

Fundamental study of a one-step ambient temperature ferrite process for treatment of acid mine drainage waters

BE Morgan, RE Loewenthal and O Lahav*

Department of Civil Engineering, University of Cape Town, Rondebosch 7700, South Africa

Abstract

A novel approach towards the removal of iron and heavy metals from South African acid mine drainage (AMD) waters is presented. The approach involves the controlled oxidation of ferrous-containing AMD water at ambient temperatures in the presence of magnetite seed. The resulting oxidation product is the ferrite ($M1^{3+}_2M2^{2+}O_4$) magnetite (Fe_3O_4), which has the capacity for non-ferrous metal removal, and which forms a stable sludge that is easily separated from the effluent. Sludge characterisation studies (XRD, SEM and dissolution tests) show that oxidation of ferrous solutions under controlled pH and oxidation conditions (pH 10.5, air flow rate = 0.05 l/min) in the presence of magnetite seed (initial seed : ferrous ratio = 7:1) yields almost pure magnetite at ambient temperature. It was found that magnetite seed channels the end products of the AMD oxidation reaction towards magnetite. Under identical conditions, but in the absence of magnetite seed, a poorly characterised mixture of largely amorphous iron oxides are formed with magnetite comprising not more than 17% of the total iron. The kinetics of the reaction under the investigated conditions were found to be very favourable, with magnetite forming at a rate of 12.8 mg Fe/l/min. The total iron concentration in the effluent was always less than 1 mg/l representing an iron removal efficiency of 99.9%. The precipitant settled well (SVI 8 ml/g) and showed substantial stability at pH 3 (dissolution of 1.1% after 120 h). An outline for a one-step ambient temperature ferrite process is presented.

Introduction

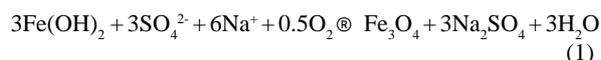
Acid mine drainage (AMD) impacts negatively on freshwater resources in the mining areas of South Africa and many other parts of the world. AMD waters are characterised by low pH, very high iron concentrations, significantly high concentrations of non-ferrous (mainly heavy) metals, and very high salinity, principally in the form of sulphate. The chemical makeup of AMD is directly explicable in terms of the biogeochemical process whereby AMD arises: put most simply, mining activities allow atmospheric oxygen and water to contact and, together with the action of aerobic bacteria, oxidise iron pyrite (FeS_2) in the rock. This releases sulphate and iron into underground water making the latter strongly acidic, causing leaching of non-ferrous metals from the rock (Kleinmann et al., 1981). A comprehensive solution to AMD pollution requires both metal and sulphate removal. The latter can be effected by either biological or membrane-based methods. Irrespective of the method of sulphate removal, iron and non-ferrous metals must be removed beforehand.

Current strategies for metal removal from AMD have several shortcomings (Loewenthal et al., in press; Bosman, 1983). The high density sludge (HDS) process, deployed on several South African mines, utilises lime for pH adjustment and oxygen to vigorously oxidise ferrous iron. A recycle loop is used to densify the ferrihydrite precipitant which is otherwise difficult to separate from the liquid phase. Minimal non-ferrous metals are removed and high oxygen concentrations are required. These limitations, coupled with the magnitude of the AMD problem (some mining basins pump up to 60 Ml of water per day), underscore the need for improved cost-effective treatment methods.

Magnetite is a partially oxidised iron oxide with the formula Fe_3O_4 (i.e. $Fe^{3+}_2Fe^{2+}O_4$). Thus, it conforms to the general formula $M1^{3+}_2M2^{2+}O_4$ for ferrites, where M1 and M2 stand for any of a number of possible metal elements. Magnetite is a ferrite in which the metal component is made up purely of iron. If a solution dominated by soluble iron but containing smaller concentrations of other divalent and trivalent metal species (such as are found in AMD) is transformed into ferrite, then the resulting precipitant will be dominated by magnetite but some of the iron atoms will be replaced by non-ferrous cations, making for "substituted magnetite" or "mixed-species" ferrites.

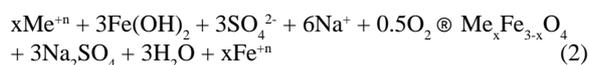
Barrado et al. (1998) proposed the following stoichiometric reactions for ferrite formation from ferrous at pH > 10.5:

In the absence of heavy metals and with a slow oxidation rate



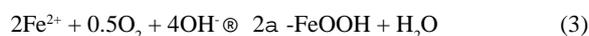
Equation (1) shows that alkalinity is neither produced nor consumed during the formation of magnetite from ferrous hydroxide, and that 10.47 mg/l of magnetite (as Fe) are formed for every 1 mg/l of oxygen consumed.

In the presence of heavy metals and with a slow oxidation rate



Fe^{+n} represents the total concentration of iron which is replaced by metal cations in the ferrite structure. This displaced iron will appear as ferrous or ferric depending on the valence of the displacing cation. These ferrous and ferric ions will react to form magnetite.

However, it is to be noted that with excess oxidising agent, goethite is formed instead of magnetite:



* To whom all correspondence should be addressed.

☎(021) 650-2618; fax (021)689-7471; e-mail: olahav@eng.uct.ac.za

Received 28 February 2001.