STEEL SLAG: APPLICATIONS FOR AMD CONTROL

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ABSTRACT

In both laboratory and field studies, steel slags were found to generate exceptionally high levels of alkalinity over extended periods. Steel slags also have high neutralization potentials and can be used as alkaline amendments to acid-producing materials. This paper discusses the alkalinity-generating capacity of steel slags, their metal leaching potential and applications for acid mine drainage control. Results indicate that steel slags can provide highly concentrated alkaline recharge to acid mine wastes. Proper design and sizing offers the potential for a low- to zero-maintenance method for treating acid mine drainage (AMD) within the spoil pile itself.

Since slags form around the melting point of iron, >2,700°F, most compounds which have a low boiling point have been driven off. Most of the residuals are encased as oxides or in a calcium-alumino-silicate glassy matrix. Fortunately, the matrix is soluble and releases calcium and manganese oxides which drive the pH above 10. Since slag is a glass in its coarser form (e.g. -1/8 in.) it will, unless compacted, maintain high permeability regardless of how much water has passed through it. Unlike lime, steel slags do not absorb CO_2 from the air and convert back to relatively insoluble calcite: $Ca (OH)_2 + CO_2 \text{®} Ca CO_3 + H_2O$. This is an extremely important property, since it means slag will generate high levels of alkalinity even after years of open storage.

Key words: *steel slag, acid mine drainage treatment*

STEEL SLAG: WHAT IS IT?

Technically, slag is nearly any solid which melts and forms a silicate glass during a metal refining process. In the power industry, slag is ash which melts and sticks to the walls or pipes of the boiler. In the base-metal industry, slags result from the smelting of various ores of copper, zinc, lead, etc. These slags can have high concentrations of heavy metals. In this paper, we are only discussing slags from the steel-making process.

In making steel, iron ore or scrap metal is melted in combination with limestone, dolomite or lime. Pure iron is soft, bends easily under loads, and has limited uses. Small amounts of carbon, nickel, manganese, and other elements turn iron into various alloys of steel. There are hundreds of grades of steel ranging from basic carbon steel to high grade stainless.

Steel making begins by reducing any metal oxides in the melt to pure iron metal, while scavenging ions such as aluminum, silicon, and phosphorous. The later three elements are bad news for steel as they cause it to become weak, brittle, or otherwise difficult to roll into sheet in a predictable way. For that matter, they make it nearly impossible to make anything useful out of iron. (Even though iron is much more readily available, its impurities caused bronze to become the metal of choice for tools after stone became obsolete.) Fortunately, our ancestors discovered that iron's imperfections could be controlled by adding limestone or dolomite. These calcium compounds mix with aluminum, silicon and phosphorous to form slag. Slag then floats to the top of the melt, is poured off, and sent to disposal. Slag starts its life at about 2,700°F and cools almost immediately.

So quickly, in fact, that very few crystals form. Rather, it forms amorphous, glassy solids ranging from fine sand to large blocks which can be extremely hard.

Enormous slag dumps can be found just about anywhere steel has been made over the past 150 years. Many of them are being processed for use as aggregate in road construction, rail ballast, and structural fill. This involves crushing and grading the slag. Much of the metallic fraction is removed with large magnets and sold as steel scrap. All of the resulting grades have applications in construction. The finest fraction (-1/8 in.) is the one of particular interest for AMD treatment. This product is referred to as slag fines. Some slag fines are further refined using the proprietary Recmix process. This involves further grinding and a hydraulic separation process. The fine grinding and flotation further remove metals which are imbedded in the glassy matrix.

Previous work at the National Mine Land Reclamation Center has centered on other low-cost alkalinity sources: kiln dusts and Fluidized Bed Combustion (FBC) ash (Skousen and Ziemkiewicz 1995). Both are effective for AMD control and both are heavily utilized. In an effort to provide the coal industry with the broadest choice of materials, we looked for other low-cost alkaline products which were available in large supply with short-haul distances to our mining districts. We have worked with slag fines produced by International Mill Service, Inc. (IMS) and Recmix, a product of Recmix of PA Inc., and found that both have a lot of promise for AMD control. The products are very different and have different applications.

