Session 4

Hydrologic Long-Term Monitoring

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WATER QUALITY EFFECTS OF BENEFICIAL CCBS USE AT COAL MINES

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Abstract

One hundred and five million tons of coal combustion products (CCP) were produced by American power generating utilities in 1997 (ACAA, 1998). Of that total, 1.68 million tons were used in mining applications. Twenty years ago coal ashes, bottom and fly ashes, constituted nearly all CCPs. With the shift to new emission control technologies at power plants, however, large volumes of new products are being generated. Many do not lend themselves to traditional ash applications such as cement formulation. Mine filling has the potential to absorb substantial proportions of annual fly ash and other CCP production, and State and Federal policies encourage beneficial use of CCPs. Beneficial uses in mines include acid drainage control, subsidence control, grading, and soil reconstruction. Results have ranged from the environmentally beneficial to neutral and, in some cases, detrimental. States such as Pennsylvania and West Virginia have developed policies which define and regulate beneficial use of CCPs for coal mine remediation. These successful policies will be summarized.

Many CCP disposal sites are not documented with reliable pre and post application monitoring. In this report we will discuss the types of CCP, their relevant characteristics, and the mining environment. We have attempted to identify a range of documented applications and to draw conclusions about their environmental effects including benefits and adverse impacts.

Types of Coal Combustion Products

Coal combustion products can be grouped into four main classes: 1) Class F ashes; 2) Class C ashes; 3) Fluidized Bed Combustion ashes; and 4) Flue Gas Desulfurization solids. Class F and C ashes are produced in large pulverized coal boilers. They comprise the bulk of CCBs produced in the United States. They are distinguished by the American Society for Testing and Materials (ASTM) on the basis of their free lime (CaO) content[2]. Class F ashes have less than 10% lime while Class C ashes have more than 10% lime. Nearly all ashes produced by pulverized coal boilers in the eastern United States are Class F while those burning western United States coal are typically Class C. Table 1 shows typical chemical compositions for both Class F and Class C ashes.

Fluidized Bed Combustion (FBC) ashes and Flue Gas Desulfurization (FGD) sludges result from relatively new clean coal technologies. Both use lime or limestone ($CaCO_3$) to generate CaO to capture SO_x in the boiler exhaust gas stream. FBC ashes are produced when high sulfur coal and/or coal tailings are burned with limestone in a fluidized bed boiler. SO_x is precipitated as gypsum ($CaSO_4$) along with unreacted lime in a strongly alkaline ash (typically 25 to 30% free lime). Flue Gas Desulfurization solids are produced when lime or limestone slurries are injected into the exhaust gas downstream of the boiler. SO_x is precipitated either as gypsum or calcium sulfite ($CaSO_3$). Some utilities combine FGD solids with fly ash to improve solidification so FGD solids may or may not contain fly ash. In either case, sulfites may then be converted to gypsum by forced oxidation.

Currently 25 million tons of FGD solids are produced each year with 9% of that total being beneficially used[1] as mine fill. The remainder is land filled. FGD solids normally have little inherent lime. However, they are often amended (fixated) with lime (CaO) for solidification, otherwise they have the consistency of a thin paste.

Table 1. Typical Composition of Class F and C ashes as defined by ASTM (1997).

Parameter	**Class F**	**Class C**
SiO_2	54.9%	39.9%
Al_2O_3	25.8%	16.7%
Fe_2O_3	6.9%	5.8%
CaO	8.7%	24.3%
SO_3	0.6%	3.3%
Moisture content	0.3%	0.9%
Loss on Ignition (LOI)(@750C)	2.8%	0.5%
Available alkalies as Na_2O	0.5%	0.7%
Specific gravity	2.34	2.67
fineness, retained on #325 mesh sieve	14%	8%

Beneficial CCP Applications in Coal Mines

CCPs are typically used in the following beneficial applications at coal mines:
- Neutralization of acid forming materials,
- Barriers to acid mine drainage (AMD) formation/transport,
- Subsidence control in underground mines,
- Pit filling to reach approximate original contour (AOC) in surface mines, and
- Soil reconstruction.

