THE USE OF COAL COMBUSTION RESIDUES TO CONTROL ACID MINE DRAINAGE[1]

by

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Abstract: The Federal Energy Technology Center of the U.S. Department of Energy is monitoring changes in water quality at three inactive mining sites where a coal combustion residue (fly ash) was injected into the spoil to control the production of acid mine drainage. Since most combustion residues are alkaline, their addition to the subsurface environment raises the pH, limiting the propagation of pyrite oxidizing bacteria and reducing the rate of acid generation. Grouts of fly ash, lime and cement, when injected underground, decrease permeability and porosity, diverting water away from the pyritic material. Both mechanisms, alkaline addition and water diversion, are expected to reduce the amount of acid produced. Changes in water quality parameters (pH, acidity, anions and cations) in water samples from wells and seeps are monitored to assess the effect of CCR injection. The concentration of heavy metals in the water flowing through the sites, before and after CCR injection, is also determined. The use of underground mine sites for disposal of coal combustion residues provides a stable, low maintenance alternative to landfills, benefitting the mining and electric power industries.

Additional Key Words: Acid mine drainage, fly ash

Introduction

Acid mine drainage (AMD) from reclaimed surface mines is a major problem in the coal fields. After cessation of mining, a ground water system typically re-establishes itself within the spoil backfill and often results in acidic seeps on the down-gradient parts of the site. AMD is generated by the oxidation of pyrite, occuring naturally within surface mine lithologies, and consequently in the spoil, and from buried refuse and pyritic coal. It was previously a common practice to dump refuse from coal cleaning plants in open pits. It is unlikely that the extent of this practice will ever be known. Coal of poor quality was also buried in the open pits. Mining companies operating under current regulations are required to treat acidic discharges. At abandoned sites, water treatment is not legally mandated and consequently, the natural water quality is degraded, thus reducing the commercial, recreational and aesthetic value of the ground and surface water resources. Varying success has been attributed to an inability to accurately delineate where acid production occurs within the backfill. Several geophysical techniques have been developed and used during the past decade to accurately locate acid-producing zones within the spoil (see Schueck, 1988 for a review).

This paper summarizes the effectiveness of coal combustion residue (CCR) injection as an abatement technique to reduce water pollution and presents the results of detrimental effects on water quality associated with in-spoil placement at reclaimed surface mines. Water quality data and volume of injected CCR served as the primary evaluation criteria. The initial site investigation work at three reclaimed surface mines discussed in this paper was initiated in the 1980s, and the grout injection progressed at varying rates afterwards. Coal mine drainage parameters (e.g., pH, acidity, iron, manganese, aluminum) were monitored at each site. Only standard coal mine drainage parameters will be presented in this report, although trace element concentrations were determined for some samples. The volume and type of CCR injected at each site also varied. Geophysical site characterization and grout injection techniques have been previously described in the literature (Ackman and Kim, 1993; Schueck et al, 1994) and will not be addressed in this paper.

Summary of Field Sites and Operations

Two of the three sites (Upshur, WV and Clinton, PA Counties) were abandoned sites, third site (Green County, PA) contained an active water

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[1] Paper presented at the 1997 National Meeting of the American Society for Surface Mining and Reclamation, Austin, TX, May 10-15, 1997.

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Proceedings America Society of Mining and Reclamation, 1997 pp 496-502
DOI: 10.21000/JASMR97010496

https://doi.org/10.21000/JASMR98010496

Table I - Summary of site information..

ITEM	CLINTON CO	GREENE CO	UPSHUR CO
TOTAL FLY ASH VOLUME	3,420 m^3	191 m^3	358 m^3
SITE HECTARES	15	15	32
VOLUME FOR 3 METERS ABOVE PIT FLOOR	456,415 m^3	444,800 m^3	974,508 m^3
AVAILABLE VOID VOLUME[1]	82,155 m^3	79,934 m^3	175,411 m^3
FILLED VOID, %	4	0.2	0.2
AVERAGE DISCHARGE[2] L/sec	2.21	1.82 l	2.04 l
MONITORING WELLS	42	12	14
INJECTION WELLS	650	22	62
RANGE OF WELL DEPTH	3 - 10 METERS		
TYPE OF CCR	FBC[3]	2 SOURCES OF CLASS F AND FBC & AMD SLUDGE	CLASS F[4] & CEMENT

[1] Volume is based on an 18 percent porosity for the first 3-m of spoil above the pit floor.

