A new look at designing steel slag leach beds

Natalie A. Kruse[1], Kimberly Brewster[1], R. Guy Riefler[2]

[1]*Environmental Studies, Voinovich School of Leadership and Public Affairs, Ohio University, Building 22, The Ridges, Athens, Ohio, 45701, krusen@ohio.edu*
[2]*School of Civil Engineering, Russ College of Engineering and Technology, Ohio University, Stocker Center, Athens, Ohio, 45701*

Abstract A frequently used method of remediating mine water is a steel slag leach bed (SSLB), but the long term hydraulics and performance of SSLBs are poorly understood. An SSLB is a vertical flow pond filled with steel slag, through which clean water is directed before combination with mine water. This paper presents initial results from lab experiments of alternative designs of SSLBs. The goal of the lab experiments is to determine the long-term permeability and the long-term alkalinity production of different steel slag mixes. The treatments tested are: slag only, slag mixed with river gravel or wood chips and slag with a wood chip overlayer. Early results show that reducing the amount of steel slag by mixing with another material does not reduce the alkalinity generation of the bed and that there is no significant difference between hydraulic conductivity of each column.

Key Words steel slag, passive treatment, acid mine drainage

Introduction

Acid mine drainage is a serious environmental legacy left by a long history of mining. It is a worldwide problem and has significant effects on the water environment in Appalachia. Since mine drainage is often found in rural Appalachia, it is important to develop and improve effective, low cost, low energy solutions.

Treatment systems aim to add alkalinity to acidic water and to remove metals. In rural areas, it is important to use low cost, low energy treatment systems. Most often, either a doser (hydropowered limestone addition) or a passive treatment system (little or no added chemicals or energy) are used. Most passive treatment systems are some form of constructed wetland or alkaline addition ponds. Passive treatment systems are an inexact science at present, improvement of both the design and maintenance of passive treatment systems could both reduce contaminant load into Appalachian streams and lower the cost of treatment.

Steel slag is formed from the addition of calcium compounds to iron ore during the steelmaking process. To make a stronger and more manageable steel product, limestone, lime, or dolomite is added to remove the aluminum, silicon, and phosphorus ions found in the iron ore. The process results in a slag, which separates to the top of the melt and is disposed of. This glass-like material is a low-cost source of alkalinity suitable for use in the remediation of acid mine drainage (Ziemkiewicz and Skousen 1998).

Steel slags consist of calcium alumino-silicate oxides; their composition varies according to the desired quality of steel and the steel-making process involved (Ziemkiewicz and Skousen 1998). Deionized water passed through one type of steel slag yielded metal concentrations within the acceptable limits for the U.S. Environmental Protection Agency's Toxicity Characteristic Leaching Procedure (TCLP) and an elevated level of only one metal (Ni) under EPA drinking water standards. Metals present and at acceptable limits included selenium, barium, zinc, lead, beryllium, and chromium (Ziemkiewicz and Skousen 1998). Aluminum, calcium, iron, magnesium, and chlorine were present in other slags (Gahan et al. 2009). Some slags have been tested with potentially toxic levels of hazardous elements such as fluoride, chromium and vanadium (Gahan et al. 2009) and lead, cadmium, nickel and chromium (El-Mahllawy 2007). A potential disadvantage of the use of SSLBs is the mobilization of metals if the slag's alkalinity is exhausted or an inadequate amount of slag is used. Therefore, it is important to place slag in environments that will not become acidic and to take care when placing slag in non-surface locations (Ziemkiewicz and Skousen 1998).

Steel slag leach beds (SSLBs) are an ideal alternative to limestone in the passive treatment of acid mine damage (AMD) because they have been shown to have a greater daily alkaline load than both open and closed limestone leach beds. In West Virginia, Ziemkiewicz and Skousen measured an alkalinity generation of 1,500 mg/L per day in one open SSLB versus 79 mg/L per day and 196 mg/L per day for open and closed limestone leach beds, respectively (1998). In another study of passive treatment systems in the eastern U.S., the average acid load reduction for slag leech beds was 76 t/yr, compared with 15 t/yr for limestone leach beds and 9 t/yr for open limestone channels, anaerobic wetlands, aerobic wetlands, and vertical flow wetlands (Skousen and Ziemkiewicz 2005).

