Reclamation, Recovery and the Synthesis of Valuable Minerals from Acid Mine Drainage Treatment Process

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Abstract

In this pilot study, the treatment of acid mine drainage (AMD) using an integrated approach was evaluated. The developed approach uses an integration of pre-treated magnesite, lime, soda ash, and Reverse Osmosis (RO) system to produce valuable minerals. AMD and product water were mixed with magnesite, lime, soda at 0.7 g:100 mL, 0.7 g:100 mL and 0.5 g:100 mL S/L ratios respectively. The product water was determined to surpass the South African National Standards (SANS 241) water quality specifications for drinking water. Recovered minerals include Fe-based minerals, gypsum and limestone. The resultant minerals were drinking water, Fe-based minerals (75% purity), gypsum (75% purity) and calcium carbonate (100% purity). Selling of the recovered minerals will make this technology feasible and more economically viable since the returns will aid in off-set the running cost of the treatment process.

Keywords: Acid mine drainage, treatment, drinking water, minerals recovery, minerals synthesis

Introduction

Pollution of surface and subsurface water resources by Acid Mine Drainage (AMD) emanating from Coal and Gold mine activities has rendered the environment unfit to foster life and render its intrinsic values. This is attributed to the fact that AMD contains potentially toxic and hazardous chemical components that originate from the weathering of host rocks. The embedding seams and lithologies in coal and gold mining area contain sulphide bearing minerals that when they get into contact with water and oxygen lead to the formation of a very acidic and metals-rich drainage. The acidic nature of AMD further degrades the surrounding geology by leaching out heavy metals in the surrounding aqueous media. AMD mainly contain Fe, Al, Mn, S as sulphate and traces of other chemical components (Masindi et al. 2018).

In an attempt to protect the environment, governments and environmental activists are advocating for proper management of AMD prior discharge to different receiving environments. To date, progress has been made but mining houses are still in a quest for effective, efficient and sustainable approaches in treating acid mine drainage (AMD) and attain value from the treatment process since most of the treatment technologies pose secondary pollution due to sludge generation (Masindi 2016). Active and passive treatment approaches have been widely used in the treatment of AMD. Those approaches use different chemical attenuating mechanisms and they include precipitation, adsorption, filtration, bio-sorption, ion-exchange, phytoremediation, desalination, or an integration approach (Simate and Ndlovu 2014).

The present study was therefore designed with the aim of treating acid mine drainage and attain valuable minerals that has commercial value. It involves the use of a number of treatment processes that relies on calcined magnesite, lime, soda ash, and RO in a stage-wise fashion. The first stage uses calcined magnesite to recover Fe-based minerals and partially sulphate as gypsum, the 2nd stage entails the use of lime to synthesize gypsum, and the 3rd stage entails the use of lime to remove residual Ca and Mg to synthesize limestone. The product minerals have a number of industrial applications hence demonstration a room for products valorisation. The product water is soft due to removal of Ca and Mg and it is safer for RO system purification. The water will be purified and Na-rich brine will be taken to a number of emerging processes such as membrane distillation, eutectic freeze or cooling systems for further minerals acquisition.

Materials and Methods

Treatment of field AMD at optimized conditions

The schematic presentation of acid mine drainage treatment process is depicted in Figure 1.

As shown in **Figure 1**, calcined cryptocrystalline magnesite, lime and soda ash (MASRO process) were utilised to recover valuable minerals that have commercial value, and to produce water that is fit for myriads of defined uses such as drinking, irrigation, and industrial purposes. The minerals recovery, synthesis, and water reclamation process used authentic AMD from coal mining processes. In the first reactor, a sequential and fractional precipitation method was executed for precipitation of metals as hydroxides. Masindi et al. (2016) reported that the interaction of magnesite with AMD lead to the precipitation of metals as hydroxides (solids). The formation of complexes, precipitates and other products was investigated in each stage of the process. Stage two focuses on gypsum synthesis from lime additions, stage three focuses on calcium carbonate synthesis from soda ash addition. The last stage is the RO system which further purifies the water to drinking standard.

Neutralization of AMD and the recovery of Fe-based minerals

Magnesite was calcined at 900°C. Calcined cryptocrystalline magnesite was used to treat authentic AMD samples at 60 minutes of equilibration, 0.7 g:100 mL S/L ratios, 650 rpm agitation speed and ≤ 32 µm particle size of calcined cryptocrystalline magnesite, as optimized.

Synthesis of gypsum

For synthesis of gypsum ($CaSO_4 \cdot 2H_2O$), an industrial grade lime was used, where alkaline reagent was added to magnesite-treated water which is rich in magnesium sulphate as a complex. 0.7 g:100 mL of lime per treated water was used as optimised. The mixture was then equilibrated at 650 rpm shaking speed for 120 mins using an overhead stirrer. The resultant residues and water were taken for analysis.

