Feasibility of Utilizing Acid Mine Drainage Sludge in an Innovative Iron-based Wastewater Treatment Process

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Acid mine drainage (AMD) is a common pollution source in coal and mineral producing regions, requiring treatment to comply with pollution control regulations. In the Appalachian Basin of the U.S., mine drainage is produced in vast quantities at both abandoned and current coal mining and preparation facilities. Clean Water Act section 402 permits regulate pollution discharge and specify allowable concentrations of iron (Fe), aluminum (Al), manganese (Mn), pH, and suspended solids. Common compliance treatment consists of acid neutralization, mechanical oxidation, and settling of metal precipitates. These precipitates consist largely of hydroxides of the target metals and are collected in settling basins while treated water is decanted to discharge. Initially formed AMD sludge is about 99% water (Skousen and Ziemkiewicz, 1995), and depending on the treatment and storage process, the sludge may reach solids concentrations of 15% to 35%. In a previous study, our research team estimated regional sludge production to be about 2.3 million tons/year. Disposing the sludge materials currently represents an environmental and economic burden.

Iron-based wastewater treatment technology

This study presents the feasibility of utilizing AMD sludge in an innovative, energy-efficient iron-based wastewater treatment process recently developed at West Virginia University. A basic treatment train of the iron-based wastewater treatment process consists of primary, secondary, and polishing treatment units (Figure 1). Both the primary and secondary units are to be dosed with iron-containing materials. Various iron-containing materials including those in aqueous (e.g., ferric chloride) or solids (e.g., acid mine sludge) can possibly be used in these treatment units. The primary unit is a clarifier where the iron is mixed with raw wastewater to remove phosphorus and other settleable solids. The secondary treatment is an anaerobic bioreactor in which remaining organic matters are oxidized by iron reducing bacteria (IRB) and sulfate reducing bacteria (SRB). Also in the anaerobic bioreactor, nitrogen (if present) is removed from the wastewater by converting ammonium to di-nitrogen gas through an ammonium oxidation reaction coupled to iron reduction (a process termed Feammox), and additional denitrification reactions (Clement et al. 2005; Sawayama, 2006; Yang et al. 2012). The polishing treatment is designed to remove the remaining biological instability (e.g., ferrous Fe, sulfide, etc.) and any pathogens in the effluent. Chlorine is a commonly used oxidant that can be used to achieve both removal of biological instability and control of pathogens. The treated effluent can be reused for a range of different purposes, which may or may not require additional treatment.

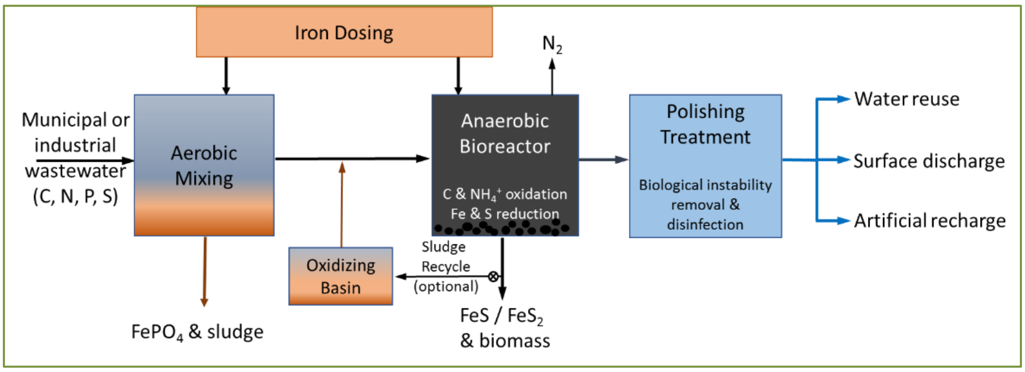

Figure 1. Basic configuration of the innovative iron-based wastewater treatment process

This treatment method offers an optional sludge recycling operation depending on the incoming wastewater characteristics. The sludge recycling involves pumping a fraction of the sludge materials from the anaerobic bioreactor to an oxidizing basin in which the sludge materials are oxidized to ferric and sulfate, and mixing the oxidized stream with the wastewater influent. The iron-based treatment concept and technical feasibility have been demonstrated in laboratory experiments and published in a series of peer-reviewed journal papers (Deng and Lin 2013; Deng *et al.*, 2016; Deng and Lin, 2017; Deng *et al.*, 2018; Ahmed and Lin, 2017).

Feasibility of using AMD sludge in the iron-dosed wastewater treatment

Our research team has conducted a field survey on 138 AMD sludge cells in Maryland, Pennsylvania, Ohio, and West Virginia, which indicates suitability of their uses as a ferric source for iron-based technologies (Figure 2). The composition of AMD sludge varies according to source but general classes develop according to the nature of the untreated AMD. Net alkaline AMD has approximately 80% $Fe(OH)_3$, and net acid AMD contains, on average, 55% $Fe(OH)_3$ and 22% $Al(OH)_3$. The results indicate that, while proportions of the secondary elements Mn and Si are relatively consistent across AMD types, Al and Fe concentrations vary among types. Both Fe and Al are known to scavenge phosphorus.