PROPERTIES OF STEEL SLAG

Steel slags are glasses. Since they form at the melting point of iron, >2,700^{o}F, most compounds which have a low boiling point have been driven off. These include sulfur, selenium carbon, cadmium, lead, copper, and mercury. Most of the residuals are encased as oxides in a calcium-alumino-silicate glassy matrix. Fortunately, the matrix is soluble and releases calcium and manganese oxides which drive the pH above 10. Since slag is a glass, in its coarser form (slag fines) it will, unless compacted, maintain high (around 4.5×10^{-2} cm/sec.) permeability regardless of how much water has passed through it. Recmix, on the other hand is a much finer material and barely lets any water through (permeability ~ 1.0×10^{-6} cm/sec.). Unlike lime, steel slags do not absorb CO_2 from the air and convert back to relatively insoluble limestone: $Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$. This is an extremely important property since it means you can leave slag in the open for years and still get high levels of alkalinity.

The neutralization potentials (NP) of steel slags range from 45 to 70% (Table 1). Most of the residuals are in the form of alumino-silicates and iron oxides. Table 2 summarizes the chemical compositions of slag fines and Recmix.

WHAT CAN SLAG DO FOR ACID MINE DRAINAGE?

Alkaline leaching

AMD produced from surface-mine spoil has the potential to require treatment for many decades. Treatment costs include chemicals, manpower, and operations. Minimization of chemical costs may be achieved only by selection of the lowest cost alkaline chemical additives based on material and shipping costs. Minimization of manpower and operations costs may be achieved by reduction in either of three categories: (a) chemical handling, and application; (b) sludge removal, handling and disposal; or (c) discharge monitoring.

Limestone, the least expensive base per equivalent effectiveness, has been utilized at point-of-discharge sites using anoxic alkaline drains; however, results indicate only

partial effectiveness due to iron hydroxide fouling and/or plugging with metal/gypsum sludge. Limestone trenches or funnels, installed atop spoil rather than at AMD discharge points, have been tested by Caruccio and co-workers at West Virginia sites (Caruccio and others, 1988; Caruccio, 1995). Results indicate local and partial effectiveness, perhaps due to limits imposed by solubility of limestone in the vadose zone or to unfavorable mass-balances between alkaline recharge and strongly acidic AMD.

Nonetheless, the concept of introducing base into solution in spoil shows demonstrated potential for long-term stabilization of acid mine drainage (Nawrot and others, 1994). One major benefit of alkaline injection is neutralization *in situ* of AMD, resulting in reduced discharges of metal-most falling within NPDES compliance discharge limits, except for possibly manganese. Reduced sludge handling and disposal would result if *all* iron and aluminum in solution were removed *in situ* within the spoil as oxyhydroxides. Under these circumstances, between 95% and 98% of the total sludge load would be contained within the spoil itself, rather than being discharged as dissolved acidity. Effective *in situ* removal of metals by alkaline leakage could dramatically reduce operational costs for (a) sludge handling and disposal, and (b) monitoring.

Steel slag fines can leach extremely high levels of alkalinity over very long periods. They have the potential to serve as a highly effective alkalinity source for *in situ* AMD treatment. Column leaching studies were performed with various thicknesses of -1/8 in. IMS slag from Mingo Junction, Ohio. Two-inch-diameter columns were filled to depths from 4 inches to 24 inches and deionized water was poured through over a period of three months. Figure 1 summarizes the alkalinity concentrations of the leachate. Average porosity was in the range of 4.5×10^{-2} cm/sec., which is similar to fine gravel. Alkalinity concentrations stayed near 2,000 mg/l for extended periods, depending on the thickness of the slag layer. After a period, it fell off as the finer particles were dissolved. Eventually, concentrations of about 100 mg/l were reached, which in turn showed little tendency to decrease further. In comparison, limestone leached in a similar way will yield alkalinities near 5 mg/l. In order to reach its maximum alkalinity (under open conditions) of 80 mg/l, limestone must be kept in contact with leach water for about 12 hours.

Potential to leach heavy metals

Leaching tests were performed on slags to identify the extent to which soluble metal species would be produced. It is important to note that not all steel slags are the same. Nonetheless, similar processes-basic steel vs. specialty or stainless steels should produce slags that are at least comparable. In general, basic steel slags like Mingo Junction have lower concentrations of metals such as manganese and nickel. Recmix has even lower concentrations of metal.

