



# Recovery of drinking water and valuable minerals from acid mine drainage using an integration of magnesite, lime, soda ash, CO<sub>2</sub> and reverse osmosis treatment processes



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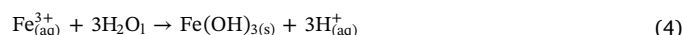
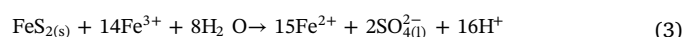
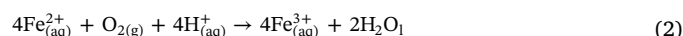
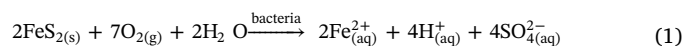
Acid mine drainage  
Gypsum  
Brucite and limestone recovery  
Magnesite  
Lime  
Soda ash  
CO<sub>2</sub> bubbling

## ABSTRACT

In this study, the possibility of recovering valuable minerals and drinking water from acid mine drainage was explored. Neutralisation of Acid Mine Drainage (AMD) and recovery of metals were done at 60 mins of equilibration. DOW water & Process solutions, Reverse Osmosis System Analysis (ROSA), version 9.1 was used to further purify the resultant water to meet the drinking quality standards as required by the South African National Standard (SANS) report (SANS 241). The obtained results revealed that drinking water, metals, gypsum, hydrated lime/limestone were recovered from the treatment process as valuable resources. This was confirmed by X-ray diffraction (XRD) and X-ray Fluorescence (XRF). Morphological properties of initial and recovered minerals were examined using High Resolution Scanning Electron Microscopy (HR-SEM). Carbon Dioxide (CO<sub>2</sub>) was bubbled through soda treated water to recover limestone and to stabilise the pH of the product water (pH ≈ 7.5). Post treatment, the resultant water was further purified by simulated Reverse Osmosis (RO) system to produce water that meet the drinking water quality as stipulated by SANS 241 standards. The pH of recovered drinking water was ≈ 6.5. The metals removal efficiency of the RO system was ≈ 100%. In general, this study demonstrated that the integration of magnesite, lime, soda ash, CO<sub>2</sub> and reverse osmosis treatment processes can convert environmental pollutants and waste resources into commercially valuable products that have industrial applications.

## 1. Introduction

Mine drainages are classified into three types, namely: acid, neutral and basic drainages [1–3]. Of prime concern is acid mine drainage (AMD) because it contains very low pH (pH ≈ 2 – 3) and elevated concentration of Fe, Al, Mn and sulphate in addition to traces of Zn, Ni, Co, Cd, Cu, Hg and Pb [4]. The acidic pH in AMD accelerate the solubilisation of metals from the surrounding geologies on contact [4]. This makes the elements in acid mine drainage a paramount concern due to their residual impacts to the environment and living organisms including human beings. Metals, metalloids and non-metals in acid mine drainage can pose hazardous impacts to terrestrial and aquatic ecosystems [5–7]. The primary source of AMD is the oxidation of sulphide bearing minerals [8]. Using pyrite as an example, the chemical reactions that an AMD formation process underwent is represented by the following chemical reactions [4,9]:



These reactions are also mediated by Fe and sulphate oxidising bacteria (FOB and SOB) (Eq. (1)) [6] and since the earlier reactions catalyse the later ones, it is difficult to stop the reaction series once it has started [10].

To counter for mine water problems, there is a wide range of documented, piloted and adopted mine water treatment technologies and studies [3,7,11]. Mine water treatment technologies are classified into passive, active and integrated treatment processes [7]. Active treatment process involves addition of neutralisation materials such as magnesite, periclase, brucite, lime, hydrated lime, limestone, soda ash

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and caustic soda whereas passive processes involves the use of wetland, reactive barriers, lime drains and biological processes [3,9,11,12]. Integrated approach entails the use of active treatment process such as neutralisation upstream and purification of resultant water downstream using wetlands or bio-barriers [7,13,14]. Bologo, et al. [15] integrated of brucite and barium salts to remove metals in the first phase and sulphate in the second phase.

Most of these technologies have the pros and cons which may range from the generation of voluminous sludge that is expensive to dispose, high running cost and poor efficiencies [1,3,7,11]. This has encouraged the research community to be in a quest of metal recovering technologies. Advancement in research has proved that valuable resources are recovered from AMD [7,16,17]. Their principal aims are to off-set the running costs and to make the mine water treatment process sustainable. Researchers have recovered ferric iron which is used as pigments [18], synthesised magnetite from acid mine drainage which has myriads of industrial applications such as wastewater treatment and separation processes [6,19], recovery of sulphuric acids [11], recovery of metals through sequential precipitation [13,18,20–23], recovery of gypsum through the use of lime [2,13] and etc. This has triggered the focus of this study since most of the study focus on specific units like neutralisation only [24–26], neutralisation with partial removal of sulphates, neutralisation and sulphate removal in a second step [24]. The challenge is to produce water that can meet the drinking standard as stipulated by water quality regulations. Therefore, the ultimate goal of this study was to integrated magnesite, lime, soda ash, CO<sub>2</sub> and reverse osmosis treatment processes to produce drinking water and recover valuable minerals that have commercial value and industrial applications.