[2] *Units are in liters per second.*

[3] FBC is an acronym for fluidized bed combustion ash.

[4] Class F ash commonly refers to bituminous coal that has been burned using conventional technology.

Table II- Selected monitoring well and discharge (seep) water quality means for both Clinton and Green Counties one year before and after CCR grout injection.

Parameter[1]	Clinton County, PA				Greene County, PA			
	Before		After		Before		After	
	K20	Seep	K20	Seep	Well 12	Seep	Well 12	Seep
pH	2.00	2.55	2.23	2.56	3.07	3.19	4.08	3.30
Acidity	12,762	2,684	5,514	2,882	1,726	1,735	599	1,202
Total Iron	3,339	433	1752	343	138	381	51	239
Calcium	52	102	55	82	449	399	513	440
Aluminum	436	268	232	228	237	177	107	123
Manganese	34.8	NA[2]	21.6	61.1	87	126	76	84
Sulfates	8,929	2,564	3,583	3,475	4,832	4,965	2,932	3,771
Count	15	15	10	15	11	21	15	21

[1] pH is presented in standard units and all other parameters are presented in terms of milligrams per liter (mg/L)

[2] Parameter Not Analyzed

Table III - Selected monitoring well and discharge (seep) water quality means for Upshur County; one year before and one and five years after CCR grout injection.

Parameter[1]	Upshur County, WV					
	Before		1 Year After		5 Years After	
	Well 4	Seep	Well 4	Seep	Well 4	Seep
pH	3.1	3.2	3.0	3.3	3.4	3.5
Acidity	536	143	410	126	185	101
Total Iron	164	15	161	12	47	22
Calcium	63	34	56	36	33	35
Aluminum	34	9	23	7	12	6
Manganese	9	8	8	6	3	7
Sulfates	768	323	677	283	330	280
Count	11	11	16	16	3	3

[1] pH is presented in standard units and all other parameters are presented in terms of milligrams per liter (mg/L)

treatment facility operated by a mining company. The Upshur County site contained a 32- hectare (ha) surface operation that mined the Lower and Middle Kittanning coal seams in the mid-1970s. The Clinton County site contained a reclaimed 15- ha surface mining operation that had mined the Lower Kittanning coal seam, also in the mid-1970's. Mining of the Waynesburg coal seam ceased and reclamation occurred in the early 1980's at the 15- ha Green County site.

Subsequent to locating buried acid sources within the mine spoil at all three sites using geophysical techniques, CCR grout was used as a capping material (Kim and Ackman, 1994; 1995; Schueck, 1988). This work was an attempt to isolate the pyritic material from air and water, and thus, prevent the formation of AMD. The volume and type of CCR used at each site varied (Table 1). All CCR used at the three sites was tested and met the guidelines established by the U.S. Environmental Protection Agency's Extraction Procedure Toxicity Test method (EP Tox test) or Toxicity Characteristic Leaching Procedure (TCLP) (U.S. Code of Federal Regulations, 1986; Federal Register, 1990). The estimated volume or pore space for CCR injection was based on an 18% porosity within the first 3 meters (m) above the pit floor. Possible natural segregation during reclamation (larger boulders typically fall to the pit floor first) suggests that the assumed 18 % porosity may be conservative (Jones and Anderson, 1990). The intent of this AMD abatement technique was to inject targeted areas and not to totally fill all void spaces within the spoil field. Table 1 shows that less than 4% of the available subsurface void space at all sites was filled with CCR grout.