This report will discuss only the first four scenarios since soil reconstruction is fundamentally an agricultural application.

Coal Mine Environments and Their Implications for CCP Use

Mine environments are complex and a given mine will contain zones of high groundwater flux and others nearby, which are nearly stagnant. Mine groundwater can be oxidizing or reducing. Reducing conditions are often found in saturated zones while unsaturated zones tend to be oxidizing. Certain redox-sensitive metals and oxy-anions of elements tend to be more soluble in reducing conditions.

Mine groundwaters also vary according to their acidity/alkalinity. Many mine waters, particularly in the eastern United States are slightly to strongly acidic with significant concentrations of iron, aluminum and manganese. These ions are more soluble in acid conditions, and alkalinity from CCPs are often used to neutralize acid mine drainage. The resulting metal hydroxides formed in these conditions will scavenge many trace elements such as arsenic and zinc.

In a given mine one might encounter acid/oxidizing, acid/reducing, alkaline/oxidizing, and alkaline/reducing conditions. Care must be taken to ensure that CCPs are matched to zones that take advantage of their beneficial properties and minimize their exposure to conditions that will mobilize toxic concentrations.

The CCPs can be placed in permeable or impermeable forms. At one end of the spectrum, bottom ashes have the hydraulic conductivity of gravel, while fly ash is closer to silt. Class F ashes tend to be more permeable than class C ashes due to the tendency of class C ashes to self-cement. At the opposite extreme, fixated FGD solids have very low hydraulic conductivity, and the various CCP grouts behave like concrete and are virtually impermeable.

Nearly all CCPs contain soluble and insoluble salts. If permeable and exposed to groundwater, soluble salts will dissolve. These include salts of boron, chlorides, and sodium carbonates. On the other hand, the solubility of sulfates and calcium or magnesium carbonates is controlled by their concentrations in the mine water. It is not unusual to find mine waters that are already saturated with respect to gypsum or calcium carbonate. In such cases, little or no net dissolution will occur. Care should be taken that CCPs containing substantial amounts of soluble salts are not exposed to zones of significant groundwater flux.

State Beneficial Use Policies for CCPs

The State of West Virginia's Coal Policy (13 Jan 98) distinguishes between coal combustion wastes and coal combustion by-products. While both consist of coal ash, boiler slag and flue gas desulfurization solids, wastes are not used beneficially. Coal combustion wastes, therefore, are regulated under solid waste regulations. Allowable beneficial uses include:

- Subsidence control as part of a confined cementitious mixture,
- Abatement of underground mine fires as part of a cementitious mixture,
- Soil amendment or substitute,
- Alkaline amendment to neutralize acid producing rock,
- Encapsulation of acid producing rock, and
- Filling underground coal mine voids to control acid drainage.

Quality criteria are included in the policy. For example, beneficially used CCPs must pass the USEPA's Test Methods for Evaluating Solid Waste, SW-846, Method 1311 (Toxicity Characteristic Leaching Procedure or TCLP) for non-organics. They also must have at least 0.5% alkalinity (calcium carbonate equivalent) and be applied at a rate needed to treat any acidity which could be generated by the acid producing rock. The later is calculated by the following formula:

$$A = \left(\left(W * \%S * 3.125 \right) / \%NNP \right) * 1.1$$

Where: A = Required amendment (tonnes)
W = Amount of waste rock to be neutralized (tonnes)
%S = Percent sulfur in waste rock
%NNP = Percent net neutralization potential of amendment e.g. %NP - %MPA

The West Virginia ash policy calls for a 10% safety factor. Hence the total is multiplied by 1.1.

