Alkaline Addition Techniques in the Prevention of Acid Mine Drainage

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Introduction

Recent studies have indicated that certain types of alkaline amendments can successfully control acid mine drainage (AMD) from pyritic spoil and refuse (Brady et al., 1990; Perry and Brady, 1995; Rich and Hutchison, 1990; Rose et al., 1995). Nearly all alkaline amendment schemes rely on Acid-Base Accounting (ABA) to identify the required alkalinity for neutralization of pyritic materials. Alkaline amendment methods are a modification of the concept of selective handling. Selective handling seeks to blend acid-producing and acid-neutralizing rock units in the mining process to develop a neutral rock mass. Selective handling may also create a postmining hydrologic regime that minimizes the contact between acid-forming rock and groundwater, or it may isolate acid-producing rocks from the rest of the backfill by use of barriers.

Accurate, representative overburden analyses before mining are crucial in developing mining plans and alkaline addition programs in acid-producing areas. Therefore, it is best to generate cost-effective control strategies when acid problems are identified during premining planning. Errors in predicting postmining water quality from premining overburden analyses include unrepresentative sampling of overburdens and inaccurate analyses (Rymer et al., 1991; Wiram and Naumann, 1995), and non-homogeneous placement of spoils. For example, Schueck (1990) reported AMD generation from a surface mine in Pennsylvania resulted largely from buried refuse and pit cleanings within an otherwise neutral to alkaline spoil matrix as identified by ABA.

Some spoils are composed of a mixture of acid-forming and alkaline rocks, while other materials like refuse are dominated by acid-producing rocks with no NP. In spite of significant alkalinity in overburdens, AMD originates from localized sites within the backfill. While finding the path of least resistance to the downstream side of the backfill, infiltrating water is influenced only by acid and alkaline rocks directly in its path. If water flows primarily through permeable acid sandstones, AMD can result, and the water flows freely to the nearest stream while the alkalinity in the pile remains unreacted. Unless contacted directly by acid water, most of the spoil limestone will remain in solid form. Thus, the presence of alkalinity in the backfill does not ensure that it will neutralize acidity. For efficient neutralization, the acid-forming and alkaline material must be thoroughly mixed.

In the eastern USA coal fields, the pit floor is often rich in pyrite, so isolating it from groundwater may be necessary. Isolation methods can include building highwall drains which move incoming groundwater away from the pit floor or placing impermeable barriers on the pit floor. For example, acid-forming material can be compacted or capped within the spoil (Meek, 1994). If insufficient alkalinity is available in the spoil, then external sources of alkalinity may be imported (Skousen and Larew, 1994; Wiram and Naumann, 1995).

Limestone is often the least expensive and most readily available source of alkalinity. It has a NP of between 75 and 100%, and is safe and easy to handle. On the other hand, it has no cementing properties and cannot be used as a barrier.

Fluidized Bed Combustion (FBC) ash is produced at power generating plants that burn high sulfur coal or refuse in a FBC system. Sulfur dioxide emissions are controlled by injecting limestone into the combustion bed. At combustion temperatures, the limestone calcines leaving calcium oxide. About one-half of the CaO reacts with sulfur dioxide to form gypsum and the rest remains unreacted. Therefore, FBC ashes generally have NPs of between 20 and 40%, and they tend to harden into a cement after wetting (Skousen et al., 1997). Other power-generation ashes, like flue gas desulfurization products and scrubber sludges, may also have significant NP, which make them suitable alkaline amendment materials (Stehouwer et al., 1995).

Other alkaline materials, such as kiln dust and steel-making slags, may have higher NPs than limestone, but the source of the material should be checked and a complete analysis should be done to evaluate NP and metal content before use. Quicklime, kiln dust and hydrated lime all have higher activities than limestone, though it is not clear that the kinetics of pyrite oxidation favor readily soluble sources of alkalinity.

Accurately predicting the amount of a particular alkaline amendment to add in a certain situation has significant cost and long-term liability implications. diPretoro and Rauch (1988) found sites with >3% NP as calcium carbonate equivalent in overburden produced alkaline drainages, while acidic drainage resulted at < 1% NP. Brady and Hornberger (1989) suggest threshold values of NP > 3% and S < 0.5% as guidelines for delineating alkaline-producing strata. Brady et al. (1994) showed that 3% net NP in an overburden caused alkaline drainage while less than 1% net NP produced acidic drainage from 38 mines in PA. They concluded that mining practices (such as selective handling, and concurrent reclamation) enhanced the effect of alkaline addition on reducing acidity. Further refinements (Perry and Brady, 1995) gave a value of 21 tons/1000 tons net NP (or 2.1%) to produce alkaline drainage on 40 sites in Pennsylvania. Alkaline addition of lime kiln dust at rates to neutralize the MPA was successful in producing alkaline drainage from a Pennsylvania site after mining (Rose et al., 1995).

