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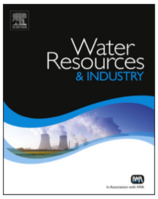

Reclamation of water and the synthesis of gypsum and limestone from acid mine drainage treatment process using a combination of pre-treated magnesite nanosheets, lime, and CO_2 bubbling

Vhahangwele Masindi[a,b,*], Godfrey Madzivire[b,c], Memory Tekere[b]

[a] *Council for Scientific and Industrial Research (CSIR), Built Environment (BE), Hydraulic Infrastructure Engineering (HIE), P.O Box 395, Pretoria 0001, South Africa*

[b] *Department of Environmental Sciences, School of Agriculture and Environmental Sciences, University of South Africa (UNISA), P. O. Box 392, Florida 1710, South Africa*

[c] *Council for Geoscience, Water and Environment Unit, 280 Pretoria Street, Silverton, Pretoria, South Africa*

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ABSTRACT

In this study, an integration of pre-treated magnesite, lime, and CO_2 bubbling (MLC) was used for the treatment of acid mine drainage (AMD). The primary aim was to reclaim clean water and synthesize valuable minerals. This treatment process comprises three steps which include neutralisation (i) using magnesite, gypsum synthesis (ii) using lime and limestone synthesis (iii) using CO_2 bubbling. Reactors at a semi-pilot scale system were used to fulfil the goals of this study. AMD was mixed with magnesite and lime at 1 g: 100 mL S/L and 8 g: 100 mL S/L ratios respectively. Pilot results revealed that amorphous hydroxides of Fe, gypsum, and limestone can be obtained from the secondary sludge/product. The obtained materials were of high purity ($> 75\%$). This was further confirmed by X-ray Diffraction, X-ray Fluorescence, and Fourier Transform Infrared Spectrometer analytical techniques. The product water was suitable for irrigation, industrial and agricultural use as per South African standards. Furthermore, it was observed that the initial pH of AMD was 2.5 and it was increased to pH ≥ 10 and > 12 after contacting magnesite and lime respectively. To stabilise the pH, CO_2 was bubbled and the pH was reduced to ≤ 7.29 which was suitable for a number of applications. Moreover, $\geq 99\%$ and $\geq 95\%$ of metal species and sulphate were removed from an aqueous system, respectively. The techno-economic evaluation indicated that it can cost R806.40 (66 USD) to treat 3.5 KL of acid mine drainage and have a return of R11263.60 (933 USD) from the selling of the recovered materials, thus making this technology economically viable. From the findings of this study, it can be concluded that the application of MLC process can neutralise AMD and produce valuable products. More so, this novel and self-sustainable project will therefore go a long way in curtailing the impacts of AMD by valorising the product minerals and exploit the resultant commercial value hence aiding in off-setting the running costs of the treatment process.

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[*] Corresponding author at: Council for Scientific and Industrial Research (CSIR), Built Environment (BE), Hydraulic Infrastructure Engineering (HIE), P.O Box 395, Pretoria 0001, South Africa.

E-mail addresses: VMasindi@csir.co.za, masindivhahangwele@gmail.com (V. Masindi).

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1. Introduction

Depending on hydrogeology, mine effluents have different physicochemical properties that range from acidic, neutral and basic drainage [1–3]. Amongst those, acid mine drainage (AMD) forms the crux of the largest liabilities faced by the mining industry due to the extent of potential impacts, scale and magnitudes of its threat to water resources, human health and the environment [4–7]. Acid mine drainage results from the weathering of pyrite (FeS_2) and other reactive sulphide-bearing minerals when exposed to atmospheric air and water leading to the release of a drainage that is rich in acid, sulphate and metal ions into the environment [8,9], as shown in Fig. 1(A) and (B). These minerals may be embedded in the tailings or host rocks of a mineral in quest. As such, AMD can be formed from the tailings seepage (Fig. 1(**B**)) or decanting from underground voids (Fig. 1(**A**)).