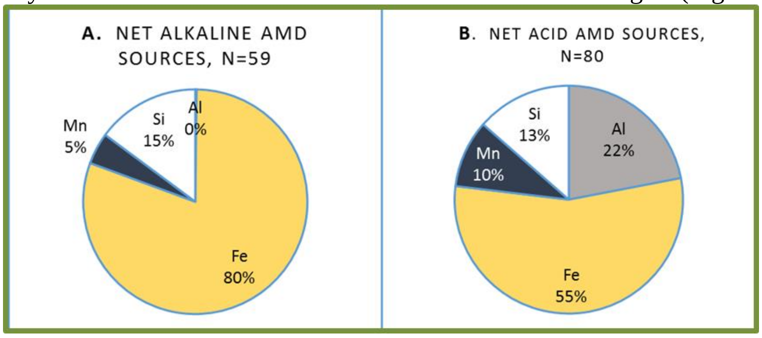

Figure 2. Distribution of major chemical elements in the AMD sludge. Concentrations are based on the dry weight basis.

Literature review of the AMD sludge indicates that goethite, schwertmannite, lepidocrocite, hematite and magnetite are the common dominant mineral phases due to dewatering and diagenetic process (Ma *et al.*, 2012; Kirby *et al.*, 1999; Aube and Zinck, 1999; Florence *et al.*, 2016). The crystallinity and solubility of these iron materials can be critical issues influencing the microbial reduction kinetics (Munch and Ottow, 1983), and, in turn, the organics removal from wastewater. Toxic elements (e.g., As, Cd, Zn) that may be present in the sludge materials can be removed by forming metal sulfide precipitation in the anaerobic bioreactor with biogenic sulfide from sulfate reduction. This paper will also review and discuss fundamental microbial processes such as electron transfer between IRB and iron mineral surfaces, and potential production and harvest of useful products such as pili, protein-based nanowires of *Geobacter* from this treatment process.

References

Ahmed M. and Lin, L.-S. (2017) Ferric Reduction in Organic Matter Oxidation and Its Applicability for Anaerobic Wastewater Treatment: A Review and Future Aspects, Reviews in Environmental Science and Bio/Technology, 16(2), pp. 273-287, DOI: 10.1007/s11157-017-9424-3.

Aube, B. C., & Zinck, J. M. (1999). *Comparison of AMD treatment Processes and Their Impact on Sludge Characteristics.* Canada.

Clement, J.-C., Shrestha, J., Ehrenfeld J.G., Jaffe PR (2005). Ammonium oxidation coupled to dissimilatory reduction of iron under anaerobic conditions in wetland soils. *Soil Biology & Biochemistry*, 37: 2323-2328.

Deng, D. and Lin, L.-S. (2013). Two-stage Combined Treatment of Acid Mine Drainage and Municipal Wastewater, *Water Science & Technology*, 67(5), 1000-1007.

Deng, D. and Lin, L.-S. (2017). Continuous Sulfidogenic Wastewater Treatment with Iron Sulfide Sludge Oxidation and Recycle, Water Research, 114, 210-217, DOI: 10.1016/j.watres.2017.02.048.

Deng, D., Weidhaas, J. and Lin, L.-S. (2016). Kinetics and Microbial Ecology of Sulfidogenic Reactors for Co-treatment of Municipal Wastewater and Acid Mine Drainage, *J. of Hazardous Materials*, 305(15), 200-208.

Deng, D., Lin, O., Rubenstein, A., Weidhaas, J. and Lin, L.-S. (2018). Elucidating biogeochemical transformations of Fe and S in an innovative iron-dosed anaerobic wastewater treatment process using spectroscopic and phylogenetic analyses, paper submitted to *Water Research*. (under review).

F, M., MA, C., TS, R., R, P.-L., JM, N., and C, A. (2012). From highly polluted Zn-rich acid mine drainage to non-metallic waters: implementation of a multi-step alkaline passive treatment system to remediate metal pollution. *Sci Total Environ*, *435*, 323-330. doi:10.1016/j.scitotenv.2012.06.084

Florence, K., Sapsford, D., Johnson, D., Kay, C., and Wolkersdorfer, C. (2016). Iron-mineral accretion from acid mine drainage and its application in passive treatment. *ENVIRONMENTAL TECHNOLOGY, 37*(11), 1428-1440.

Kirby, C. S., Decker, S. M., and Macander, N. K. (1999). Comparison of color, chemical and mineralogical compositions of mine drainage sediments to pigment. *Environmental Geology, 37*, 243-254.

Munch, J. & Ottow, J. (1983). Reductive transformation mechanism of ferric oxides in hydromorphic soils. Environmental Biogeochemistry, Volume 35, pp. 383-394.

Skousen, J.G. and Ziemkiewicz, P.F. eds. (1995). *Acid Mine Drainage Control and Treatment*. National Mine Land Reclamation Center Publication. 27 ch. 254 pp.32. -in 2nd edition.

Sawayama S (2006) Possibility of Anoxic Ferric Ammonium Oxidation. *Journal of Bioscience and Bioengineering*, 101, pp. 70-72.

Yang WH, Weber KA, Silver WL (2012). Nitrogen loss from soil through anaerobic ammonium oxidation coupled to iron reduction. *Nature Geoscience*, 5, pp. 538-541.