It appears that material mixtures with an NP/MPA ratio above 2 and a net NP above 30 Mg/1000 Mg (3% net NP) generate alkaline water. Even at high NP/MPA ratios, acidity may be produced if the acid-producing materials are incorrectly placed so that they intercept groundwater, or the alkaline material is added only to the surface (Lusari and Erickson, 1985). Thorough mixing during materials handling can reduce the required NP/MPA ratio considerably.

Adding alkalinity to spoil requires special care during mining and reclamation. The high volume of spoil necessitates applying alkalinity only to those rock masses that need it (like coal roof rock, partings and pavement). Surface mining operations can remove this rock with front end loaders after the prime excavator exposes the coal and place the acid-producing material in cells in the backfill for treatment with an alkaline amendment (Skousen and Larew, 1994), or it can be removed directly and placed in refuse piles. Often the final pit floor contains considerable pyrite, much of it within 30 cm of the coal. Three approaches can be taken: 1) remove the pyritic material and place it in cells for alkaline amendment, 2) apply heavy amounts of lime to neutralize the pit floor, or 3) seal the pit floor with a self-cementing material such as FBC ash.

This paper discusses one mine site in northern West Virginia where the Kittanning coal seam was surface mined in a historically acid-producing area. Computer spreadsheets developed by the Pennsylvania Department of Environmental Protection (PADEP) were used to evaluate site-specific ABA data and to compute alkaline addition rates. Documented amounts of alkalinity were added and mixed with the overburden during backfilling and reclamation. Also additional acid-producing materials encountered on the site were also removed to a refuse area. Liming of the pit floor was also practiced. Finally, quality of leachate water is provided for three contiguous areas, where each received three different levels of alkaline addition.

Study Site Descriptions and Results

This site was first mined by New Allegheny, Inc. (NAI) on Permit No. S-2007-89 (Job 88). The Acid-Base Account of the disturbed strata is shown in Table 1. During mining and reclamation of Job 88, no special handling or alkaline addition was practiced. In 1994, NAI applied for Permit S-2007-93 (Job 90), which was just to the north (but downgradient) of Job 88. At that time, due to concerns by the West Virginia Division of Environmental Protection (WVDEP) of poor water quality coming from Job 88, a complex material-handling plan was developed for the site. Potentially toxic strata (PTS) were identified in the Acid-Base Account and are marked in Table 1. This plan for Job 90 was approved and the permit issued. NAI mined on this permit until February 1997, when Vindex Energy Corporation assumed control of the operation. During the time that NAI mined on both Job 88 and Job 90, the primary stripping equipment was comprised of a dragline and dozers.

Vindex assumed control of the site in February 1997 and completed reclamation on Job 90 in the spring of 1998. Following reclamation, the quality of water seeping from an artesian borehole (DH-66) located at the lowest end of Job 90 began to show signs of degradation.

A new permit was issued to Vindex Energy in July 1997 (S-2001-96) for a site to the south of Job 88. This site, known as the Job 88 Extension, began to be mined during the summer of 1997 using the special handling plan designed for Job 90. In addition to the special handling plan, about 174 tons of limestone fines were placed on the pit floor. Primary excavation equipment consisted of dozers and a hydraulic excavator with 50-ton rock trucks, instead of a dragline. In spite of the material handling plan, liming the pavement, and the use of different equipment on Job 88 Extension, the site produced alkaline mine drainage with high iron concentrations.

In order to continue mining on an adjacent permit (Vindex 3, S-2008-98), additional special handling was practiced, including the removal of potentially toxic strata (PTS) and the import of alkaline material. Two PADEP overburden analysis spreadsheets are shown (Figures 1 and 2) giving maximum potential acidity (MPA), neutralization potential (NP), and net NP values. Figure 1 shows these values without alkaline addition. Figure 2 shows these values with the addition of 2000 tons/ac of limestone fines at 90% calcium carbonate equivalent and the removal of 95% of PTS.

A review of records for 1996 shows that the PTS hauled from Job 90 by NAI was 8.4% of the clean coal tonnage for that year. In 1997, the PTS tonnage hauled from Job 90 by Vindex was 32% of the clean coal tonnage. At the Job 88 Extension during 1998, the PTS hauled to the refuse site equated to 49% of the clean coal tonnage. So, almost six times more PTS was hauled from Job 88 Extension in 1998 compared with 1996.