Acid mine drainage is primarily composed of H^+, SO_4^{2-}, and Fe(II), as the major components [10]. Masindi, Gitari, Tutu and DeBeer [11] further pointed out that AMD also contains Al(III) and Mn(II), As, Cu, Ni, Zn, Co and Cr and alkaline earth metals such as Mg and Ca. The formation of AMD may be depicted by the following chemical equation [12,13]:

$$4FeS_2 + 15O_2 + 14H_2O \xrightarrow{\text{bacteria}} 4Fe(OH)_3 + 8SO_4^{2-} + 16H^+ \quad (1)$$

High acidity in secondary water increases the solubility, mobility and bio-availability of metals species, hence raising the concentration to unacceptable, and often, toxic levels [4,8,14]. The adverse effects of acidification on aquatic ecosystems are associated with deteriorating quality of water in the receiving environment, destruction of the bicarbonate buffer (neutralizing) capacity of water, the loss of bicarbonate-dependant photosynthetic organisms as bicarbonate is consumed, the reduction and eventual cessation of nutrient cycling processes in water bodies, and loss of organisms through damage to carbonate exoskeletons or cell components [15,16]. The most visual legacy of AMD is undoubtedly the precipitation of ferric (Fe^{3+}) hydroxide and oxy-hydroxide and oxy-hydrosulphates complexes as a yellow or orange coating in stream channels [17,18]. These precipitates lead to a reduction in dissolved oxygen concentrations in affected water bodies during their formation, and have abrasive effects on biota and clog streambeds once formed. It can also prevent the penetration of light to aquatic ecosystem, hence suffocating aquatic organisms [19–23].

In South Africa, recent studies have reported that there are enormous volumes of AMD produced by the Western Basin on the West Rand basin in Gauteng Province that amount to ~60 mL/d, carrying sulphate (SO_4) concentrations of ~4.5–5 g/L and ferrous iron (Fe^{2+}) concentrations of up to ~1.5 g/L depending on seasons and host rock, during and after rainfall it can even go beyond that limit [2,10]. The Mpumalanga coal basins can have up to ± 18 g/L of sulphate and ± 6 g/L of Fe-species [10,18,24].

Worldwide, a number of treatment methods, both passive and active, have been proposed and used for abating AMD [4,14,25–29]. Among these, the common ones include ion-exchange [30–32], adsorption [33–38], bio-sorption [39–43], bio-precipitation [44–47], neutralisation [29,48–53], coagulation and precipitation [54–59]. The extent of application of most of these methods has largely been limited by factors such as cost and generation of excessive secondary sludge [14,16,31,60–64]. Adsorption has been regarded as the best technology for water depollution but its effectiveness is limited to dilute solutions due to quick saturation of the adsorbent and selective adsorption. In light of the above, precipitation of chemical species coupled with adsorption has received paramount attention lately. This is attributed to its ability to treat large volumes of water with high efficiency.

The principal aim of this study was to treat AMD using calcined cryptocrystalline magnesite. The treated water was taken to subsequent reactors for gypsum and limestone synthesis. The resale of recovered products will off-set the running cost of this technology, hence making it to be self-sustainable. This integrated approach has three phases of water treatment and they include: (i) neutralisation and metals removal using calcined cryptocrystalline magnesite, (ii) gypsum synthesis in the secondary process using lime and (iii) bubbling of CO_2 into the third reactor to synthesize limestone. The product water is anticipated to meet the discharge and irrigation requirements as per regulatory frameworks.

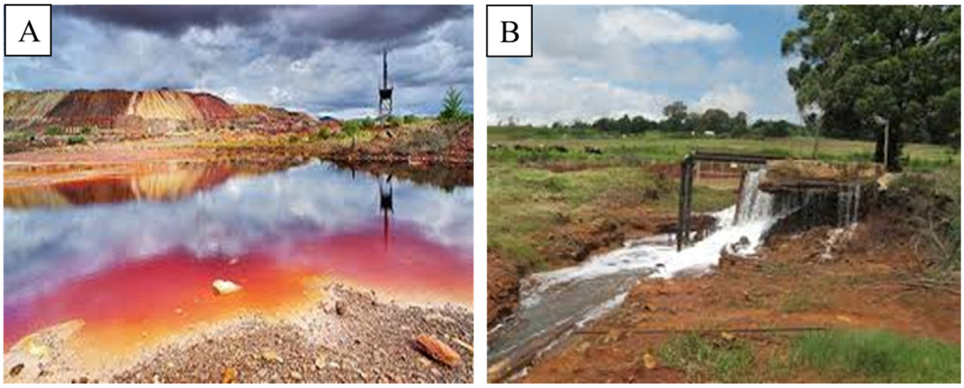

Fig. 1. AMD from tailings leachates (A) and underground shaft decant (B).