Water quality monitoring and grout injection wells were installed at all sites (Table 1). The depth of the wells were relatively shallow, typically in the 3 to 10 m depth range. Water quality was monitored at each site for at least one year prior to CCR injection; monitoring continued for at least one year after grouting activities ceased. The frequency of monitoring varied at the three sites. Water samples were collected on either a monthly and/or quarterly basis for the specific sites.

Water Quality

Most monitoring well water quality and the seep (discharge) at the various sites were variabile, and transient, for about 2 to 4 weeks after CCR injection. This was considered to be the result of a plug flow of highly alkaline water, which was generated by the injection of the thin and watery grout slurry. There have been slight long term improvements in water quality at the surface seeps (Tables 2,3). Monitoring locations on any of the three sites showed that water quality had not significantly degraded after CCR injection. Numerous monitoring wells on the various sites have generally shown long-term water quality improvements on the local level. In Tables 2 and 3 averaged water quality values before and after CCR grout injection for the seeps and selected monitering wells illustrate local water quality improvements on each site.

Water Quality: Clinton Country, PA

Water quality improved in several monitoring wells located down gradient of the pods grouted in 1992. Abundant snowfall and heavy spring precipitation (1992/1993) provided an opportunity for the site to be well flushed following the grouting effort. Concentration decreases of 50 to 90% in mine drainage parameters were noted in several of these downgadient wells. For example. Table 2 compares pregrouting and postgrouting samples of Well K20 located within a pod grouted during September 1992. This well is also in the primary flow path of mine drainage produced to the north, and the postgrouting water quality is influenced by that drainage. The reduction in sulfate levels suggests that at least part of the improvement is due to decreased AMD production. Other parameters commonly associated with AMD also show reduced values. Water quality in wells not located down gradient of the 1992 grouting remained within observed pregrouting ranges.

A series of one-tailed t-tests of significance ($p \leq 0.05$) was used to determine if water quality in the monitoring wells improved after fly ash grout injection. To test if the measured variables of pH, sulfate, cadmium, total iron and aluminum significantly improved after fly ash had been injected into a proximal injection well, samples collected prior to grout injection from the monitoring wells at the site were grouped as one set. Samples collected after grout injection were grouped at the other set. For the overall site, significant improvements were noted emerged for total iron, sulfate and cadmium while aluminum and pH showed no significant improvement. To evaluate these changes within a spatial connect by each well, a significance of change map was prepared for each of these water quality variables (Fig. 1 a-e). These maps for the five water quality water variables illustrates water quality change across the site after grouting.