We passed deionized water through a 2 in. x 24 in.-column of Mingo Junction steel slag fines. The leachate was compared to standards for the EPA TCLP test and to EPA drinking water standards. Results indicate that the slag passed TCLP limits for every element. As for drinking water, other than high pH and alkalinity, only Ni was above the EPA drinking water limit: observed 41 ug/l vs. DW standard 10 ug/l (Table 3). The same slag was subjected to a TCLP test according to EPA procedures. All leachate parameters were below the maximum allowable limits (Table 4).

Given the amount of alkalinity in steel slag, it is expected that few metals would be mobilized unless the leaching medium becomes acid. To check this, we took an acid prone coal refuse and added only one-quarter to one-half the amount of slag needed to neutralize it. Both slags used in this study were from specialty steel mills. As expected, most of the columns became acid. Nonetheless, the leachate concentrations were, in nearly every case, less than that from the untreated refuse (Table 5). Two key exceptions were nickel and manganese; both increased.

TAKING ADVANTAGE OF STEEL SLAG'S PROPERTIES

Slag leach beds

Alkalinity production from a slag leach bed is determined by the amount of fresh water available to drive the leaching process. It is important to note that slag fines leach beds will plug up if exposed to AMD or sediment. Metals will precipitate within the slag mass and cause it to stop transmitting water. Slag fines leach beds should only be used in conjunction with fresh (metal free) water. Slag beds can be constructed so as to catch sediment-free runoff or to use direct rainfall. The effluent from the leach beds can be allowed to infiltrate directly into a spoil or refuse pile to achieve *in-situ* AMD treatment or it can be combined with an AMD source to treat downstream of the spoil. Either application has potential for very low maintenance AMD treatment in either active mining or AML programs. Figure 2 shows how a leach bed might be designed.

In general, steel slag yields several hundred times more alkalinity per equal weight as limestone. Hydrated lime or quicklime will yield similar alkalinities for a short period but they expand when wet, seal off,and gradually revert to limestone. In order to be effective in a leach bed application, lime products would need periodic agitation. Table 6 indicates expected performance and volume requirements in both limestone and steel slag leach beds. Also included are expected alkalinity generation rates.

Direct water treatment

We also experimented with direct water treatment using slag. This involved placing slag directly in a stream of AMD as a replacement for lime in an Aquafix doser. We selected a site at Lenox, West Virginia, with high manganese (56 mg/l) and moderate iron (10 mg/l). This approach had mixed results. Slag fines were too coarse to dissolve quickly and very high application rates were needed to achieve treatment. Recmix, on the other hand worked well. It removed manganese at a pH of 8.7 at about twice the application rate of CaO. Table 7 shows the performance of Recmix in the Lenox trial. In addition to monitoring for Fe, Mn, and Al, we analyzed for TCLP metals. The results indicate that all of the TCLP metals dropped substantially after treatment with Recmix.

Things to avoid

Until we understand more about the leachability of various slags in acid environments, it would be wise to avoid putting them in a place which could become acid. In other words: surface applications such as caps or fresh water leaching beds will not become acid. Direct water treatment with Recmix looks promising as long as treatment is maintained. Using slag as an alkaline amendment would require care in that enough is added to ensure that the spoil or refuse never becomes acid. Given the solubility of slag=s alkalinity, this might be a promising application. Placing slag in acid underground mine pools would require a thorough understanding of the pool=s hydrology and the commitment to overwhelm its acid-producing potential.

CASE STUDY: SLAG LEACH BED DEMONSTRATION-MINGO COUNTY, WEST VIRGINIA

The site

The study focused on the Taywood Valley fill #5 (VF5). It is part of a surface coal mine in Mingo County, West Virginia. It had been reclaimed and revegetated 10 years earlier and acidic water was still discharging from the site, preventing bond release. VF5 is located in the head of a steep valley over natural ground. It is 1450 feet long and about 500 feet wide near the top. Hydrogeologic studies indicated that most of the acid water leaving the toe of VF5 came from the pit floor above its uppermost bench and flowed along the foundation to its chimney drain (Figure 3). It contains about 1.5 million cubic yards of largely sandstone spoil. The discharge water quality was mildly acid with acidity 350 mg/l and manganese concentrations of about 55 mg/l and a pH of 3.9. The company installed a series of chemical water treatment stations at a substantial construction and operations cost. The objective of the project was to develop an AMD treatment scheme which would eliminate the need for continued water treatment.