## 2. Materials and methods

### 2.1. Materials

Raw magnesite rock was collected from the Folvhodwe Magnesite Mine in Limpopo Province, South Africa. Commercial grade lime and soda ash was obtained from lab-consumables. Field AMD samples were collected from a coal mine in Mpumalanga province, South Africa. Carbon Dioxide (CO<sub>2</sub>) was obtained from AFROX Gas Company in Johannesburg, South Africa.

### 2.2. Preparation of materials

Magnesite samples were milled to a fine powder for 15 min at 800 rpm using a Retsch RS 200 vibratory ball mill and passed through a 32 µm particle size sieve. The lime was fine enough for gypsum recovery experiments. Soda ash was fine enough for hydrated lime recovery. The samples were kept in a zip-lock plastic bag until utilization for AMD treatment and valuables recovery. CO<sub>2</sub> was used for limestone recovery.

### 2.3. Characterisation of aqueous samples

pH, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were monitored using CRISON MM40 portable pH/EC/TDS/

**Table 1**  
chemical composition of AMD and treated water after going through different water treatment units.

| Parameters                             | AMD   | Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|----------------------------------------|-------|--------|--------|--------|--------|
| pH                                     | 2     | 9      | 11     | 12     | 7.5    |
| Acidity (mg/L CaCO <sub>3</sub> )      | 800   | 0      | 0      | 0      | 0      |
| Alkalinity (mg/L CaCO <sub>3</sub> )   | < 5,0 | 60     | 50     | 800    | 80     |
| Aluminium (mg/L Al)                    | 300   | 0.1    | 0      | 0      | 0      |
| Calcium (mg/L Ca)                      | 300   | 700    | 4500   | 0      | 0      |
| Electrical Conductivity (mS/m [25 °C]) | 600   | 600    | 700    | 1000   | 200    |
| Iron (mg/L Fe)                         | 8000  | 0.1    | 0.1    | 0      | 0      |
| Magnesium (mg/L Mg)                    | 300   | 1500   | 150    | 100    | 0.5    |
| Manganese (mg/L Mn)                    | 75    | 10     | 0      | 0      | 0      |
| Sodium (mg/L Na)                       | 0     | 0      | 0      | 5000   | 5      |
| Sulphate (mg/L SO <sub>4</sub> )       | 30000 | 19000  | 800    | 500    | 50     |
| Total Dissolved Solids (mg/L)          | 3500  | 4000   | 4500   | 3000   | 1000   |
| Total Hardness (mg/L)                  | 2000  | 8000   | 8000   | 500    | 200    |

\*Note: Unit 1–AMD and magnesite, Unit 2–Unit 1 water and Lime, Unit 3–Unit 2 water and soda ash and Unit 4–Unit 3 water and CO<sub>2</sub> bubbling.

Temperature multimeter probe. Aqueous samples were analysed using Inductively coupled plasma mass spectrometry (ICP-MS) (7500ce, Agilent, Alpharetta, GA, USA) for metal cations and sulphate was analysed using Ion chromatography (IC) (850 professional IC Metrohm, Herisau, Switzerland). The accuracy of the analysis was monitored by analysis of National Institute of Standards and Technology (NIST) water standards. Three replicate measurements were made on each sample and results are reported as mean average.

### 2.4. Characterization of the feedstocks and recovered valuables

Mineralogical compositions of synthesised magnetite samples were determined using X-ray diffraction (XRD). Elemental composition was determined using X-ray fluorescence (XRF). Morphological properties were examined using Scanning Electron Microscopy (SEM) (JEOL JSM – 840, Hitachi, Tokyo, Japan).

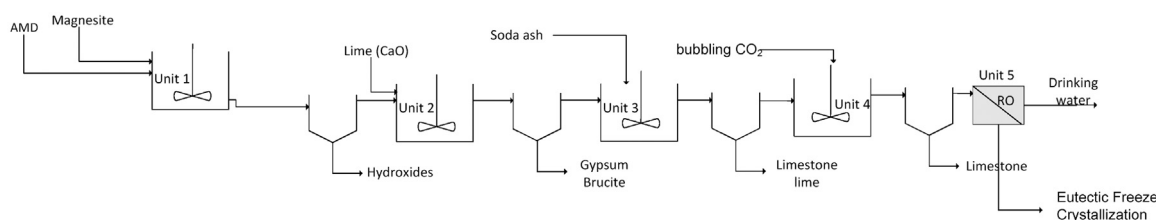
### 2.5. Quality control/quality assurance

A QA/QC programme was established and implemented to ensure the production of trustworthy results. The QA/QC process entailed conducting the experiments in triplicate and reporting the data as mean value. Data was considered acceptable when percentage difference within triplicate samples and percent error were below 10%. The analytical values below detection limit (BDL) were managed in according to EPA guideline. The accuracy of the analysis was monitored by analysis of National Institute of Standards and Technology (NIST) water standards. Inter-laboratory analysis was also done to further verify the validity of the results.

### 2.6. Developed valuables and drinking water recovery process

A schematic presentation of the drinking water and valuable minerals recovery is depicted in Fig. 1.

This system is separated into 5 units. Unit 1 represent a system that



**Fig. 1.** Schematic presentation of drinking water and valuable minerals recovery.

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