Under Pennsylvania's Certification Guidelines for Beneficial Uses of Coal Ash (30 Apr 98) beneficial ash applications include:

- Coal Ash Placement: pH between 7.0 and 12.5 at the generator's site.
- Soil substitute or soil additive: for use as a liming agent, the calcium carbonate equivalent must be at least 100 tons/1000 tons of ash.
- For use as a soil substitute or soil additive, the generator must provide a description and justification for the intended use. Certification would be granted on a site specific basis.
- Alkaline addition: for use as an alkaline amendment, the pH must be in the range 7.0 to 12.5 at the generator's site. Also, the calcium carbonate equivalent must be at least 100 tons/1000 tons of ash.
- Low-permeability material: To be certified for low-permeability material, the pH of the coal ash must be in the range of 7.0 to 12.5 at the generator's site. However, if an additive is used, the mixture can be adjusted to the pH range of 7.0 to 12.5 at the site of beneficial use. To be certified as a low-permeability material, the hydraulic conductivity of the coal ash/additive mixture must be 1.0 x 10^{-6} cm/sec or less based on

ASTM D 5084-90 or other test approved by the state and using compaction and other preparation techniques that will duplicate expected conditions at the site of the beneficial use.

Pennsylvania also requires leachate testing prior to approval of beneficial uses for CCPs. Extracts from the USEPA's Test Methods for Evaluating Solid Waste, SW-846, Method 1312 (Synthetic Precipitation Leaching Procedure or SPLP) are evaluated prior to approval of beneficial use. Table 2 summarizes the test methods used by West Virginia and Pennsylvania and leachate concentration.

Table 2. Comparison of West Virginia and Pennsylvania standards for CCP leachate concentrations.

	Maximum acceptable Leachate Concentrations (mg/L)	
State:	West Virginia	Pennsylvania
Test Method:	TCLP	SPLP
Al		5.0
Sb	1	0.15
As	5	1.25
Ba	100	50
Be	0.007	
B		31.50
Cd	1	0.13
Cr	5	2.5
Cu		32.5
Fe		7.5
Pb	5	1.25
Mn		1.25
Hg	0.2	0.05
Mo		4.38
Ni	70	2.5
Se	1	1.00
Ag	5	
Tl	7	
Zn		125
SO4		2500
Cl		2500

Case Studies of CCPs used in Mine Environments Eastern United States Projects

Case Study 1. Winding Ridge

The Maryland Department of Natural Resources Power Plant Research Program and the Maryland Department of the Environment initiated a project in 1995 to demonstrate the use of CCPs for AMD abatement in an underground mine (Rafalko et al., 1999). The strategy was to completely fill the mine voids and replace mine water with CCP grout. The demonstration occurred at the Frazee Mine on Winding Ridge, near Friendsville, Maryland. The mine was abandoned in the 1930s and continued to produce acid drainage. By filling the mine voids, the grout was intended to minimize contact between groundwater and pyrite remaining in the mine. A grout was developed consisting of solid phase (CCPs) with acid mine water used for slurry makeup. The grout was injected into both dry and inundated portions of the mine.

The grout consisted of FGD material and Class F fly ash from Virginia Power Company's Mount Storm power plant and FBC ash from Morgantown Energy Associates' Morgantown power plant. The FGD material, containing mostly calcium sulfite and calcium sulfate and no free lime, was used as an inert filler. The Class F ash was used as a pozzolan while the FBC ash was used as the cementing agent. The grout contained approximately 60% fresh FBC

(<24 hours old), 20% FGD, and 20% Class F fly ash. The FBC ash arrived from the power plant containing about 15% moisture. The final design mix yielded 8 inches of spread using ASTM PS 28-95, and a 28 day unconfined compressive strength of 520 pounds per square inch (psi) as determined by ASTM C 39-94.

Prior to injection, the grout was subjected to a Toxicity Characteristic Leaching Procedure or TCLP for non-organics. None of the analytes exceeded their respective regulatory limits for characterization as a hazardous waste.

During the fall of 1996, more than 5,600 cubic yards of grout were injected into the mine. The original design was for 3,900 cubic yards but additional void space was encountered and grouted. During the injection it became apparent that the Frazee Mine was larger and more complex than determined during the mine characterization phase. As a result, the mine was not completely filled and the mine continues to produce AMD.