Slag leach beds were designed to take advantage of the site=s hydrogeology to deliver highly alkaline leachate from steel slag beds to the spoil water before it leaves the dump, thereby depositing most of the precipitated metal flocs within the spoil, blinding off pyrite exposures and reducing AMD generation. By using a low-cost material like steel slag, the chemical costs were substantially reduced. Also, the process was designed to be recharged by runoff, thus lowering maintenance costs. If successful, this approach could be used on any AMD-producing site which receives fresh water either through on-site runoff or runon.

The study site was chosen because its hydrogeology is well understood and because it has demonstrated a need for a long-term, low-cost water treatment alternative. Both the hydraulic characteristics of this and similar West Virginia coal spoils were studied (Maher and Donovan, 1995; Maher, 1996). Also, the large-scale groundwater flow characteristics (Frysinger, 1996) have been examined to the point that the groundwater flow pattern is well understood. This aquifer is very heterogeneous in local permeability distribution but, importantly to *in situ* treatment on a large scale, it behaves like a continuous aquifer.

As a result of the earlier work on the site, there is an established monitoring network for the major seeps and there are several monitoring wells on the property. Nearly all of the spoil water exits at a single point at the toe of the spoil.

Design

VF5 was constructed with a rock core drain running along its center line. At its highest point, it is about 20 feet below the pit floor. The pit was backfilled with interburden and spoil and now local height of land. Slightly above the pit floor level, a diversion ditch (1100 feet long x 10 feet wide x 4 feet deep) had been constructed to route runoff water away from the head of VF5. Over the years, the ditch developed standing water in a number of locations and tracer studies indicated that it communicated with VF5's discharge. Surface flows to the ditch were estimated and used to design a steel slag leach bed. Table 8 indicates the key design parameters.

In July 1997, the company brought in a backhoe to muck out the diversion ditch to an average depth of about 5 feet. 1,200 tons of IMS Mingo Junction steel slag were placed in the diversion ditch above VF5 on July 31, 1997. The slag was placed in a 2-foot-thick bed and the surface of the bed was concave so that water would flow through the slag bed rather than out the sides. The overall arrangement is depicted in Figure 4.

RESULTS

The following results summarize nine months of monitoring the discharge of VF5. While the slag leach bed was expected to neutralize 33% of VF5's acidity, reductions of 85% were achieved (from 350 to 50 mg/l). Meanwhile, pH increased from 3.8 to over 5. Manganese concentrations dropped from 55 to 12 mg/l (Figure 5). The elements used to assess the TCLP test are tested monthly. None were detected at levels which would indicate concern vis a vis TCLP standards (Table 9).

The results suggest higher alkalinity production levels than expected and extremely high efficiencies. We will monitor the site for the next several years to assess the longevity of the treatment.

CONCLUSIONS

Due to their alkalinity generation, transmissivity, low cost, availability, and safety, steel slags can provide long-term passive, *in situ* treatment of acid mine drainage with little or no maintenance. Issues such as longevity remain to be answered but the results of a nine month operationally scaled field are promising.

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Table 1. Neutralization potential of various steel slags. Those in bold are either near Taywood or accessible via barge/truck from source.

		Neutralization Potential	
Steel Slag Type	**Supplier**	**(%)**	**Tons/1000 tons**
C fines, Mingo Jct., OH	IMS	78	780
C fines, Weirton, WV	IMS	77	770
Slag fines 1/2 x 0, Weirton, WV	IMS	76	760
Fallen slag: Cartech, Reading, PA	IMS	71	710
Fallen slag: Lukens, Coatsville, PA	IMS	70	700
Recmix, Washington, PA	Recmix	69	690
Slag fines - 1/8 in., Mingo Jct., OH	IMS	66	660
EAF: Waylite, Johnstown, PA	Waylite	59	590
Slag fines - 1/8 in., Hecate, Ashland, KY	Hecate	59	590
Slag fines - 1/8 in., USX, Fairfiled, AL	Vulcan	53	530

Table 2. Total element compositions of Recmix and Mingo Junction slag fines.

Element	Recmix (mg/kg)	Mingo Jct. Slag Fines (mg/kg)
Al	21,625	29,200
As	6	<3
Ba	130	34
Be		<3
Cd	5	67
C		4,300
Ca	297,320	501,000
Cr	1,988	1,227
Cu	30	75
Fe	8,327	284,000
Pb	14	84
Mg	57,162	98,000
Mn	9,252	70,000
Hg	0.05	<1
Mo	87	36
Ni	157	12
P	74	8,260
K	325	<100
Sb		<3
Se	5	<3
Si	142,196	85,000
Ag	5	<3
Na	299	
S	1,805	1,492
Tl	3,285	6,000
Tl		<3
Zn	61	80

Table 3. Summary of metal analyses, Mingo Junction steel slag leached with deionized water.

