - 12	4 - 11	10 - 18
Sulfate	140 - 1,769	495 - 5,840	870 - 1,858	87 - 760	209 - 2948	500 - 1,513	620 - 1,600
Chloride	<1 - 37	ND - 27	ND - 17	<1 - 14 (4)	1 - 18	3 - 9	5 - 17
Trace Elements (1), mg/L							
Aluminum	20 - 110	28 - 250	10 - 78	4 - 48	12 - 175	18 - 62	4 - 28
Cobalt	0.62 - 0.93 (2)	0.58 - 2	0.35 - 0.69	0.04 - 0.39 (3)	0.08 - 1	0.18 - 0.56	0.02 - 0.341
Copper	0.02 - 0.32	0.14 - 2	0.03 - 0.17	0.01 - 0.24	0.03 - 1.09	0.08 - 0.12	ND - 0.08
Manganese	3 - 16	1 - 13	2 - 17	0.48 - 5.7	1.4 - 6	1.2 - 4.3	2 - 5.5
Nickel	<1 - 2	1 - 5	0.20 - 1.76	0.08 - 1.78	0.23 - 2.74	0.38 - 1.15	0.57 - 1
Zinc	3 - 4	2.5 - 11	1.5 - 12	0.26 - 1.75	0.56 - 6	0.89 - 2.3	0.5 - 3

Notes:
ND - Not Detected
(1) - Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver, Thallium, and Vanadium were sporadically detected, in generally less than 25% of the mine discharge samples.
(2) - Does not include anomalous result of 42 mg/L on 10/6/95.
(3) - Does not include anomalous result of 6.3 mg/L on 11/20/95.
(4) - Does not include anomalous result of 42 mg/L on 1/4/96.

The mine water displaced during grout injection caused short-term or transient water quality trends during the first year (October 1996 to September 1997) after grout injection, during which the concentrations and loadings for AMD-related parameters increased significantly compared to the pre-injection conditions. This is demonstrated in the temporal plot of total acidity in Figure

1, where the post-injection concentrations peaked at about 3,000 milligrams per liter (mg/L) for total acidity within the first year after injection. This transient condition, however, has since leveled off during the second year (September 1997 to January 1999) after grout injection. Since October 1997 (Figure 1), acidity concentrations and loadings have consistently been within or lower than the observed range during pre-injection. Iron and sulfate show essentially the same pattern as total acidity.

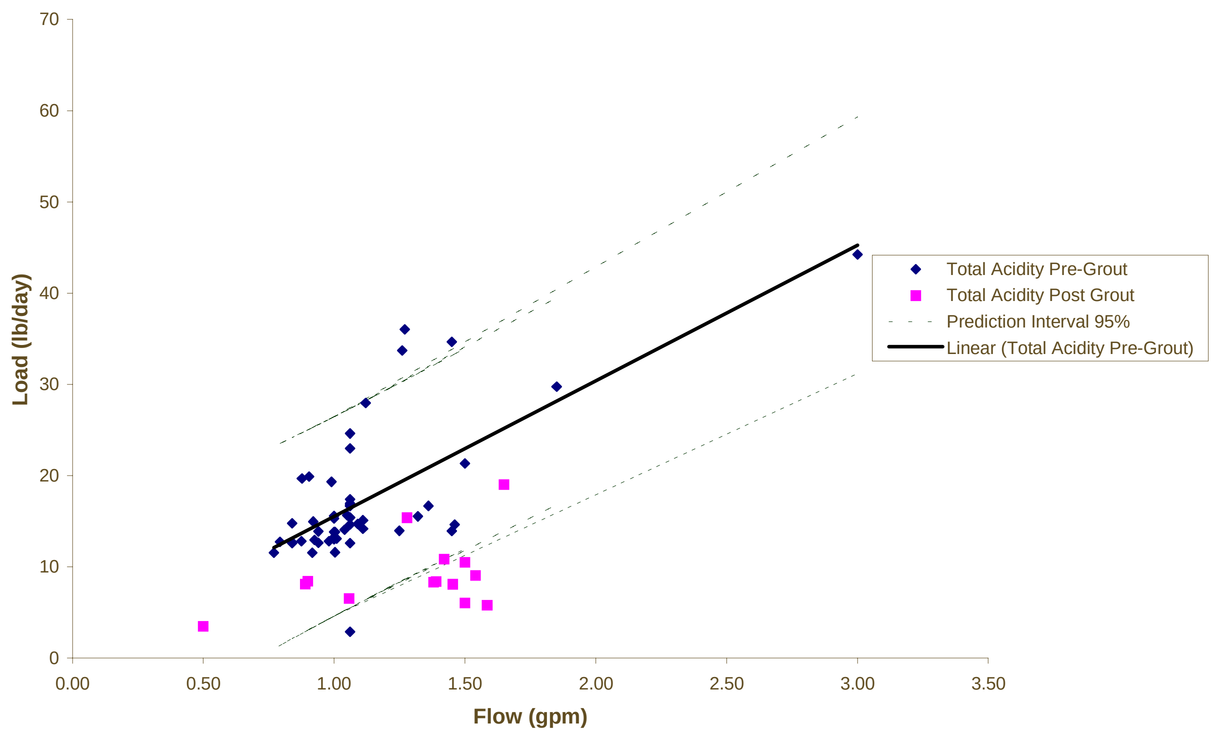
Figure 1
Total Acidity Results for the Lower Seep
at Mine Opening 2 of the Frazee Mine