The mine's discharge pH remained around 3.0 during and after grout injection while Ca, Na, and K concentrations increased by nearly an order of magnitude (Aljoe, 1999). Sulfate, Cu, Ni, Zn, and Cl all nearly doubled with both Ni and Zn in excess of water quality discharge limits. Both Ni and Zn had exceeded water quality limits prior to injection. Two years after injection, however, concentrations of both Ni and Zn were at or slightly above pre-injection levels (Table 3).

Table 3. Summary of pre and post injection water quality at the Frazee Mine, Friendsville, Maryland. The data are for samples taken and analyzed by the USDOE Federal Energy Technology Center. (All values in mg/L)

RCRA Element	TCLP Limit	EPA Drinking Water)	Pre-CCB n=18	Post-CCB n=15
Sb	1	0.006	<0.2	<0.2
As	5	0.05	<0.2	<0.2
Ba	100	2	0.029	<0.02
Be	0.007	0.004	<0.02	<0.02
Cd	1	0.005	<0.02	<0.02
Cr (6+)	5	0.1	0.03	0.04
Pb	5	0.015	<0.02	<0.02
Ni	70	0.01	0.62	1.13
Se	1	0.05	<0.5	<0.5
Al			37	56
Ca			25	223
Cl			2.3	7.3
Co			0.3	0.5
Cu			0.08	0.25
Fe			67	67
Mg			26	32
Mn			2.7	2.8
K			0.9	13.3
Zn			1.4	2.3
Na			1	8
SO4			564	1182

In September 1997, nine core holes were drilled into the Frazee Mine to recover grout. The core hole locations targeted previously wet and dry sections of the mine. The grout samples were submitted to the laboratory for testing of density, permeability (hydraulic conductivity), and unconfined compressive strength. Grout was encountered at five holes. In general, the cores showed little sign of in situ weathering and displayed good mine roof and pavement contact. Cores recovered from the grout after one year yielded permeabilities between $1.89\text{x}10^{-6}$ and $6.02\text{x}10^{-8}$ cm/sec.

The measured permeabilities range from 6.02×10^{-8} to 1.89×10^{-6} cm/sec. Core hole 1 matched the target strength in the 28 day laboratory test. The other holes all had approximately twice the strength achieved in the laboratory after 28 days.

The behavior of calcium and sulfate after injection was significantly different than that of acidity, iron and aluminum. Calcium concentrations increased by a factor of 3 to 6 and remained at these levels for more than 16 months after injection. Sulfate levels remained at about twice the pre-injection level. These persistent increases in calcium and sulfate can probably be attributed to the dissolution of these ions from the injected FBC and FGD materials. Trends in sodium, potassium, and chloride concentrations were similar to those of calcium. It is likely that their elevated concentrations resulted from some grout dissolution.

Also note that prior to injection the grout itself was subjected to a TCLP. The results were that arsenic and barium were found at levels of 0.13 and 0.11 mg/l, respectively. Post grouting water quality of the mine discharge did not detect these constituents (the detection limit for arsenic in the mine water was 0.2 mg/l but the detection limit for barium is one order of magnitude below the TCLP result). The data show that with the exception of a short-term increase in Ni and Zn, no toxins are leaching from the ash even though the ash is dissolving due to acid attack. The permeabilities exhibited by the ash (see Table 2) would indicate that the grout could withstand surface attack for some time.

The grout was placed under nearly worst case conditions: there was insufficient grout placement to neutralize acid in the mine water and as a result it was subjected to continuous weathering by pH 3.0 water. Further, the flow of this water through the mine was unhindered. The objective of such mine grouting projects is to occlude voids and eliminate mine drainage. This project, however, represents a case where this objective was not achieved and the grout was subject to a high flux, chemically aggressive mine water.