		TCLP			EPA Drinking Water		
		Limit	**Pass**	**Comments**	**Limit**	**Pass**	**Comments**
pH	11.7	5 mg/l		no limit			no limit
Cond.	4780 uS			no limit			no limit
alkalinity	1450 mg/l			no limit			no limit
As	<0.05 mg/l	5 mg/l	yes		50 ug/l	yes	
Se	0.05 mg/l	1 mg/l	yes		50 ug/l	yes	
Ba	0.02 mg/l	100 mg/l	yes		2000 ug/l	yes	
Cd	<0.001 mg/l	1 mg/l	yes		5 ug/l	yes	
Cr	0.03 mg/l	5 mg/l	yes	our analysis includes Cr(3+ and Cr6+)	100 ug/l	yes	our analysis includes Cr(3+ and Cr6+)
Cu	0.058 mg/l			no limit			no limit
Pb	0.1 mg/l	5 mg/l	yes		15 ug/l	yes	
Ni	0.041 mg/l	70 mg/l	yes		10 ug/l	no	
Zn	<0.002 mg/l	1 mg/l	yes		6 ug/l	yes	
V	<0.05 mg/l			no limit			no limit
Tl	<0.055 mg/l	7 mg/l	yes		2 ug/l	?	Below ICP detection limit
Be	0.0013 mg/l	0.007 mg/l	yes		4 ug/l	yes	
Tl	<0.05 mg/l			no limit			no limit
Sb	0.08			no limit			no limit
Mo	0.008 mg/l			no limit			no limit
Ag	<0.005 mg/l	5 mg/l	yes				
Hg	<0.0003 mg/l	0.2 mg/l	yes		2 ug/l	yes	
SO4	1.6 mg/l			no limit			no limit

Table 4. TCLP test results, Mingo Junction slag fines.

Element	Concentration (mg/kg)	Detection Limit (mg/kg)	Maximum Allowance (mg/kg)
As	BLD	<0.005	5.0
Ba	BLD	<0.005	100.0
Be	BLD	<0.005	NL
Cd	BLD	<0.005	1.0
Cr total	0.047	<0.010	5.0
Cu	0.017	<0.005	NL
Pb	0.006	<0.005	5.0
Hg	BLD	<0.001	0.2
Ni	BLD	<0.005	NL
Sb	BLD	<0.005	NL
Se	BLD	<0.005	1.0
Ag	BLD	<0.005	5.0
Tl	BLD	<0.005	NL
V	BLD	<0.005	NL
Zn	0.012	<0.002	NL

BLD = Below Detection Limit
NL = Not Listed in TCLP (40 CFR 261 7/1/91)

Table 5. Leachate water quality resulting from addition of 2 and 4% slag from two sources. The results are from the fifth leach cycle in an accelerated leaching procedure and represent changes from the control (no slag).

	Units	EPA TCLP Limit	EPA Drinking Water	Control No Slag	Refuse + 2% J&L Slag	Refuse + 4% J&L Slag	Refuse + 2% CarTech Slag	Refuse + 4% CarTech Slag
acidity	mg/l			1155	157	24	139	9
alkalinity	mg/l			0	0	7	0	25
SO4	mg/l			2080	1551	1424	1650	1413
Cond.	uS/cm			2463	2432	2073	2350	1900
As	ug/l	5,000	50	34	18	31	32	40
Se	ug/l	1,000	50	1	5	15	3	30
Ba	ug/l	100,000	2,000	639	21	31	773	28
Ag	ug/l	5,000	N/A	2	11	3	2	2
Cr	ug/l	5,000	100	41	5	5	36	3
Ni	ug/l	70,000	10	507	1000	283	713	57
Cd	ug/l	1,000	5	23	38	6	18	3
Pb	ug/l	5,000	15	25	9	13	3	20
		(600,000) = Pennsylvania Standard for Industrial Sites						
Mn	mg/l			8	36	22	17	3
Fe	mg/l			207	162		216	0
Al	mg/l			10	1		6	1

Table 6. Expected performance from leach beds constructed with limestone versus steel slag. Two types of leach beds are presented, those with steady flow of fresh water (wet) and those which rely on direct precipitation (dry).

