INVESTIGATION OF THE ACID MINE DRAINAGE AT THE TAB-SIMCO MINE, ILLINOIS: OBSERVATIONS AND IMPLICATIONS FOR TREATMENT[1]

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Abstract. Tab-Simco is an abandoned coal mine located southeast of Carbondale in Jackson County, Illinois. Underground mining of two coal beds of the Pennsylvanian age Spoon Formation occurred between 1890 and 1955; surface coal mining re-affected the area in the 1960's and 1970's. Acidic mine drainage (AMD) discharges from the mine workings at a rate of about 35,000 gallons per day, which has resulted in a significant aquatic impact on nearby Sycamore Creek. Two AMD discharges were observed at Tab-Simco; both are channeled though flume structures constructed in earlier investigations. The largest, a 19 GPM (1.2 LPS) discharge, had a pH = 2.4, dissolved Fe = 422 mg/L, dissolved Al = 147 mg/L, dissolved Mn = 31.4 mg/L, SO_4^{2-} = 2,370 mg/L, and total acidity = 1,816 mg/L $CaCO_3$ equivalent (CCE; all median values). This discharge flowed across small floodplain and created a 9-acre area devoid of vegetation. Bacterial-aided, low pH Fe oxidation occurred in this "kill zone," which partially treated the discharge. Following low pH oxidation Fe was reduced to 204.7 mg/L a 51.5 percent reduction; Al was reduced to 124.4 mg/L a 15.4 percent reduction; and SO_4^{2-} was reduced to 1,834 mg/L a 22.6 percent reduction. Geochemical modeling indicates that the large seep is supersaturated with respect to the hydrous sulfate mineral jarosite and the iron oxyhydrate goethite. It is presumed that authogenic precipitation of these minerals account for the loss of metals and sulfate in the mine drainage. Although significant metal load reduction occurred by natural biologic process in the "kill zone" a large quantity of low pH (2.48) metal laden water remained that impacted the receiving stream. To abate the large seep a passive-type treatment system was constructed in 2007 by the Illinois Department of Natural Resources, Office of Mines and Minerals. The principle technology employed is a 0.75-acre (0.3 ha.) sulfate-reducing bioreactor, which is one of the first full scale bioreactor employed for the treatment of acidic, coal mine drainage in the US. This bioreactor is constructed in three layers: a shallow acid impoundment, an underlying thick (6-foot) layer of compost, and finally limestone with embedded drain pipes. A series of oxidation cells/wetlands follow the bioreactor unit to precipitate most of the remaining metals before discharge into Sycamore Creek. A smaller, untreated 5 GPM (0.3 LPS) discharge exists with a pH = 2.5, dissolved Fe = 143 mg/L, dissolved Al = 54.9 mg/L, dissolved Mn = 18 mg/L, SO_4^{2-} = 2,370 mg/L, and total acidity = 817 mg/L CCE (median values).

Additional Key Words: Geochemical modeling, acid mine drainage, and passive treatment.

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The Tab Simco Project currently treats a 21.5 GPM (1.35 LPS) coal mine discharge with a high Fe and Al content (Table 1 and Fig. 1; Smith, 2002; Lewis, 2008; Lefticariu and others, 2009). The Tab-Simco bioreactor is composed of approximately 7,700 yd^3 (5,887 m^3) of "compost" composed of by volume: 53% wood chips, 27% straw, 11% seasoned municipal (yard waste) compost and 9% agricultural ground limestone (aglime; Lewis, 2008). This system has proven highly successful in treating this poor quality AMD. Due to the geotechnical constraints to the site (Lewis, 2008) the Tab-Simco system is smaller than optimum with a high SO_4^{2-} loading of 0.61 moles/m^3/day and a cumulative metal loading (excluding Mn) of 0.232 moles/m^3/day (Table 1). Note that this is somewhat higher than the cumulative heavy metal flux value of 0.15 moles/m^3/day recommended limit by the URS report (URS, 2003); inlet heavy metal flux must be less than the rate of SO_4^{2-} reduction for compete removal. Nevertheless, in the first two years of the Tab-Simco operation metal removal is impressive at 81.8 percent for Fe, 99.9% for Al, 98.5% for Ni and 95.7% for Zn. Subsequent Fe precipitation occurs as ferrohydrate in follow up oxidation cells (Fig. 1) with a median system discharge of only 2 mg/L. The design team realized that the longevity of typical reducing and alkalinity producing (RAPS)-type vertical flow systems when treating high Al (> 20 mg/L) drainage is limited. This design limitation is due to increase in pH > 4.5 within the RAP's limestone layer. At this pH prodigious amounts of $Al(OH)_3$ will accumulate and normally clog the system.

$$Al^{3+} + 3H_20 \rightleftharpoons \underset{\text{(Gibbsite)}}{Al(OH)_{3(s)}} + 3H^+ \qquad (1)$$

Regular flushing of RAPS under drains is a common procedure to expend system life. However, unlike a RAPS-type system, Gusek and Wildeman (2002) suspected that Al precipitates within compost SRB bioreactors relatively insoluble aluminum sulfate minerals such as alunite:

$$3Al^{3+} + K^+ + 6H_2O + 2SO_4^{\ 2-} \rightleftharpoons \underset{\text{(Alunite)}}{KAl_3(OH)_6(SO_4)_2} + 6H^+ \qquad (2)$$

Alunite deposits are more compact than the bulky, amorphous gibbsite deposits. Additional research is needed to characterize the fate of Al within SRB bioreactors. Research by Thomas and Romanek (2002) and McCauley and others (2009) confirmed the presence of Al oxyhydrosulfates in deeper substrate zones of bench-scale bioreactor microcosms. Iron is removed as iron hydroxides and oxyhydroxides in the upper oxidized zone, whereas the lower sulfidic zones contained black iron monosulfide precipitates. In general, divalent metals Fe, Ni, Zn and Cu are mostly retained as sulfides. Because of the higher solubility of MnS and the moderate pH (<7.0) most manganese passes though the bioreactor cell (Table 1).

