



## Review

## Sustainability assessment of the recovery and utilisation of acid from acid mine drainage



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## ABSTRACT

Acid mine drainage (AMD) presents serious threats to the environment due to its toxic constituents. Traditional wastewater treatment methods such as neutralization, precipitation, membrane processes, ion exchange and biological sulphate removal, etc., have been applied to remediate AMD and reduce its negative impact on the receiving environment. However, the challenge with most of these methods is that the constituents of AMD have not been viewed as valuable resources. The constituents, though toxic can be recovered and transformed into valuable materials which could be marketed. Amongst the various AMD constituents, is sulphuric acid which has an appreciable market in the chemical and metallurgical industry. The acid value could be recovered from AMD and used to meet the demands of various sulphuric acid consumers. The financial benefits obtained could then be used to offset the overall AMD treatment cost. Hence, this paper reviews some of the techniques used to recover sulphuric acid from various wastewater solutions. The techniques reviewed include: rectification, membrane separation, solvent extraction, crystallization and acid retardation. The technical and economic feasibility of each process for application to AMD is also evaluated. Subsequently, the acid retardation and crystallization technologies are recommended as the most promising technologies for acid recovery from AMD.

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## 1. Introduction

Acid mine drainage (AMD) is a severe environmental problem which results from the oxidation of pyrite and other sulphide minerals found in mining tailings, rock stock piles and

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underground mine workings (Evangelou, 1995; Johnson and Hallberg, 2005). The AMD is highly acidic and is enriched with sulphate, iron, nickel, manganese, lead and many other heavy metals (Evangelou, 1995). The acidic nature of AMD provides a desirable medium for heavy metals to remain in solution rendering the water highly toxic and corrosive. Although naturally occurring systems found in association with some geological strata are able to neutralize the formed acid and precipitate the heavy metals either as carbonates or hydroxides (Johnson and Hallberg, 2005; Dold, 2010), they are overwhelmed in most cases. Excess quantities of acid that are beyond the natural neutralizing systems are produced. Therefore, the release of the toxic water onto land and water streams is unavoidable thus, causing dire environmental consequences. For example, massive fish eradication, ecological imbalance, plant poisoning, equipment scaling and corrosion are some of the consequences (Earle and Callaghan, 1998; Jennings et al., 2008; Yadav, 2010).

Over the past 50 years, assiduous efforts have been directed at remediating AMD through acid and metal removal so as to reduce the impact of the acidic water on the environment and produce water suitable for re-use (Johnson and Hallberg, 2005; Simate and Ndlovu, 2014). A conventional and popular method used to treat AMD is neutralization by limestone. However, the main drawback of this method is the huge amount of sludge produced which presents serious disposal challenges (Johnson and Hallberg, 2005). Furthermore, valuable resources such as sulphuric acid which could otherwise be recovered are lost in the process. Other methods such as adsorption, ion exchange, membrane processes and electro-winning have also been used in the past. However, the downside of all these efforts is that the constituents of AMD have not been viewed as valuable resources.

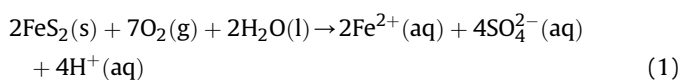
In a world where environmental protection and rehabilitation are fast becoming a priority, economic sustainability and technical feasibility become key drivers in determining the suitability of any proposed method or system for any application. Methods that can transform undesirable waste materials to useful products are highly preferred. Therefore, research in the recent years has focused on the recovery and marketing of valuable AMD constituents such as iron oxides, water and sulphuric acid, etc., (Hedin, 2002; Buzzi et al., 2013; Martí-Calatayud et al., 2013). Of growing interest is the recovery of sulphuric acid from AMD (Martí-Calatayud et al., 2013) which is partly due to its appreciable market in the chemical and metal industries. The recent growth in uranium, nickel laterites and copper–cobalt oxide industries has also played a major role in the demand for sulphuric acid used for leaching. Therefore, alternative methods for meeting the chemical demand, apart from sulphur and pyrite burning in a smelter, are being considered. This approach could prove to be useful in developing countries like South Africa where power supply challenges can possibly cause cutbacks in the operation of smelters and other facilities that produce sulphuric acid. In such cases, the recovery and usage of sulphuric acid from AMD could provide an alternative solution to the increasing demand. Furthermore, from an environmental standpoint, the recovery of the sulphuric acid from AMD provides the benefit of a water by-product which is significantly less harmful to the environment. Hence, this paper focuses on the recovery of sulphuric acid from AMD and its possible utilization in various processes. The paper brings to light a number of technologies that have been studied or applied to acid recovery from aqueous and other waste water solutions including AMD. Each technology is reviewed and evaluated with the perspective of application to AMD solutions. The successful recovery of sulphuric acid from AMD will go a long way in alleviating problems associated with AMD. Apart from the production of re-usable water, the recovery of the valuable sulphuric acid would be used to offset the