<table>
<tr><th colspan="8">Wet Leach Bed</th></tr>
<tr><th></th><th>FLOW gpm</th><th>SIDE LENGTH ft.</th><th>DEPTH ft.</th><th>MATERIAL REQUIRED tons</th><th>FINAL ALK mg/l</th><th>LIFE yrs.</th><th>ALKALINE LOAD lbs/day</th></tr>
<tr><td colspan="8">Limestone</td></tr>
<tr><td>Open</td><td>100</td><td>135</td><td>4</td><td>6,160</td><td>79</td><td>200+</td><td>95</td></tr>
<tr><td>Closed</td><td>100</td><td>120</td><td>4</td><td>4,900</td><td>196</td><td>100+</td><td>235</td></tr>
<tr><td colspan="8">Steel Slag</td></tr>
<tr><td>Open</td><td>100</td><td>118</td><td>4</td><td>3,009</td><td>1,200</td><td>12</td><td>1,440</td></tr>
<tr><td colspan="8">Dry Leach Bed</td></tr>
<tr><td></td><td>AREA acres</td><td>DEPTH ft.</td><td>FLOW gpm</td><td>MATERIAL REQUIRED tons</td><td>COST</td><td>FINAL ALK mg/l</td><td>ALKALINE LOAD lbs/day</td></tr>
<tr><td>Limestone</td><td>5</td><td>1</td><td>9.13</td><td>16,000</td><td>$240,000</td><td>20</td><td>2.2</td></tr>
<tr><td>Steel Slag</td><td>5</td><td>1</td><td>9.13</td><td>11,760</td><td>$176,400</td><td>800</td><td>87.6</td></tr>
</table>

Table 7. Recmix demonstration at Lenox, West Virginia, October 7, 1997. Recmix was applied via an Aquafix doser. Samples were taken upstream (US) of the Aquafix and at various distances.

	Pre-Treatment	**Post-Treatment**		**Difference**	
	US doser lenox B	**30' DS doser lenox 2**	**300' DS doser pond inlet**	**US doser 300' DS**	**Percent change**
pH	4.35	8.11	8.70	4.35	100%
alk	<MDL	25.10	555.00	555.00	n/a
acd	270.00	61.50	<MDL	-270.00	-100%
Al	31.00	5.70	6.60	-24.40	-79%
Fe	10.00	.10	<MDL	-10.00	-100%
Mn	56.00	21.00	<MDL	-56.00	-100%
cond.	2190.00	2180.00	2150.00	-40.00	-2%
Sb	.5		.36	-.22	-38%
As	.68		.52	-.16	-24%
Ba	<MDL		<MDL	0.00	n/a
Be	<MDL		<MDL	0.00	n/a
Cd	.13		<MDL	-.13	-100%
Cr	.11		<MDL	-.11	-100%
Pb	.39		.34	-.05	-13%
Ni	1.20		<MDL	-1.20	-100%
Se	.78		.62	-.16	-21%
Ag	<MDL		<MDL	0.00	n/a
Tl	1.30		.89	-.41	-32%
Hg	<MDL		<MDL	0.00	n/a

Table 8. Design considerations for the slag leach bed above the Taywood valley fill #5.

INPUT:	
available surface area	11,000 sq. ft.
depth	2 ft.
length	1,100 ft.
width	8 ft.
design flow	5 gpm
resulting alkalinity	1,000 mg/l
design factor	1.0
DISCHARGE:	
acidity	300 mg/l
flow	5 gpm
acid load	180 lbs/day
acid load	33 tpy
OUTPUT:	
max. infiltration	834 gpm
alkaline load generation	60 lbs/day
alkaline load generation	11 tpy
required slag	1,188 tons
life	21.6 years
delivered slag cost	$15.00/ton
slag cost	$17,820
expected acid load treated	33%

Table 9. Concentrations of toxic elements at the valley fill #5 discharge. TCLP and EPA drinking water limits are provided for comparison.