From May to November 2000 at the Vindex 3 site, about 11.5 acres were mined and 23,822 tons of lime were applied to the site (Table 2). This is slightly more than the 23,000 tons required by the permit. In addition, 82,825 tons of PTS were hauled from the site to the refuse pile, comprising more than 90% of the clean coal tonnage.

Due to the geology and structural contours of the coal pavement, groundwater from Jobs 88 and 90 flow north to a groundwater well, DH-66. Groundwater from the Job 88 Extension flows to the south, and a 48-inch diameter well was installed in August 1998 near the downgradient end of Job 88 Extension to capture groundwater. An additional 48-inch diameter well was installed at the downgradient end of Vindex 3. Water quality from the three areas has been collected and is shown in Table 3.

The data shows high acidity and high iron in groundwater from Jobs 88 and 90. At Job 88 Extension, where special handling was practiced, pH of the water shows neutral water with no acidity, but some iron and alkalinity. At Vindex 3, the pH is 7.5, alkalinity is above 100 mg/L, and iron is < 0.5 mg/L.

It seems apparent that special handling was required in order to mine these areas since acid mine drainage resulted where no special handling was conducted. On Job 88 Extension, special handling and the 174 tons of limestone added to the pit floor was not sufficient to stop the formation of acid mine drainage at the site, but was sufficient to neutralize the acid drainage, thereby causing alkaline mine drainage. However, reduced ferrous iron was found in groundwater and evidently was not precipitated in the backfill. Upon oxidation, ferrous iron converts to ferric iron and then rapidly drops out of solution in a settling pond. On Vindex 3, special handling, along with removal of PTS and the addition of 2000 tons of lime/ac resulted in alkaline drainage and no iron in the groundwater.

The amount of alkaline material as determined by the PADEP spreadsheets (Figures 1 and 2) appear to be correct in controlling and eliminating the acid mine drainage from the site. Further study is needed in determining reasons for alkaline mine drainage containing high iron concentrations and perhaps the levels of alkaline addition to maintain alkaline water, but with no iron.

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Table 2. Monthly Alkaline Amendment Report at the Vindex 3 surface mine.

Date	Pit Area	Lime Required	Lime Applied	PTS Removed
	acres	---- tons	----	----
May 2000	1.89	3,780	4,092	10,426
June 2000	2.04	4,080	4,185	4,986
July 2000	2.19	4,380	4,835	7,920
Aug 2000	2.17	4,340	4,380	15,013
Sept 2000	1.29	2,580	2,580	25,223
Oct 2000	1.15	2,300	2,310	17,592
Nov 2000	0.74	1,480	1,480	1,666
Totals	11.50	22,940	23,822	82,825

Table 3. Water quality from three groundwater wells, which represent the quality of groundwater from Jobs 88 and 90 (where there was no special handling), Job 88 Extension (with special handling and 174 tons of limestone on the pit floor), and Vindex 3 (with special handling, 2000 tons of alkaline amendment, and removal of PTS).

Site	pH	Alkalinity	Acidity	Total Iron
	s.u.	----- mg/L as $CaCO_3$	-----	mg/L
Job 88-90				
DH-66	5.2	4	496	325.4
Job 88 Extension				
48" Pipe	6.3	150	0	82.0
Pond Entrance	7.1	36	0	10.3
Pond Discharge	7.1	18	0	0.5
Vindex 3				
48" Pipe	7.5	161	0	0.3
Pond Discharge	7.4			0.3

