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A novel technology for neutralizing acidity and attenuating toxic chemical species from acid mine drainage using cryptocrystalline magnesite tailings

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ABSTRACT

The present study was developed with the aim of beneficiating two waste materials by converting them into a resource. Magnesite tailings, which is the byproduct of magnesite mining, was used to remediate acid mine drainage (AMD) which is the byproduct of gold mining. This will go a long way in minimizing the use of virgin resources and thus fostering the process of sustainable development. AMD was reacted with magnesite tailings at an optimum equilibration time of 30 min and 1 g of magnesite tailings dosage. Contact of AMD with magnesite tailings led to an increase in pH (pH > 10) and a drastic reduction in inorganic contaminants (>99%), except for sulphate that achieved >80% for sulphate removal efficiency. Kinetic studies showed that ·adsorption of chemical species by magnesite tailings fitted well to pseudo-second-order adsorption kinetics hence confirming chemisorption. Pore diffusion was also determined to be one of the principal mechanisms acting as a major rate governing step. pH Redox Equilibria (PHREEQC, in C language) geochemical modelling predicted that Fe removed as $Fe(OH)_3$, goethite (FeOOH), and jarosite ($KFe_3(SO_4)_2(OH)_6$), Al as basaluminite ($Al_4(SO_4)(OH)_{10}\cdot 5(H_2O)$), boehmite ($\gamma$-AlO(OH)), jurbanite ($AlSO_4(OH)\cdot 5H_2O$, and $Al(OH)_3$ as gibbsite and diaspore. Al and Fe also precipitated as iron (oxy)-hydroxides and aluminium (oxy)-hydroxides. Mn precipitated as rhodochrosite ($MnCO_3$) and manganite (MnOOH). Ca was removed as gypsum ($CaSO_4\cdot 2H_2O$) and dolomite ($CaMg(CO_3)_2$). Sulphate was removed as gypsum and Fe, Al hydroxyl sulphate minerals. Mg was removed as brucite ($Mg(OH)_2$) and dolomite ($CaMg(CO_3)_2$). This would explain the reduction in the chemical species contents in the treated water. Based on the above, it was concluded that magnesite tailings can neutralize and attenuate elevated concentrations of chemical species in AMD to within prescribed legal frameworks for water use in agricultural and industrial sectors in South Africa.

1. Introduction

Due to a rapid increase in population growth, South Africa is facing a serious water crisis. The demand of water resources that are safe for human consumptions and other defined uses has also expanded alarmingly [1–3]. Pragmatic technologies need to be developed to counter for the crisis by reclaiming polluted water to drinkable standards. However, the legacy of gold and coal mining has rendered water unfit for myriad defined uses. Approximately 360 000 000 l of metalliferous mine effluents are discharged to adjacent aquatic ecosystems per day. This water is characterised of high acidity, electrical conductivity and total dissolved solids [4,5].

Acid mine drainage is formed when sulphides bearing minerals such as iron, gold, copper, lead, zinc, mercury, silver, etc., are exposed to water and oxygen. The release of metals to effluent waters makes the water metalliferous. In numerous occasions, the formation of AMD can be represented by the following chemical equations [6,7]:

$$2FeS_{2(s)} + 7O_{2(g)} + 2H_2O \overset{bacteria}{\rightarrow} 2Fe^{2+}_{(aq)} + 4H^{+}_{(aq)} + 4SO^{2-}_{4(aq)} \quad (1)$$

$$4Fe^{2+}_{(aq)} + O_{2(g)} + 4H^{+}_{(aq)} \rightarrow 4Fe^{3+}_{(aq)} + 2H_2O_{l} \quad (2)$$

$$FeS_{2(s)} + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO^{2-}_{4(l)} + 16H^{+} \quad (3)$$

$$Fe^{3+}_{(aq)} + 3H_2O_{l} \rightarrow Fe(OH)_{3(s)} + 3H^{+}_{(aq)} \quad (4)$$

These reactions are also mediated by sulphate oxidising bacteria (SOB) (Eq. (1)) [7–9]. The acidity in acid mine drainage (AMD) promotes the leaching of heavy metals from the surrounding geologies