EPA method #	7/31/97	9/8/97	11/3/97	11/17/97	2/27/98	units	TCLP Limit	EPA Drinking Water
200.7 Antimony	.18	.35	.28	.23	.19	mg/l	1 mg/l	6 ug/l
200.7 Arsenic	.24	.56	.49	.4	.34	mg/l	5 mg/l	50 ug/l
200.7 Barium	.035	.041	<.1	<.1	<.1	mg/l	100 mg/l	2000 ug/l
200.7 Beryllium	.012	.01	<.1	<.1	.005	mg/l	.007 mg/l	4 ug/l
200.7 Cadmium	.006	.0092	<.1	<.1	<.1	mg/l	1 mg/l	5 ug/l
200.7 Chromium	.051	.072	<.1	<.1	<.1	mg/l	5 mg/l	100 ug/l
200.7 Lead	.084	.24	.16	.15	<.1	mg/l	5 mg/l	15 ug/l
200.7 Nickel	.39	.55	.42	.4	<.1	mg/l	70 mg/l	10 ug/l
200.7 Selinium	.24	.58	.46	.48	<.1	mg/l	1 mg/l	50 ug/l
200.7 Silver	0	.044	<.1	.12	<.1	mg/l	5 mg/l	
200.7 Thalium	.5	1.1	.77	.7	<.1	mg/l	7 mg/l	2 ug/l
245.2 Mercury		0	0			ug/l	.2 mg/l	2 ug/l

Figure 1. Alkalinity generation using Mingo Junction steel slag (<1/8”).

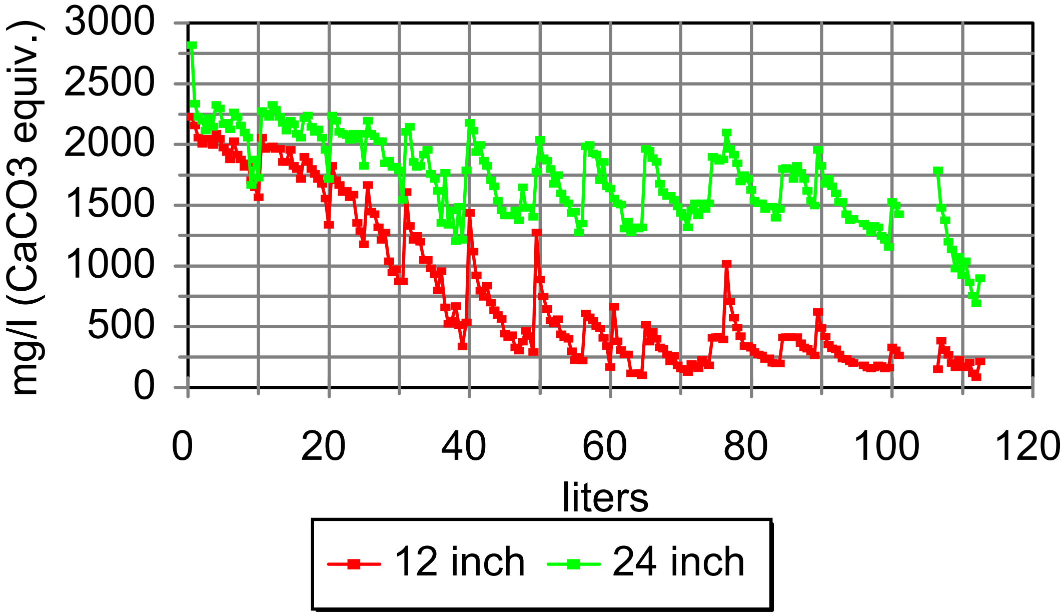

Figure 2. Leach bed.