treatment cost of AMD (Simate and Ndlovu, 2014). In this regard, what has been long recognized as an 'environmental hazard' could be transformed into a lucrative business.

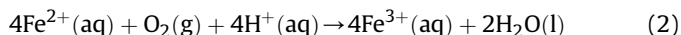
This paper is organized as follows: the occurrence and composition of AMD is discussed first, followed by the utilization of sulphuric acid. The technologies used for acid recovery, economic evaluation of each process and future prospects are outlined in the last three sections, respectively.

## 2. Occurrence and composition of acid mine drainage

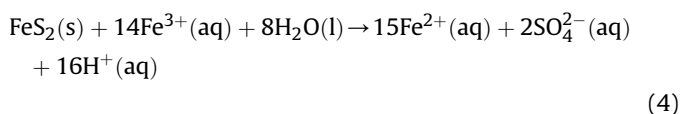
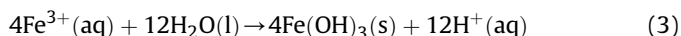
Underground mine workings, mine waste dumps, tailings and ore stockpiles are the major sources of AMD. The AMD results from a series of reactions starting with the oxidation of pyrite in the presence of oxygen and water to form ferrous iron and sulphuric acid (Singer and Stumm, 1970) as shown in Equation 1.



In sufficiently oxidising environment (dependant on  $\text{O}_2$  concentration, pH greater than 3.5 and bacterial activity) the ferrous iron released in Reaction 1 may be oxidised to ferric iron, according to the following reaction (Blowes et al., 2003; Ackil and Koldas, 2006).



At pH values between 2.3 and 3.5, ferric iron precipitates as  $\text{Fe}(\text{OH})_3$  as shown in Equation (3) (Ackil and Koldas, 2006). This causes a further drop in pH and leaves little ferric iron in solution. The remaining ferric iron reacts directly with pyrite to produce more ferrous iron and acidity as illustrated in Equation (4) (Ackil and Koldas, 2006; Jennings et al., 2008).



Upon consideration of the reaction schemes above (Equations (1)–(4)), Reaction 2 has been found to be the slowest and consequently termed the rate limiting reaction of pyrite oxidation (Singer and Stumm, 1970). However, the presence of acidophilic bacteria such as *Thiobacillus ferrooxidans* greatly accelerates the abiotic oxidation rate of ferrous ions by a factor of hundreds to as much as millions. This maintains a high concentration of ferric iron in the system (Singer and Stumm, 1970; Blowes et al., 2003; Sanchez, 2008), thus resulting in highly oxidizing conditions. These acidic oxidizing conditions provide a desirable environment for the leaching of other minerals such as galena, sphalerite, chalcopyrite, etc., which are usually found in association with pyrite (Blowes et al., 2003). The result of the overall process is a solution that is highly acidic and enriched with sulphate, iron, aluminium, nickel, lead and other toxic heavy metal ions. As already stated, discharge of this acidic solution onto land and eventually into rivers and lakes poses an instant threat to the biota and ecological balance (Evangelou, 1995; Dold, 2010). Hence, it is imperative that the acidity is removed in order to minimize the environmental impact. However, the removal of the acid should be a holistic process with the focus being on the recovery and reutilization. Recovery of the acid will not only produce potable water suitable for other purposes, but will also recover a valuable resource which could be used

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