

# Recent Developments in Recovery of Rare Earth Elements from Acid Mine Drainage

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## Abstract

Acid mine drainage (AMD) is a longstanding environmental problem and has been studied extensively since the 1960s. While the process of AMD formation, control and treatment technologies are well understood<sup>1</sup>, its potential to supply critical materials, specifically REEs has been studied only recently. AMD is produced in vast quantities at both abandoned and current coal mining and preparation facilities. Coal producers are required to treat AMD to meet permitted water quality standards. Current AMD treatment is focused on meeting the pollution discharge limits imposed by the Clean Water Act: 33 U.S.C. §1251 et seq. (1972) for regulated, compliant water<sup>2</sup>. AMD treatment consists of acid neutralization, mechanical or chemical oxidation and the settling of metal precipitates. Treatment systems remove metal contaminants as flocculated precipitates (flocs), which are then separated from discharge-quality water by either mechanical or gravitational settling methods<sup>3</sup>. Known as AMD treatment precipitates or sludge, these metal flocs are enriched in REEs. Our earlier studies demonstrated that treatment of low pH AMD (< pH 5.5) produces a sludge with exceptionally high REE concentrations, often an order of magnitude greater than the surrounding rock strata.

AMD results from the oxidation of pyrite, a mineral common to the Appalachian region's coal measures<sup>4 5 6 7</sup>. Pyrite oxidation generates sulfuric acid<sup>8</sup> which leaches REEs from associated rock. During AMD treatment, REEs precipitate with the primary regulated metal ions of iron (Fe), aluminum (Al) and manganese (Mn) hydroxides.

AMD treatment systems are tailored to specific discharges and are designed to minimize capital and operating costs while meeting regulatory discharge standards. The resultant precipitates consist largely of Al, Fe and Mn oxy-hydroxides plus gypsum and carbonates. Iron is the dominant metal in strongly acidic AMD. Initially Fe occurs in its reduced ( $\text{Fe}^{2+}$ ) state, oxidation to  $\text{Fe}^{3+}$  and precipitation as  $\text{Fe}(\text{OH})_3$  is nearly complete at pH 3.5 while  $\text{Al}^{3+}$  and  $\text{Mn}^{2+}$  hydroxides precipitate at pH values of 4.0 and 9.0, respectively. Prior results<sup>2</sup> show that REEs precipitate along a pH gradient nearly identical to  $\text{Fe}^{3+}$  supporting the thesis REEs co-precipitate with the other metal cations. These metal hydroxide precipitates are collected in settling basins while treated water is decanted to surface discharge. Initially-formed AMD sludge is about 99% water. The solid fraction settles over time and depending on the treatment and storage process, may reach solids concentrations of 20 to 30%.

This project instituted a regional sampling effort that included an initial survey of sludge REE concentrations at a wide variety of AMD treatment sites. The results were used to identify sites with a high potential for REE recovery. A subset of this original population was selected for a second phase of intensive sampling to better determine variability within sites. The dominant factor controlling the Total REE (TREE) concentration in raw AMD is the pH of the raw water.

We will summarize the findings of our regional sampling effort including REE distributions, concentrations and the factors that influence grade of a given feedstock.

## References

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