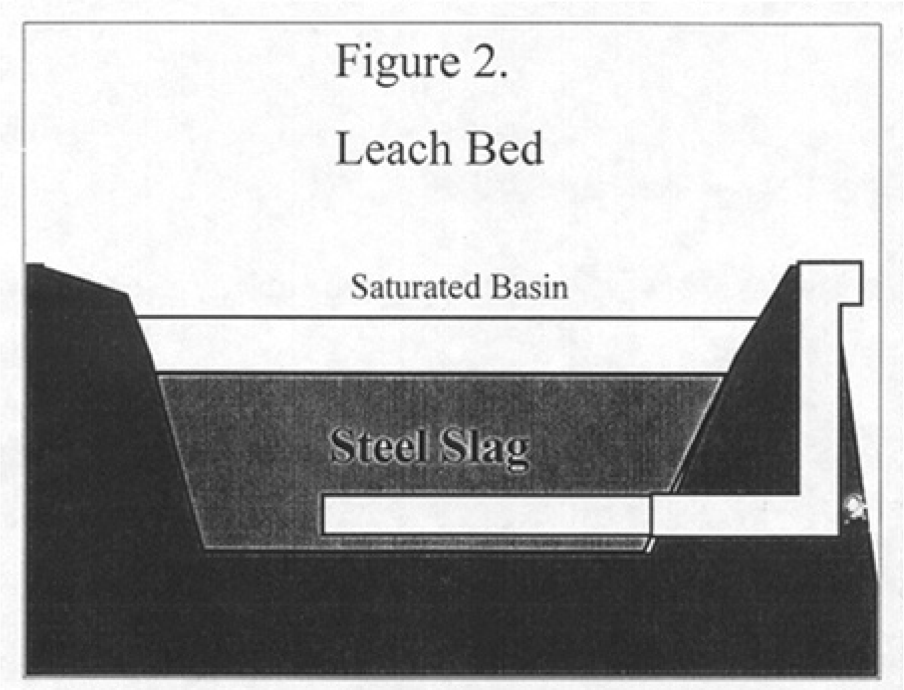

Figure 3. Taywood Valley Fill #5 before construction of slag leachbeds.

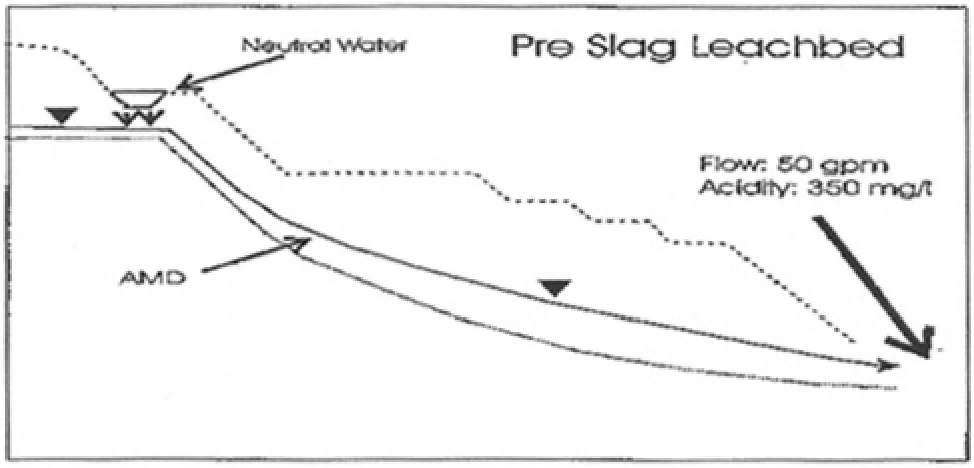

Figure 4. Taywood Valley Fill #5 after construction of slag leachbeds.

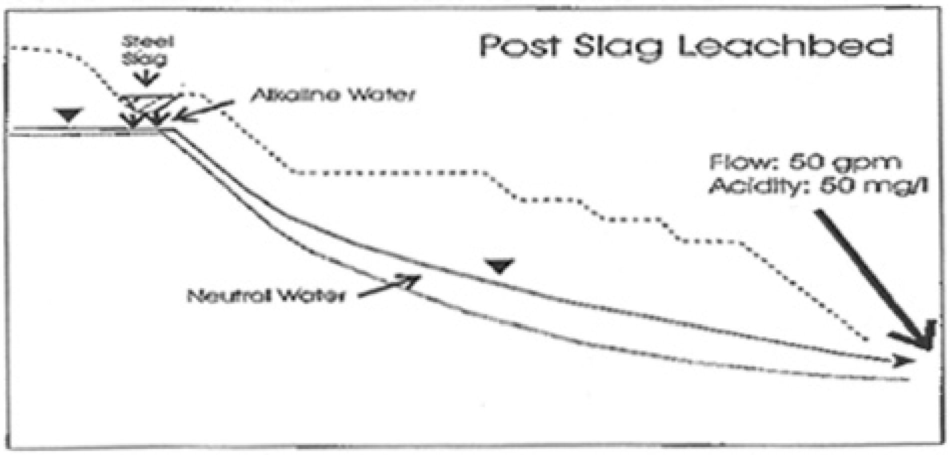

Figure 5. Changes in discharge net acidity, pH, and manganese concentrations subsequent to construction of a steel slag leachbed.