In addition, steel slag can be exposed to CO_2 in the atmosphere without a significant decline in alkalinity production, unlike lime (Ziemkiewicz and Skousen 1998). Other advantages of SSLBs include a low level of required maintenance, close proximity and high availability of slag to the Appalachian region (Ziemkiewicz and Skousen 1998), and relative ease of construction (Skousen and Ziemkiewicz 2005). In addition, reuse of steel slag for the treatment of acidic waters prevents the disposal of the byproduct into a landfill as waste, and prevents the extraction of raw limestone from the earth (Gahan et al. 2009).

For the treatment of acid mine drainage, slag with a 1/8 inch fine grade is used. Fresh, metal-free runoff or rainfall should serve as influent for a SSLB system. The alkaline effluent out of the system can treat AMD in-situ or can be allowed to flow into acidic waters downstream from the source of AMD. Slag can also be used as a direct water treatment when deposited in a stream affected by AMD (Ziemkiewicz and Skousen 1998). SSLBs require a residence time of one to three hours (Simmons et al. 2002) and are often designed for four hours of residence time (Farley 2009). The average service life of an SSLB is 6.2 years.

At one study site in southeast Ohio, multiple sources of AMD (up to fourteen) were treated by two wide basins with SSLBs. Measurements of alkalinity concentration in the SSLB effluent at the sites were between 200 and 400 mg/L, although calcite formation and flooding and drying conditions at the sites may have contributed to cementing of the slag fines (Farley and Ziemkiewicz 2005). The hydraulic clogging and the lack of predictability of alkalinity production of this system and others like it shows the need for further engineering research into their hydraulic and chemical performance.

Acid mine drainage affects over 1300 miles of streams in Ohio (Farley and Ziemkiewicz 2005). The use of SSLBs is increasingly being used to treat acid mine drainage in Ohio. However, each remediation site presents specific design needs and performance results that are unique to the project (Farley and Ziemkiewicz 2005). Therefore, it is valuable to investigate the effectiveness of SSLB treatment techniques in AMD remediation sites with a variety of treatment criteria.

This paper details the first steps in a study to improve the design of steel slag leach beds to improve the long term hydraulic conductivity of the systems.

Methods

Initially, four columns have been constructed to ASTM standard D2434—68. Each column is 90 cm long with a permeable stone sealed in the bottom to keep the porous materials in the column. Each column has a tap on the bottom and two taps in the side, 10 cm apart. The taps in the side will be used to determine head drop across the column and calculate changing permeability of the column. The outlet of each column has been set to maintain a constant head of 10 cm above the surface of the porous column material. The column setup before the constant head outlet was installed is shown in Figure 1. Tap water, to approximate clean stream water, is circulated through the columns at a very slow flow rate to maintain approximately 1 day of hydraulic residence time. Column 1 contains mixed 20% wood chips and 80% slag (by volume), Column 2 contains mixed 20% river gravel and 80% slag, Column 3 contains 100% slag and Column 4 contains 20% wood chips layered over 80% slag. All steel slag has been taken from the stockpiles at the construction site of a new steel slag leach bed at Pierce Run in Raccoon Creek Watershed in southern Ohio.

Every two days, the flow rate, alkalinity generated and head drop across the column are measured and recorded and every two weeks iron, aluminum, nickel, cadmium and zinc are measured in the effluent. Initial results are presented here.

Results

As shown in Figure 2, there are only very small variations in alkalinity concentrations between the columns. With the exception of a single spike of alkalinity in which Column 1 had increased alkalinity, Column 1 maintained the lowest alkaline loading of all the columns. The column containing only steel slag was not consistently the highest alkaline producer. This shows that the re-

Figure 1 *Laboratory column setup. Columns contain 1) 20% wood chips mixed with 80% slag, 2) 20% river gravel mixed with 80% slag, 3) 100% slag, and 20% wood chips layered on top of 80% slag*

duction of steel slag by 20% is not significant in terms of alkaline production. The results suggest that the column with wood chips layered over steel slag consistently produced alkalinity while maintaining hydraulic conductivity. Although head drop across the columns has been measured, none of the columns have shown any reduction in hydraulic conductivity.