Case Study 2. Mettiki Coal, Underground Mine Back Stowing

In December 1996, Metikki Coal Corporation began injecting a mixture of non-fixated flue gas desulfurization solids (FGD), AMD metal precipitates, and fine coal refuse into its underground coal mine near Redhouse, Maryland. Materials are mixed in a specially designed building with slurry water added and monitored in the receiving bin directly underneath the truck loadout. The slurry is injected at about 15% solids content. There is some unreacted lime in both the FGD and the AMD sludge, which would dissolve in the thin slurry. CCBs are injected into an inactive section of the mine and to date about 320,000 tons of CCB have been injected. The CCBs enter the low point in a synclinal structure and displace an otherwise acid mine pool. The FGD solids are not fixated and are not expected to solidify. On the other hand, since they are placed in the low point of the mine and well below regional drainage, the ambient mine water is expected to be stagnant. Thus, stratification of water layers above the CCBs is likely to occur with minimal mixing. Water has been sampled and analyzed since prior to injection of CCBs and these data are summarized in Table 4. Chloride was expected to be the most sensitive ion as the FGD solids have between 10,000 and 30,000 mg/l Cl. As chloride is an anion and extremely soluble it has been monitored closely. Maryland set a discharge limit of 860 mg/L on chloride.

Chloride concentrations remain well below the Maryland limit of 860 mg/L, averaging about 120 mg/L. This is nevertheless, above the pre-injection level of 3 mg/L. Other than roughly 30% increase in sulfate concentrations, the injection has had little effect other than to increase the alkalinity in the mine pool. This has caused the pH to increase from about 3 to 4.5 while Al and Fe have both dropped substantially. Prior to discharge, mine water is treated in a high density lime treatment system and discharged through a polishing pond to the NPDES monitoring point. Trout are successfully raised in the polishing pond. They are exceptionally sensitive to chloride.

Case Study 3. Clinton County, Pennsylvania. Fran Contracting, Surface Mine Grouting and Capping for AMD Control

Between 1974 and 1977 a 37 acre surface coal mine was mined and reclaimed in Clinton County, Pennsylvania. Pyrite rich pit cleanings and refuse were buried in the backfill, producing severe acid mine drainage. The pyritic material was located in discrete piles or pods within the backfill. The pods and initial contaminant plumes were identified using geophysical techniques confirmed by drilling.

Table 4. Water Quality data from Metikki FGD Underground Injection. (All values in mg/L)

RCRA Element	TCLP Limit	EPA drinking water	Pre-CCB injection Tons added 0	Post-CCB injection Tons added 51,716
Sb	1	0.006	<0.05	<0.05
As	5	0.05	<0.025	<0.025
Ba	100	2	0	0.033
Be	0.007	0.004	<0.0025	<0.0025
Cd	1	0.005	<0.0025	<0.0025
Cr (6+)	5	0.1	<0.0075	<0.0075
Pb	5	0.015	<0.025	<0.025
Hg	0.2	0.002	na	na
Ni	70	0.01	0.139	0.195
Se	1	0.05	na	na
Ag	5		<0.0025	<0.0025
Tl	7	0.002	<0.13	<0.13
Al			0.4	1.3
Ca			224	541
Cl	860		2.2	200
Co			0.1	0.14
Cu			0	0.0095
Fe			39	34
Mg			50	84
Mn			2.7	4.8
K			7.4	10.2
V			<0.0050	<0.005
Zn			na	0.27
Na			77	79
SO4			830	1346

Three approaches were taken to abate AMD: 1) direct injection of an FBC ash grout into and around the pyritic pods, 2) capping the affected area with FBC ash, and 3) a combination of the first two approaches. The first approach was tried at every pod. If the pod was too impermeable to accept the grout, the area directly above was capped to minimize contact between surface water and pyritic waste. In several cases the area around the non-receptive pod was grouted to divert groundwater flow. The project has been described in detail by Schueck, et al., 1996.

For performance monitoring, forty two wells were drilled on and adjacent to the site. Well location was guided by the results of geophysical mapping techniques. Wells located on the site were drilled through the spoil to the pit floor while wells located adjacent to the site were drilled to the unmined lower split of the Lower Kittanning coal seam. The initial drilling confirmed the locations of the pods previously identified by geophysical methods.

Pressure grouting resulted in reductions of acid mine drainage. Acidity from the pods was reduced by 23 to 52%. Significant reductions in trace metal (Cd, Cu, and Cr) concentrations from 42 to 88% also were observed. Wells down gradient of the grouted pods exhibited 16 to 37% reductions in mean concentrations of the common AMD parameters. The exception was sulfate which remained unchanged. Significant trace metal reductions also were noted in down gradient wells.