Sturm Environmental Services

Co. : Vindex Energy, Inc.
Site: Hole NA-41-97
Date: 8/10/98

ACID-BASE ACCOUNT

Calcium Carbonate Equivalent Tons/1000 Tons of Material

Sample Number	Depth (Feet)	Strata Thick. (Feet)	Rock Type	Fiz	Color	% S	Max From % S	N.P.** $CaCO_3$ Equiv.	Max Needed (pH-7)	Excess $CaCO_3$	Paste pH
71	343.9-347.6	3.7	SH	2	2.5Y 5/2	.001	.03	22.02		21.99	7.1
72	347.6-353.3	5.7	SS	1	2.5Y 6/2	.081	2.53	16.33		13.80	5.9
73	353.3-359.0	5.7	SS	0	2.5Y 6/2	.101	3.16	.97	2.19		4.8
	359.0-364.3	5.3	COAL								
74	364.3-367.0	2.7	CS	0	2.5Y 7/2	.422*	13.19	14.35		1.16	6.6
75	367.0-369.6	2.6	SH	0	2.5Y 7/2	.097	3.03	6.93		3.90	4.7
76	369.6-373.1	3.5	SH	0	2.5Y 7/1	.162	5.06	5.11		.05	5.1
77	373.1-376.5	3.4	SH	0	2.5Y 7/1	.223	6.97	8.44		1.47	5.5
78	376.5-380.0	3.5	SH	0	2.5Y 6/2	.050	1.56	6.81		5.25	5.4
79	380.0-382.9	2.9	SH	0	2.5Y 5/2	.034	1.06	7.57		6.51	5.7
	382.9-384.9	2.0	COAL								
80	384.9-385.1	.2	SH	0	2.5Y 6/1	1.71*	53.44	2.77	50.67		3.3
81	385.1-388.05	2.95	CS	0	2.5Y 7/1	1.10*	34.38	2.36	32.01		3.4
82	388.05-391.0	2.95	CS	0	2.5Y 7/2	.738*	23.06	5.34	17.72		4.4
83	391.0-395.2	4.2	SH	0	10YR 7/3	.430*	13.44	8.28	5.16		5.3
84	395.2-399.4	4.2	SH	0	2.5Y 7/1	.070	2.19	7.16		4.97	6.4
85	399.4-403.6	4.2	SH	0	2.5Y 6/1	.022	.69	7.76		7.07	6.6
86	403.6-407.8	4.2	SH	0	2.5Y 5/1	.385*	12.03	5.96	6.07		5.3
87	407.8-412.0	4.2	SH	0	2.5Y 5/1	.301	9.41	5.30	4.11		5.4
88	412.0-415.1	3.1	SH	0	2.5Y 4/1	.214	6.69	4.89	1.80		7.1
89	415.1-415.8	.7	COAL	0	2.5Y 2.5/0	3.26*	101.88	-2.36	104.24	PTS	3.5
90	415.8-416.5	.7	SH	0	2.5Y 4/1	.209	6.53	4.63	1.90		6.2
91	416.5-416.8	.3	SH	0	2.5Y 2.5/0	1.79*	55.94	7.07	48.87		5.4
92	416.8-417.5	.7	COAL	0	2.5Y 2.5/0	2.18*	68.13	3.00	65.13	PTS	4.8
93	417.5-419.0	1.5	CS	0	2.5Y 5/1	.186	5.81	4.75	1.06		7.1

*Pyritic Sulfur
**Modified H202 NP

*Corr
Page No.:
Correction
Correction

Sturm Environmental Services

Company: Vindex Energy, Inc
Site: Hole NA 41-97
Date: 8/10/98

ACID-BASE ACCOUNT

Calcium Carbonate Equivalent Tons/1000 Tons of Material

Sample Number	Depth (Feet)	Strata Thick. (Feet)	Rock Type	Fiz	Color	% S	Max From % S	N.P.** $CaCO_3$ Equiv.	Max Needed (pH-7)	Excess $CaCO_3$	Paste pH
94	419.0-423.5	4.5	SH	0	10YR 6/1	.028	.88	7.05		6.18	7.5
95	423.5-428.1	4.6	SH	0	10YR 7/1	<.001	.03	13.38		13.35	7.4
96	428.1-432.6	4.5	SH	0	2.5Y 7/1	.028	.88	12.89		12.02	7.2
97	432.6-437.2	4.6	SH	0	10YR 7/1	.061	1.91	9.12		7.21	6.5
98	437.2-441.7	4.5	SH	0	2.5Y 7/1	.140	4.38	8.71		4.34	6.1
99	441.7-446.3	4.6	SH	0	5Y 7/1	.109	3.41	7.81		4.40	6.4
100	446.3-450.8	4.5	SH	0	2.5Y 6/1	.136	4,25	8.15		3.90	6.7
101	450.8-453.9	3.1	SH	0	2.5Y 5/1	.355*	11.09	6.68	4.41		5.1
	453.9-461.7	7.8	COAL								*
~~102~~	~~461.7-463.3~~	~~1.6~~	~~SH~~	~~0~~	~~5Y 3/1~~	~~.844*~~	~~26.38~~	~~3.55~~	~~22.84~~		
103	463.3-466.15	2.85	SH	0	10YR 6/1	.169*	5.28	2.89	2.39		4.6

Figure 1. Overburden analysis summary with no alkaline addition and not removal of PTS.

