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Acid mine drainage: Challenges and opportunities

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ABSTRACT

Acid mine drainage (AMD) or acid rock drainage (ARD) is considered as one of the main pollutants of water in many countries that have historic or current mining activities. Its generation, release, mobility, and attenuation involves complex processes governed by a combination of physical, chemical, and biological factors. In general, AMD is produced by the oxidative dissolution of sulphide minerals. This paper reviews the current state-of-the-art of AMD. It critically analyses the work performed in recent years on its occurrence, effects (on human health, plant life and aquatic species), and summarizes the remediation approaches taken so far to overcome the problem of AMD. The challenges faced in tackling the remediation of AMD have also been considered. Commercially developed projects that are either in operation, being piloted or under evaluation have also been discussed. Finally, the paper speculates on future directions or opportunities that deserve exploration.

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Introduction

The problem of sulphide oxidation and the associated acid mine drainage (AMD) or acid rock drainage (ARD) has been a major focus of research over the last 50 years [1]. The term AMD is commonly used (than ARD) because the process occurs mainly at mining sites. It occurs in both operating and abandoned polymetallic sulphide mining sites [2,3] – in tunnels, mine workings, open pits, waste rock piles, and mill tailings [2–4]. Although the chemistry of AMD generation is straightforward, the final product is a function of the geology of the mining region, presence of microorganisms, temperature and also of the availability of water and oxygen [5]. These factors are highly variable from one region to another, and, for this reason, the prediction, prevention, containment and treatment of AMD must be considered carefully and with great specificity [5]. The causes of AMD are not only limited to the mining industry, but can also occur where sulphide materials are exposed, e.g. in highway and tunnel construction and other deep excavations [6–8]. In other words, any activity that disturbs mineralized materials can lead to AMD. The AMD is a strong acidic wastewater rich in high concentrations of dissolved ferrous and non-ferrous metal sulphates, and salts [9,10] and if AMD is left untreated, it can contaminate ground and surface watercourses, damaging the health of plants, humans, wildlife, and aquatic species [10,11]. Consequently, the development of cost-effective and sustainable remediation solutions for the AMD problem has been the subject of extensive research [12]. However, despite AMD being pinpointed as a looming problem as early as the 1970s, the simple cleaning processes available and the many parties with powerful incentives to act, such as government to non-governmental organizations to mining companies, no single party has produced the required combination of scale, resources and credibility to deal with the problem.

This paper reviews the current state-of-the-art of AMD. It describes the work performed in recent years on its occurrence, effects, and summarizes the control and remediation approaches taken so far to overcome the problem of AMD, the challenges faced and speculates on future directions or opportunities that deserve exploration. Accordingly, the paper is organized as follows: a background of the occurrence of AMD is presented first, followed by its effects on human health, plant life, and aquatic species. The paper then discusses some of the control and remediation strategies followed by a discussion of industrially useful materials generated from AMD. Commercially developed projects that are either in operation, being piloted or under evaluation have also been discussed. Finally, the paper explores the prospective future opportunities that may be available for treating AMD by integration of various conventional and non-conventional processes.

Occurrence of acid mine drainage

General overview

The main cause of AMD is the oxidation of sulphide minerals (Table 1) such as pyrite (FeS_2) as a result of exposure of these minerals to both oxygen and water [2,13], and microorganisms [14]. Although this process occurs naturally, mining activities accelerate the process of AMD generation because such activities increase the exposure of sulphide minerals to air, water, and microorganisms [15]. Thus, AMD is prominent in both operating and inactive or abandoned mining sites – in underground tunnels and shafts, open pits, waste rock piles, and mill tailings [4]. Though AMD is less important when the mine is in active production because the water tables are kept low by pumping, it is severe in closed and abandoned mines where pumps are turned off resulting in the rebound of water tables [2].

The process of AMD generation is extremely complex since it involves chemical, biological, and electrochemical reactions which vary with environmental conditions [8]. To start with, sulphide minerals in ore deposits are formed under reducing conditions in

Table 1
Some important metal sulphides with pyrite and marcasite being the predominant acid producers [7].

Metal sulphide	Chemical formula
Pyrite	FeS_2
Marcasite	FeS_2
Pyrrhotite	$Fe_{1-x}S$
Chalcocite	Cu_2S
Covelite	CuS
Chalcopyrite	$CuFeS_2$
Molybdenite	MoS_2
Millerite	NiS
Galena	PbS
Sphalerite	ZnS
Arsenopyrite	$FeAsS$

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