Limited performance data is available for pilot-and full-scale bioreactors treating coal mine drainage (Gusek, 2000; Gusek and Wildeman, 2002; Gusek 2005). Results from evaluations of the Tab Simco Mine are presented in Table 1. Field installations are typically designed for metal removal. A rule-of-thumb is to design the systems for 50% sulfate removal. Under these conditions most metals except manganese are retained within the bioreactor. Additional metal removal may occur by either adsorption onto organics and hydroxides or cation exchange.

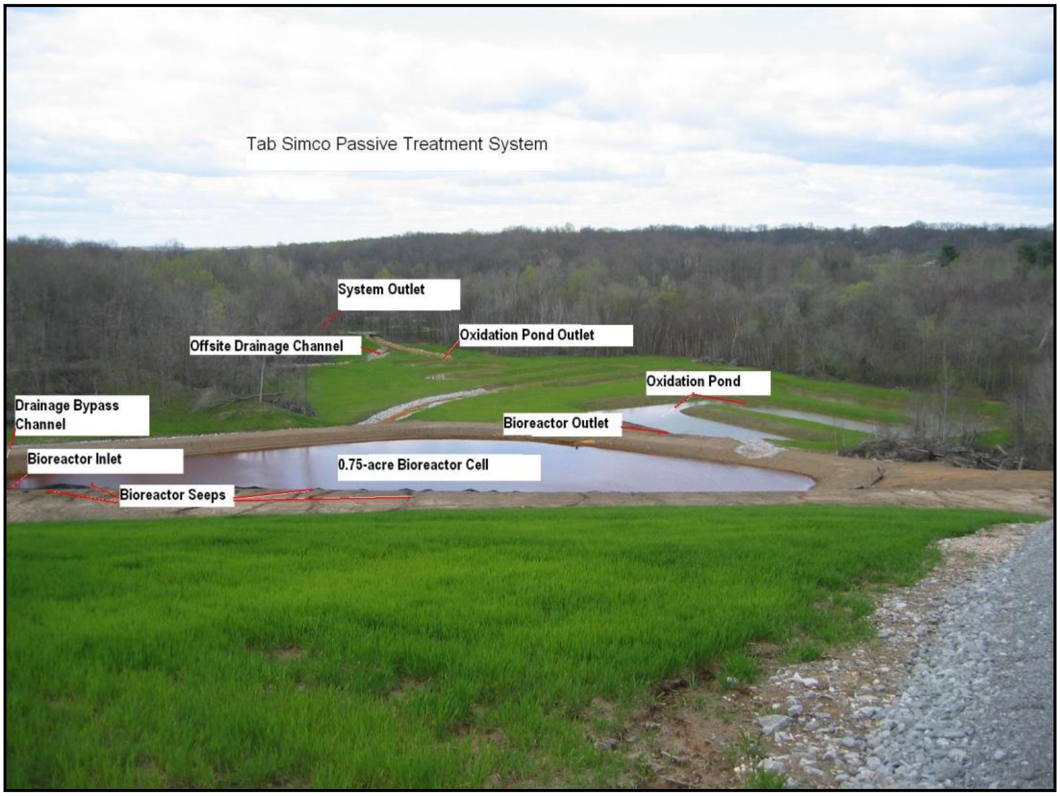

Figure 1- Overview of the Tab-Simco Bioreactor-based Treatment System, Illinois.

Considerable dissolved Fe may discharge from bioreactors where loading is high (Table 1). However, due to the high alkalinity and favorable pH of bioreactor discharge the remaining Fe will rapidly precipitate whenever adequate oxidation structures are constructed following the bioreactor cell. For example the Tab-Simco bioreactor discharge has a median pH of 6.3 and a net alkalinity of 155 mg/L CCE.

Table 1 - Median Water Quality: Tab-Simco Passive Treatment System, Illinois*

Site ID	pH	D. Fe	D. Mn	D. Al	Acidity	Alkalinity	SO_4
Bioreactor In	2.84	423.5	35.8	115.1	1,575	0	3,019
Bioreactor Out	6.31	83.2	31.5	0.27	183	338	2,100
System Out	6.94	2.0	21.3	0.96	11	36	1,719

*All values except pH are in mg/L; acidity and alkalinity are calcium carbonate equivalent values; acidity = calculated non-manganese acidity.

McCauley and others (2009) report and an average SO_4^{2-} removal rate of 0.308 moles/m^3/day in bench studies. Gusek (2002, 2005) suggests a design goal of 0.30 moles/m^3/day. Initial data from the Tab-Simco system indicates that a slightly lower rate of 0.187 moles/m^3/day. However, this system is somewhat undersized and it appears that thermodynamically more favorable nitrate reduction has taken preference to sulfate reduction at this site (Lefticariu and others, 2009).

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