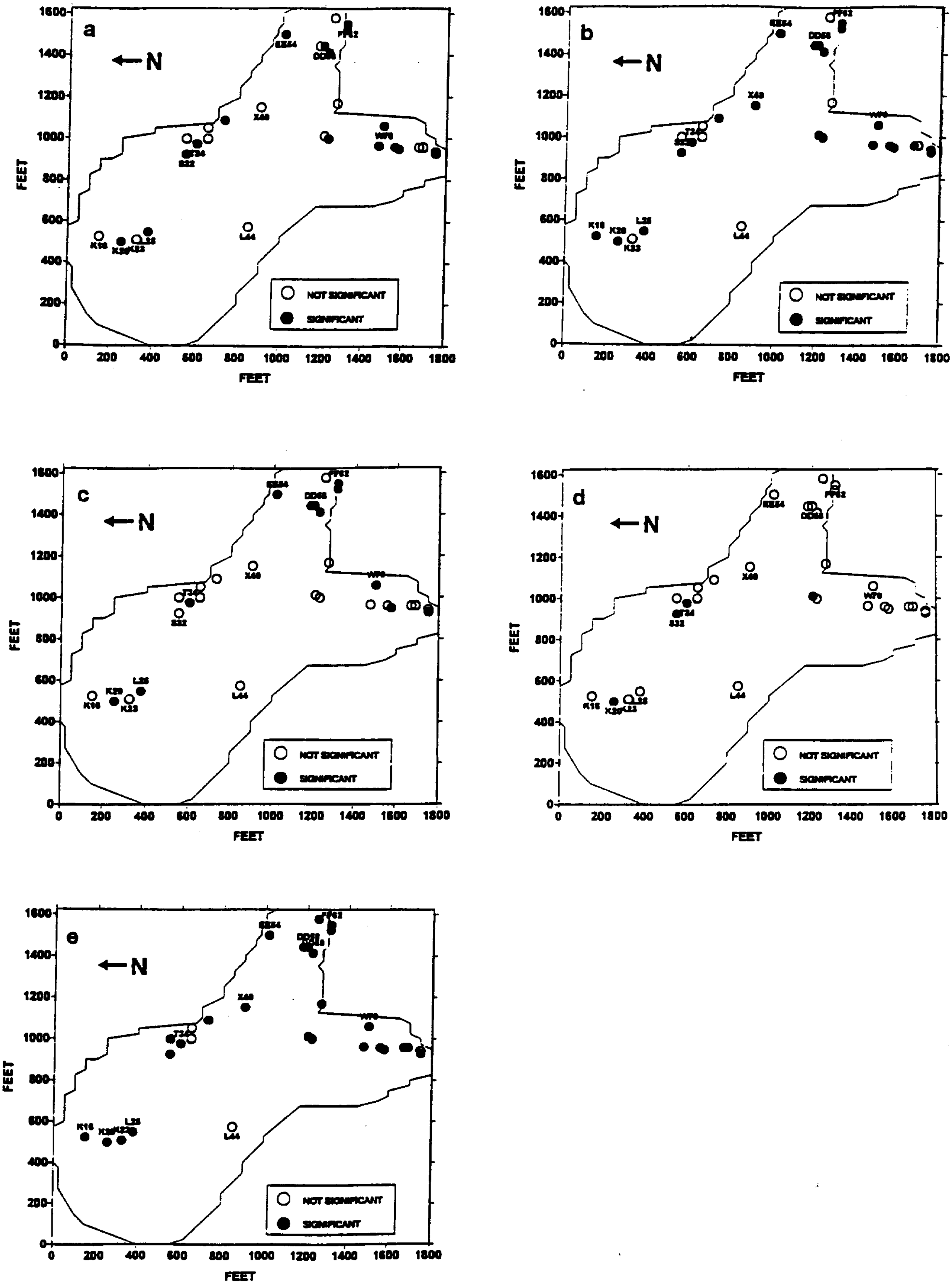

Figure 1. Significance Maps of Water Quality of Monitoring Wells at Clinton County, PA site, a) Iron, b) Al c) pH, d) SO_4, e) Cd.

Within a spatial context those wells updip of the seep and along the northeastern limits of the study area generally showed significant improvement in the aluminum and cadmium concentrations.

Water Quality: Green County, PA

The data for the seep and for Well 12 are representative of pre-and post-grouting water quality for this site (Table 2). This well was located on a flow path that was inferred from its relative distance from the buried highwall and seep and from geophysical investigations and drilling. Table 2 lists the averages of the parameters considered most relevant.

Prior to grouting, 20 water samples were collected rom the seep over a 12 month period; 10 samples were collected during the 12 month post-grouting period. Approximately 12 pre-grouting samples and 8 post-grouting samples were collected from well 12. On average, the net acidity decreased by 500 mg/L and the average total Fe concentration decreased by 120 mg/L. The Al and Mn concentrations were reduced by 46 and 35 mg/L, respectively. The reductions in all parameters was approximately 30%. The variability in the post-grouting values was comparable to that observed in the pre-grouting period. Post-grouting values at the seep have remained below the pre-grouting averages for all parameters.

Comparison of pre-and post-grouting acidity for Well 12 shows an average decrease of 1303 mg/L. Well 12 became alkaline (31 mg/L) shortly after the November 1992 grouting, but was again acidic (215 mg/L) in January 1993. After the grouting in June 1993, Well 12 remained acidic (692 mg/L).