Where a surface cap of FBC ash was applied, results were mixed. Decreased infiltration from the cap may have abated some of the AMD occurring in the upper portion of the pod but the lateral flow of water along the pit floor was sufficient to create and mobilize AMD. Wells down gradient of capped pods displayed significant reductions in mean concentrations of AMD parameters (29 to 34%).

Where both grouting and capping were employed, there were significant decreases in mean concentrations (42 to 64%) of AMD parameters. The data suggested a reduction in AMD production within the pod and reduced migration of mine drainage down gradient of the pods.

The pods which were treated with injection and capping produced the most favorable results, followed by injection only. Capping alone produced the least favorable results. The combined approach inhibits contact between water, oxygen, and pyrite by limiting infiltration and diverting lateral flow around the pods. Injection limits contact via lateral flow but vertical infiltration is uninhibited. Although percent reductions in mean concentrations vary, concentrations of AMD parameters generally decreased by 30 to 40% and the reduction of trace metals was typically higher. This is significant given that only 5% of the site was grouted. Any change in water quality is expected to be permanent because of the pozzolanic nature of the FBC grout. It was known that the entire site generated AMD and there was no intention of eliminating AMD production. The objective was to prove the effectiveness of the FBC in reducing pollutant loadings discharging from the site while evaluating the potential for increasing concentrations of toxic elements.. Table 5 summarizes pre- and post-FBC monitoring data at well T-34, down gradient of a section of the mine which had been capped and grouted with FBC ash.

Despite less than total success at AMD abatement, the investigators concluded that injection grouting is a viable AMD abatement technique worthy of application on sites which meet certain criteria. The technique would be most appropriate at reclaimed surface mines where the spoil is net alkaline but where improper placement of acidic materials (pit cleanings or refuse) resulted in an acidic discharge. In addition to reclaimed sites, the use of FBC is recommended on active surface mines and refuse disposal sites as a preventative measure. FBC ash can be directly applied to or mixed with refuse and pit cleanings to create monolithic structures capable of diverting water away from pyritic materials.

Table 5. Pre-Grouting Mean Water Quality at the Clinton County Pennsylvania spoil site capped with FBC ash. In addition, an FBC ash grout was used to isolate pyritic pit cleanings from groundwater.

RCRA Element	TCLP Limit (mg/L)	EPA Drinking Water (mg/L)	Pre-CCB (mg/L)	Post-CCB (mg/L)
			n=7	n=14
Sb	1	0.006		
As	5	0.05	0.177	0.0374
Ba	100	2	0.029	0.0455
Cd	1	0.005	0.132	0.0064
Cr (6+)	5	0.1	0.435	0.0394
Other Ions				
Al			425.14	28.36
Ca			76.44	42.69
Cu			1.84	0.0769
Fe			1193.57	124.46
Mg			87.13	14.47
Mn			63.085	50.453
Zn			7.536	0.614
Na			1.33	3.66
SO4			5513.41	430.07

Case Study 4. Chaplin Hill Mine, West Virginia. Ash for Pit Floor Sealing and Surface Capping

At the Chaplin Hill Coal Mine near Morgantown, WV, a series of surface mine pits were treated with FBC ash to control AMD. Pits in the same geological sequence had historically produced AMD due to a pyritic pit floor and pyritic units within the overburden. In 1991, the company adopted the practice of laying a 1 ft. thick layer of FBC ash on the pit floor and compacting it prior to backfilling. In addition, another 1 ft lift of FBC ash was placed on the graded spoil and compacted prior to topsoil application. All pits thus treated have not generated AMD and have no need for water treatment. Table 6 summarizes the water quality from pits completed prior to FBC ash application and after.