The non-toxic ions calcium, potassium and sodium do not exhibit the same pattern as the AMD-related parameters. Pre-injection water quality data showed that calcium, potassium and sodium concentrations were negligible. However, calcium, potassium and sodium levels have remained elevated since grout injection. The most likely source of calcium is the dissolution of calcium sulfite or calcium sulfate from the grout, which indicates that, to some extent, some grout is dissolving, and contributing to the post-injection sulfate loading. However, the grout cores show that the grout is intact and competent, which indicates that any dissolution is most likely localized to grout surfaces that are exposed to or in contact with acidic mine waters.

The significance between the pre-injection and post-injection water quality for AMD-related parameters was evaluated statistically by comparing the pre-injection data to the data collected during the second year after grout injection (Figure 2). The transient conditions were not included in these analyses since they are not representative of the water quality that would be expected over the long-term. Figure 2 was prepared by calculating a regression line (using the least-squares method) and its 95% predictive interval for the pre-injection data. Once again using total acidity as the example, Figure 2 shows that the post-injection loadings for total acidity fall within the pre-injection predictive interval or below its lower predictive interval line. These results show that the grout injection has not resulted in any statistically significant increases in AMD-related parameters. In fact, the patterns suggest that the post-injection concentrations of certain AMD-related parameters are lower than those concentrations measured prior to grout injection. Iron and sulfate show essentially the same pattern as total acidity.

Figure 2
Regression Analysis for Pre and Post-Injection Results for Total Acidity at Mine Opening 2 for the Frazee Mine

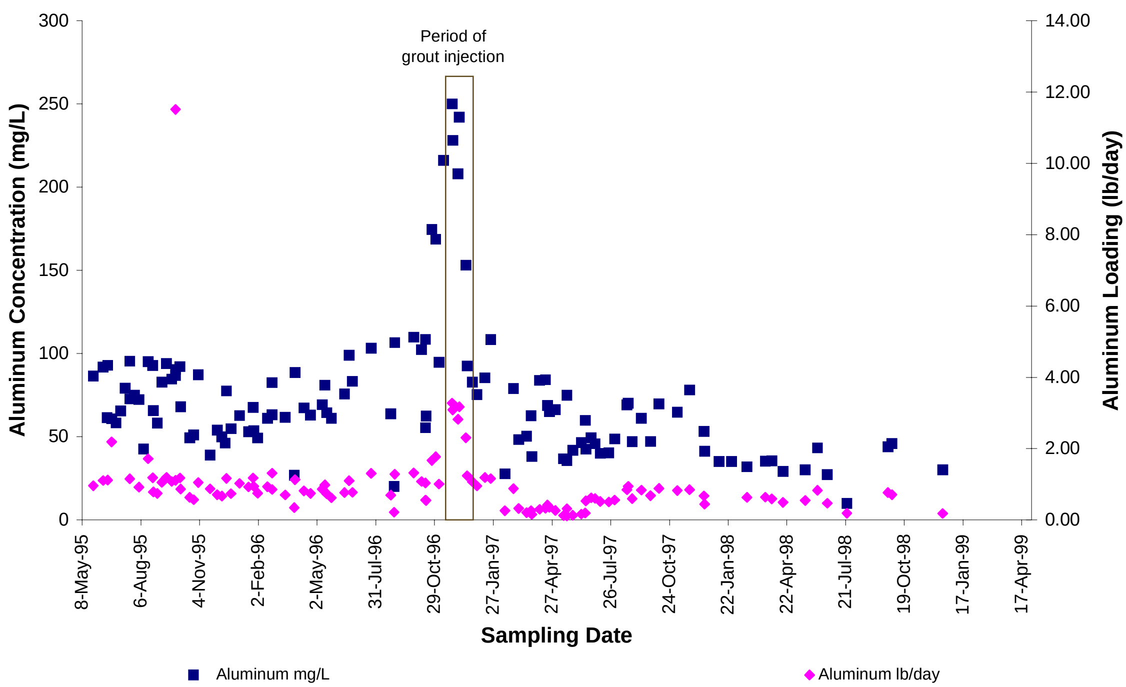


Post-grout data for October 1997 through January 1999

Regarding the trace element data, the water quality monitoring data from the mine discharge showed that all trace elements detected during post-injection monitoring were also detected during pre-injection monitoring. There was no single trace element that was present in the post-injection mine discharge that was not previously present in the pre-injection mine discharge. In fact, the only trace elements that were routinely detected during pre-and post-injection monitoring were aluminum, cobalt, copper, manganese, nickel, and zinc. Other trace elements that were sporadically detected (generally in less than 25 percent of the samples) included arsenic, beryllium, cadmium, chromium, lead, mercury, selenium, silver, thallium and vanadium.