OPERATOR	Vindex Energy	COUNTY	Grant	COAL SEAMS: Kittanning
PERMIT NO.	2008-98	TOWNSHIP		
DRILL HOLE	NA-41-97			**Analysis with no alkaline addition and no removal of PTS**

TOTAL DEPTH	TOP ACREAGE	BOTTOM ACREAGE
116	0	26

THRESHOLD VALUES

SULFUR	NP	FIZZ
0.5	30	1

MPA, NP -TH = With Thresholds

	TONS MPA -TH	TONS MPA	TONS NP -TH	TONS NP	NET NP TONS -TH	NET NP TONS	TONS OF OB
TOTAL (TONS):	7993	27062	0	35220	-7993	8158	4440209
TOTAL (TONS/THOUSAND):	2	6	0	8	-2	2	

With Thresholds @ 31.25

MPA (Total Tons)	7993	Tons/1000 tons	2
NP (Total Tons)	0	Tons/1000 tons	0
Net Tons NP	-7993	Tons/1000 tons	-2
NP/MPA Ratio	0		
Available NP (Tons per acre)	312 **DEFICIENT**		
NP Available to achieve 0.6% NNP (Tons per acre)	1353 **DEFICIENT**		

Without Thresholds @ 31.25

MPA (Total Tons)	27062	Tons/1000 tons	6
NP (Total Tons)	35220	Tons/1000 tons	8
Net Tons NP	8158	Tons/1000 tons	2
NP/MPA Ratio	1		
Available NP (Tons per acre)	319	**EXCESS**	
NP Available to achieve 1.2% NNP (Tons per acre)	1763 **DEFICIENT**		

With Thresholds @ 62.50

MPA (Total Tons)	15985	Tons/1000 tons	4
NP (Total Tons)	0	Tons/1000 tons	0
Net Tons NP	-15985	Tons/1000 tons	-4
NP/MPA Ratio	0		
Available NP (Tons per acre)	624 **DEFICIENT**		

Without Thresholds @ 62.50

MPA (Total Tons)	54124	Tons/1000 tons	12
NP (Total Tons)	35220	Tons/1000 tons	8
Net Tons NP	-18904	Tons/1000 tons	-4
NP/MPA Ratio	1		
Available NP (Tons per acre)	738 **DEFICIENT**		

Figure 2.Overburden analysis summary using the PADEP method with 2000 tons/ac of LS fines and 95% removal of PTS from the backfill.

OPERATOR	Vindex Energy	COUNTY	Grant
PERMIT NO.	2008-98	TOWNSHIP	
DRILL HOLE	NA-41-97		

COAL SEAMS: Kittanning

Analysis with 2000 Tons/ acre limestone fines @ 90% CaCO3 and 95% removal of PTS 3

TOTAL DEPTH	TOP ACREAGE	BOTTOM ACREAGE
116	0	26

THRESHOLD VALUES

SULFUR	NP	FIZZ
0.5	30	1

MPA, NP -TH = With Thresholds

	TONS MPA -TH	TONS MPA	TONS NP -TH	TONS NP	NET NP TONS -TH	NET NP TONS	TONS OF OB
TOTAL (TONS):	7993	27062	46080	81300	38087	54238	4486289
TOTAL (TONS/THOUSAND):	2	6	10	18	8	12	

With Thresholds @ 31.25

MPA (Total Tons)	7993	Tons/1000 tons	2
NP (Total Tons)	46080	Tons/1000 tons	10
Net Tons NP	38087	Tons/1000 tons	8
NP/MPA Ratio	6		
Available NP (Tons per acre)	1488	**EXCESS**	
NP Available to achieve 0.6% NNP (Tons per acre)	436	**EXCESS**	

Without Thresholds @ 31.25

MPA (Total Tons)	27062	Tons/1000 tons	6
NP (Total Tons)	81300	Tons/1000 tons	18
Net Tons NP	54238	Tons/1000 tons	12
NP/MPA Ratio	3		
Available NP (Tons per acre)	2119	**EXCESS**	
NP Available to achieve 1.2% NNP (Tons per acre)	16	**EXCESS**	

With Thresholds @ 62.50

MPA (Total Tons)	15985	Tons/1000 tons	4
NP (Total Tons)	46080	Tons/1000 tons	10
Net Tons NP	30095	Tons/1000 tons	7
NP/MPA Ratio	3		
Available NP (Tons per acre)	1176	**EXCESS**	

Without Thresholds @ 62.50

MPA (Total Tons)	54124	Tons/1000 tons	12
NP (Total Tons)	81300	Tons/1000 tons	18
Net Tons NP	27176	Tons/1000 tons	6
NP/MPA Ratio	2		
Available NP (Tons per acre)	1062	**EXCESS**	