Conclusions

The initial results of this study show that although none of the columns show a drop in permeability or hydraulic conductivity, the alkalinity generation in each column is not consistent. Over the sampling period presented here, the columns with less steel slag, mixed with other materials produced as much or more alkalinity as the column with 100% steel slag. Column 4 shows some initial promise for alkalinity generation, perhaps due to oxygen stripping by the wood chips. Future work will include continued sampling of each column, analysis of metals in the effluent, and testing other material combinations. Potential options include mixing with different percentages of gravel or wood chips, creating an underdrain system with washed river gravel.

Acknowledgements

This work has been funded by the Ohio University Research Committee and has been conducted in the Institute for Sustainable Energy and the Environment laboratory with the support of the Ohio Department of Natural Resources Division of Mineral Resources Management.

References

El-Mahllawy, M.S. 2007, "Characteristics of acid resisting bricks made from quarry residues and waste steel slag", Construction and Building Materials, vol. 22, pp. 1889—1896.

Farley, M.E. & Ziemkiewicz, P. 2005, "Selected abandoned mine reclamation projects and passive treatment in Ohio", West Virginia Mine Drainage Task Force.

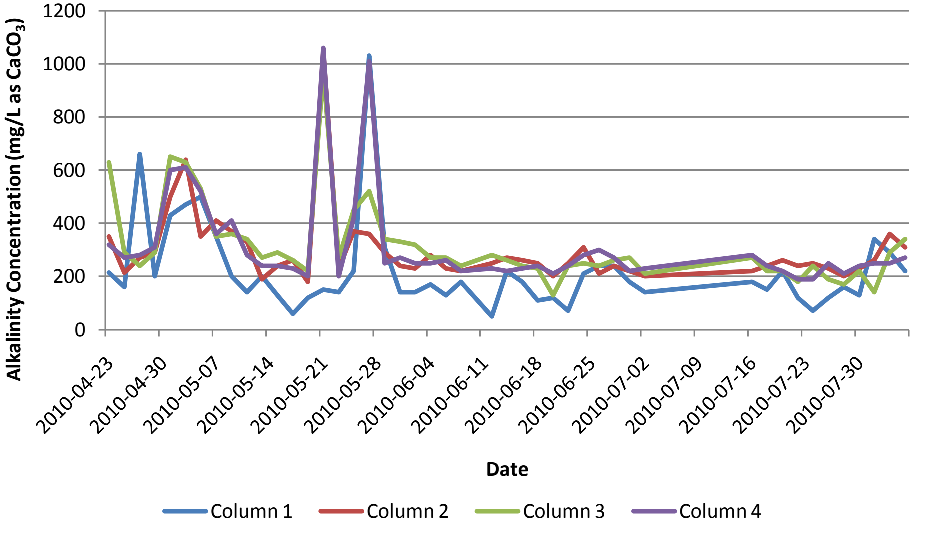

Figure 2 *Alkalinity concentration in the effluent of each column. Column 1: mixed wood chips and slag, Column 2: mixed river gravel and slag, Column 3: slag, Column 4: layered wood chips and slag*

Farley, M.E. 2009, Personal Communication. Ohio Department of Natural Resources Department of Mineral Resources Management.

Gahan, C.S., Cunha, M.L. & Sandstrom, A. 2009, "Comparative study on different steel slags as neutralising agent in bioleaching", Hydrometallurgy, vol. 95, pp. 190—197.

Simmons, J., Ziemkiewicz, P. & Black, D.C. 2002, "Use of steel slag leach beds for the treatment of acid mine drainage: The McCarty Highwall Project", American Society of Mining and Reclamation.

Skousen, J.G. & Ziemkiewicz, P. 2005, "Performance of 116 passive treatment systems for acid mine drainage", American Society of Mining and Reclamation.

Ziemkiewicz, P. & Skousen, J.G. 1998, "The use of steel slag in acid mine drainage treatment and control", Green Lands, pp. 46—56.