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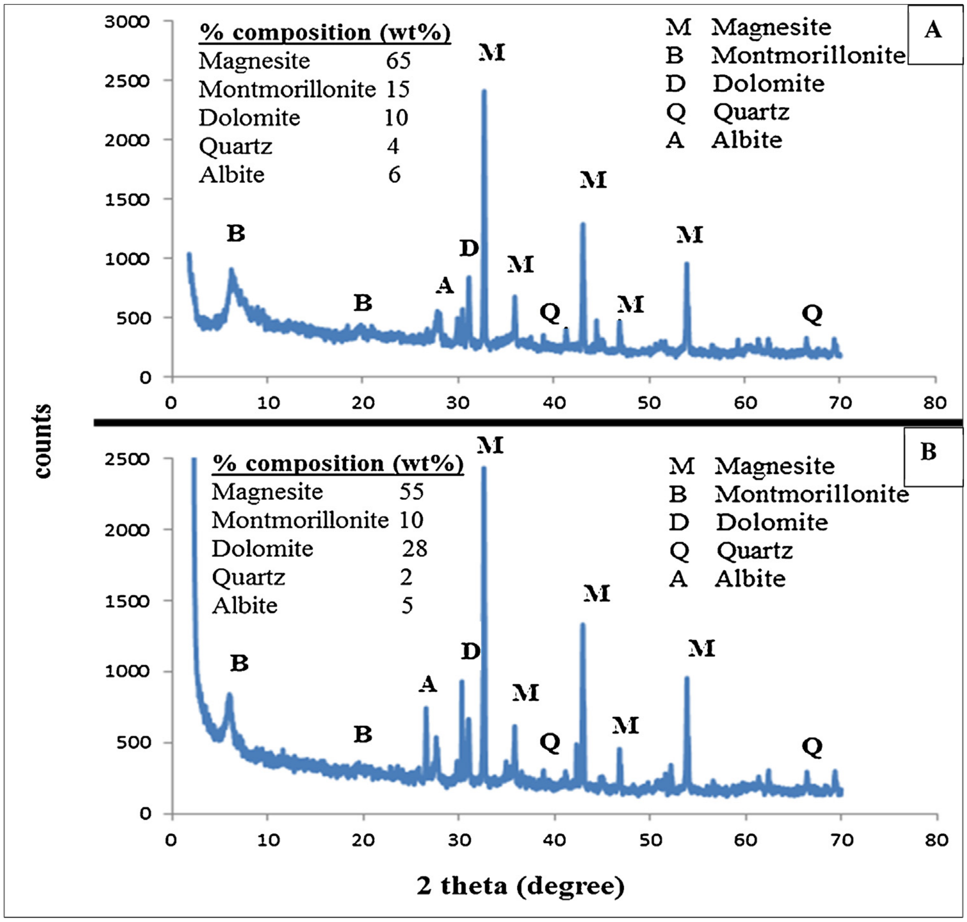

Fig. 1. Mineralogical composition of unreacted (A) and AMD-reacted magnesite tailings (B).

Table 1
Elemental composition of unreacted and AMD-reacted magnesite tailings (wt.%).

Elements	Unreacted magnesite tailings	AMD-reacted tailings
wt.%		
SiO_2	27.2	28.5
TiO_2	1.6	1.9
Al_2O_3	3.5	3.7
Fe_2O_3	6.1	9.9
MnO	0.1	0.1
MgO	28.3	26.5
CaO	6.6	8.0
Na_2O	0.4	0.3
K_2O	0.7	0.8
P_2O_5	0.2	0.2
Cr_2O_3	0.1	0.1
SO_3	4	9
LOI	21.4	15.0
Total	100.2	100.2
H_2O^-	2.01	6

[10–13]. Mining houses are in a quest to come up with sustainable technologies that are economically viable and effective in the remediation of mine effluents. An array of active and passive treatment technologies have been developed for the treatment of acid mine drainage but lead to the generation of secondary sludge that is toxic and expensive to dispose, offer poor performance in terms of treatment efficiency and high cost limits their application for AMD treatment [14].

Traditionally, precipitation, adsorption, ion exchange, reverse osmosis and bio-sorption were the commonly used technologies in AMD treatment [15–25]. South Africa mainly relies on the use of lime and limestone for treatment of acid mine drainage. However, limestone has the limitation of raising the pH to <7 which is not enough for removal of all metal species. As such, it is used as a pre-treatment technology for neutralization purposes and partial removal of metals. Lime is very efficient for neutralization of acidity and removal of inorganic chemical species from waste water but the pH needs to be adjusted in post treatment processes. Moreover, this technology produces huge volumes of solid residues that have raised serious environmental implications in terms of disposal to the environment since it contains toxic chemical species [26,4,27,5].

Thus, there is a need to come up with a sustainable technology which is environmentally friendly for acid mine drainage treatment [28]. The present study was aiming at beneficiating the waste materials originating from cryptocrystalline magnesite mining by using them for neutralization of acidity in AMD and removing the inorganic contaminants. Masindi et al. [5,29] reported that cryptocrystalline magnesite was successfully used for the remediation of acid mine drainage. Therefore, it was envisaged that the tailings could also perform better for AMD treatment. Sibanda et al. [30] reported that the magnesite mine tailings dam contains a pH of >9 which is suitable for precipitation of metals.

2. Materials and methods

2.1. Sampling and preparation of samples

Cryptocrystalline magnesite tailings were collected from the Folovhodwe Magnesite Mine (Nyala mine) in Limpopo Province, South Africa (22°35′47.0′′S and 30°25′33′′E). Magnesite tailings