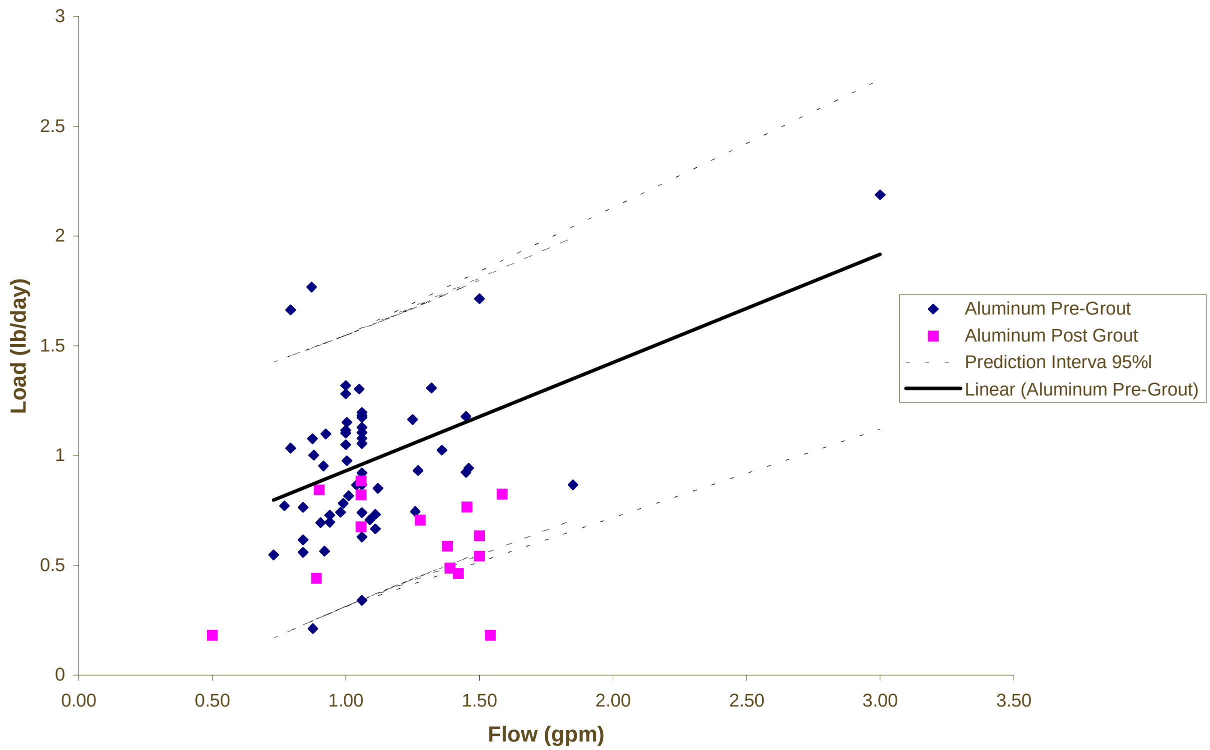
Figure 3 shows the pre- and post-injection monitoring results for aluminum, for which the pattern is similar to that shown for the AMD-related parameters. A transient period was observed for the first year after injection, but since October 1997 aluminum concentrations and loading have consistently been within or lower than its observed range during pre-injection. Plots for cobalt, copper, manganese, nickel, and zinc, are essentially the same as aluminum.

Figure 3
Aluminum Results for the Lower Seep
at Mine Opening 2 for the Frazee Mine



The significance between the pre-injection and post-injection water quality for the trace elements was evaluated as described above for the AMD-related parameters. Figure 4 shows that the post-injection loadings for aluminum all fall within the pre-injection predictive interval or below the lower predictive interval line. These results show that the grout injection has not resulted in any statistically significant increases in trace element loadings. Plots for cobalt, copper, manganese, nickel, and zinc, are essentially the same as aluminum.

Figure 4
Regression Analysis for Pre and Post-Injection Results for Aluminum at Mine Opening 2 for the Frazee Mine



Post-grout data for October 1997 through January 1999

Post-injection water quality data from downgradient ground water monitoring wells and stream sample locations also show no adverse impacts from grouting the mine. Essentially there is no evidence of AMD at these locations, so there can not be any impacts from grouting.

CONCLUSIONS

The Winding Ridge Project has demonstrated that CCPs can be used beneficially to form a grout that can be injected into an abandoned, underground coal mine. The grout core samples and the post-injection water quality data provide evidence that the grout is capable of entombing and covering pyritic mine debris during injection and curing. This capability would effectively reduce the volume of pyrite available for AMD generation. Since the grout retained it strength and low permeability, it is likely to provide a good long-term barrier between the pyritic material, and air and water. Post-injection monitoring of the Frazee Mine will continue at least through the year 2000.