Table 6. Summary of pre- and post-CCP application water quality at the Chaplin Hill Mine, Morgantown, West Virginia. The data are for samples taken and analyzed by Anker Energy Corporation and reported to the state of West Virginia. (All values in mg/L)

RCRA Element	TCLP Limit	EPA Drinking Water	Pre-CCB	Post-CCB
Sb	1	0.006	0.94	0.40
As	5	0.05	1.28	<0.1
Ba	100	2	<0.1	<0.1
Be	0.007	0.004	0.96	<0.1
Cd	1	0.005	<0.1	<0.1
Cr (6+)	5	0.1	0.0001	0.0001
Pb	5	0.015	0.72	<0.1
Hg	0.2	0.002	<0.0005	<0.0005
Ni	70	0.01	1.16	<0.1
Se	1	0.05	1.29	<0.1
Ag	5		<0.1	<0.1
Tl	7	0.002	2.68	1.21
Al			36	<0.1
Ca			450	750
Fe			4	<0.1
Mg			296	450
Mn			47	0.2
SO4			2022	1500

The data indicate elimination of AMD with no significant increase in toxic element concentrations.

Midwestern Projects

The following case studies describe several projects where CCPs were used in mine land reclamation. The projects have been described in detail by Paul et al., 1996.

Case Study 5. Illinois Direct Water Treatment Using FBC Ash

Another project investigated by Paul et al., 1996 introduced 150 tons of FBC ash into a 2 million gallon pond of pH 2 mine water. The pond was carefully monitored during and after the dose of FBC ash. Iron and aluminum precipitated and the pH rose while metal concentrations fell about an order of magnitude. No toxic metal contamination from the ash was detected. The same result was observed for arsenic which can be mobilized by acidic conditions even though the solubility of arsenic decreases very little as water is neutralized. This experiment suggests that in acidified mine waters already containing toxic metals, any release from FBC ash would be more than compensated by the precipitation of metals due to the neutralizing effects of the ash.

Conclusions

The use of CCPs as mine backfills has been beneficial in some settings, neutral in others, and harmful in yet other settings. While each setting and CCP form a unique set of circumstances requiring individual analysis and evaluation, several generalizations can be made.

1. As mine fills, CCPs are used to: neutralize acid groundwater, encapsulate toxic materials, bring the land surface to approximate original contour, prevent subsidence, and control hydraulic pressure buildup in underground coal mines.
2. CCP mine fills introduce an alkaline component into the mine fill. In acid environments this can be beneficial. By neutralizing acid, metal laden water, CCPs tend to cause metals to precipitate, lowering the concentrations of nearly all metal ions. No case was found in which metal loadings increased beyond either TCLP or drinking water limits due to the application of CCPs in mine backfill. Neutralization of mine spoil or refuse is best accomplished by blending the CCP with pyritic materials in appropriate ratios.
3. In already neutral or alkaline groundwater environments, CCPs can exacerbate soil salinity problems.
4. The extent of positive or negative impacts is a function of the groundwater flux through the CCP, its chemistry and the chemistry of the mine groundwater.
5. Water flux is governed by local hydrology and the permeability of the CCP. In flat, arid regions water flux due to precipitation may be negligible while flux along the mine pit floor may be high and regional. In mountainous, humid areas precipitation driven flux can be very high while groundwater flux is high but localized.
6. Some CCPs can be compacted or formulated as grouts such that they are nearly impermeable to water.

In mines suffering from acid mine drainage (AMD), most CCPs containing lime have positive effects. In nearly all cases, acid and metal loadings are substantially reduced or eliminated. Toxic element concentrations either decrease or increase to levels well below TCLP and even drinking water standards. In arid, alkaline mines, care should be taken to ensure that groundwater flux is minimized either by compaction/solidification or by keeping the CCPs above the re-established saturated zone above the pit floor.

Non-fixated FGD materials contain almost no neutralization potential and are presently not very useful in mine land reclamation. The non-fixated materials typically exhibit a high permeability, as well. However, fixated FGD contains excess alkalinity with low permeability. Fixated FGD materials can be useful in acid mine drainage abatement, subsidence control, high volume backfills, and as a barrier material to encapsulate acidic materials or seal pit floors on surface mines. Both materials can contain high chloride levels that are concentrated in the flue gas desulfurization units.

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