Water Quality: Upshur, County, WVA

Water quality during 1989 was monitored on a monthly basis for a variety of parameters including total iron (Fe), ferrous iron (Fe^{2+}), aluminum (Al), manganese (Mn), acidity and pH. Table 3 shows the mean values of the selected parameters. Typically, 12 water samples were collected each month from the monitoring wells and discharge location. However, several monitoring wells were dry during low flow conditions, reducing the sample count.

The post-grouting water quality data presented in this report represents monitoring from the beginning of March 1990 to the end of August 1995. Significant water quality changes have been observed between the various monitoring wells. This uncertainty of water quality improvement is related to the viscosity of the grout. The high water conditions apparently allowed the grout to flow to the pit floor and spread out in an east-westerly direction, as indicated by the post-grouting magnetometry surveys. The most notable reductions at the present time are those in acidity and sulfates. These reductions suggest that some percentage of the acid-producing material was encapsulated, perhaps along the pathway to the pit floor.

Discussion

The data presented in this paper and other literature (Kim and Ackman, 1994; 1995) show that long-term water quality improvements have been observed on a local (monitoring wells) and broad (site discharge) basis as the result of CCR injections at reclaimed surface mines. Although these water quality improvements have apparently been slight, they are significant. The following discussion will address the issue of limited water quality improvement associated with CCR injection at reclaimed surface mine sites.

There are three primary, and interrelated, considerations associated with the effectiveness of CCR injection as an AMD abatement technique. These site-specific considerations include: (1) source of acid-production, (2) ability to grout and isolate targeted zone from air and water and (3) volume of injected grout material. The ability to target sources of concentrated pyritic material (e.g., coal refuse and/or pit cleaning) in the subsurface of a reclaimed surface mine has been demonstrated with the use of geophysical techniques (Schueck, 1988). However, further site investigation work is required to determine what portion of the total pollution from the site is being generated by the geophysically targeted zones. For example, if pyritic material was emplaced on a non-acid-producing surface mine, then the targeted zones would represent 100 % of the pollution source. The effects of rendering targeted acid-producing zones inert are difficult to estimate when the entire surface mine is somewhat acid-producing (e.g., mine has pyritic overburden) and the target zones do not represent 100 % of the pollution source.

Summary and Conclusions

Encapsulating acid-producing material with a cementitious grout is intended to prevent contact with air and water. However, the effective infusion or isolating a targeted, acid-producing zone with relatively small volumes of grout is very difficult. Although grout volumes for targeted areas can easily be calculated, the pseudokarstic conditions created during the placement of spoil can redirect a large portion of the calculated grout volume away from the injection well and targeted pyritic material. As the result of subsurface communications, uninjected grout wells have been observed to discharge grout that was being injected as far away as 45-m. Additionally, pH measurements taken during the grouting phase from distant and ungrouted wells showed drastic increases (e.g., pH 3 increased to a pH 11), which also confirmed that long-range propagation of the alkaline could occur. Grout propagation away from the injection point requires that additional grout volumes need to be injected if the target area is to be encapsulated, and suggests that injection strategy should be revised. A change in injection strategy could involve drilling additional wells for injection, modifying the grout formulation or injection pressure or continual pumping until refusal occurs or a combination of two or more of these possibilities. Attempts to monitor grout propagation with geophysical techniques have been limited and inconclusive. The addition of magnetite to the CCR grout may assist in geophysical monitoring of grout propagation; however, more research is needed, in the area.

The void space in the subsurface of a reclaimed surface mine is large and the injected volume of grout at each of the three sites was very small in comparison, less than 4% by volume (Table 1). The injection of relatively small volumes of CCR, which had met TCLP or EP Tox criteria, did not significantly degrade existing water quality. Slight, but significant improvements in water quality have been observed. The improvements in water quality are indicative that at least a portion of the targeted CCR grouting was effective. A more notable improvement in water quality at the three sites may have been achieved if a larger volume of CCR grout (e.g., filling approximately 10% of available void space) had been injected. However, increase in the grout volume may necessitate a reevaluation of material handling and grout injection operations.

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