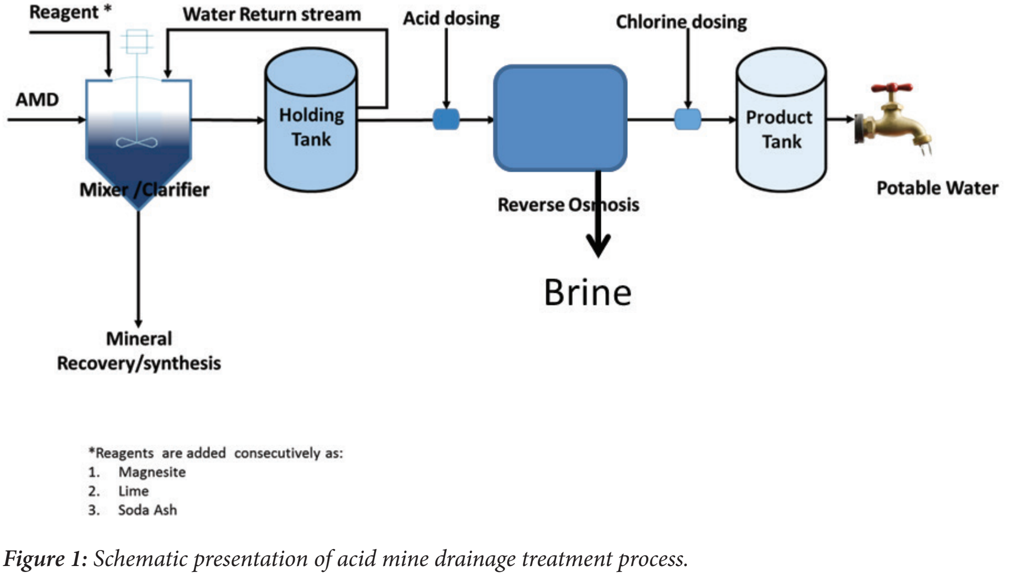

Figure 1: Schematic presentation of acid mine drainage treatment process.

Synthesis of calcium carbonate

Synthesis of calcium carbonate ($CaCO_3$) synthesis, an industrial grade soda ash was used, where the alkaline reagent was added into lime-treated water and then mixed for a specified time interval. 0.5 g:100 mL of soda ash per treated water was used as optimised. The mixture was then equilibrated at 650 rpm shaking speed for 30 mins using an overhead stirrer.

Reverse osmosis purification

In this study, FILMTEC BW30-4040 is the industry standard for reliable operation and production of the highest quality water membrane was used.

Characterisation of material

HANNA (HI 98194) portable pH/EC/DO multi-parameter probe was used to determine pH, Total Dissolved Solids (TDS) and Electrical Conductivity (EC). Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) was used to analyse aqueous samples. The National Institute of Standards and Technology (NIST) water standards were of use in monitoring the accuracy of analysis. X-ray Diffraction (XRD) was used to determine the mineralogy of synthesised materials. An Auriga Cobra FIB FESEM instrument high resolution scanning electron microscope (HR-SEM) with the precision milling and nanofabrication abilities of high resolution focused ion beam (FIB) at an accelerating voltage of 3 KeV was used to determine morphological properties (Model: Sigma VP FE-SEM with Oxford EDS Sputtering System Make: Carl Zeiss, Supplier: Carl Zeiss, USA).

Results and discussions

Morphology of synthesized materials

The morphology of Fe-based mineral, gypsum and calcium carbonate are shown in Figure 2.

As shown in Figure 2A, the recovered Fe-based mineral has spherical structures that are homogenous hence indicating that the recovered material is uniform. Figure 2B, shows the rod-like structures for the synthesized gypsum. This is consistent to what have been

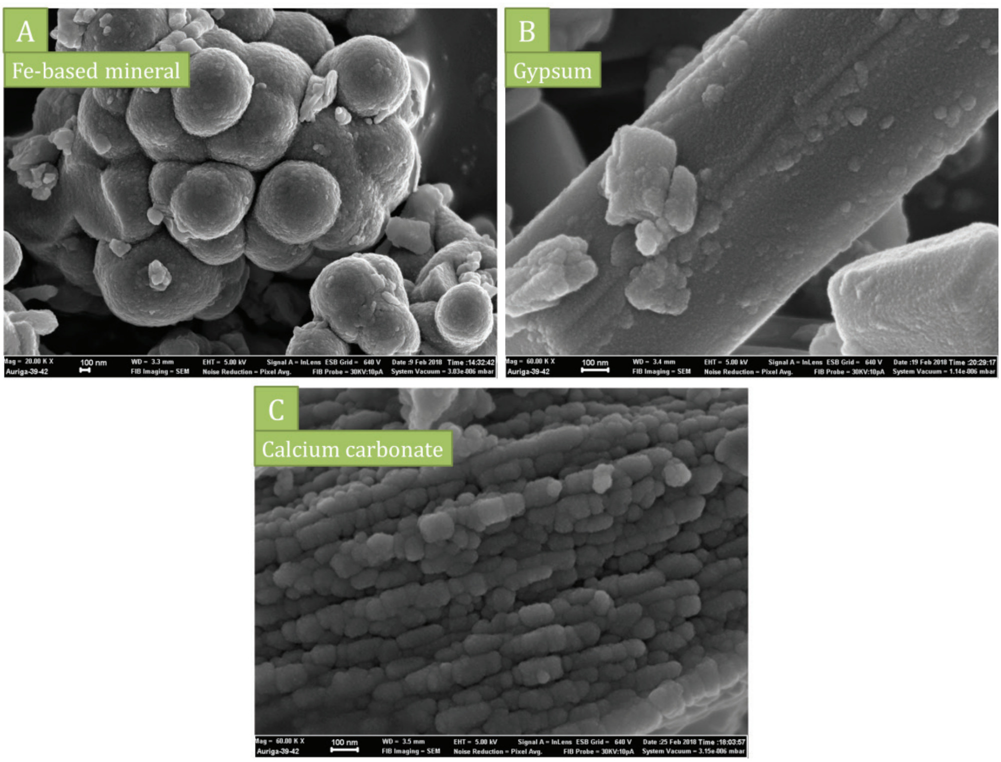

Figure 2: *Morphology of Fe-based mineral (A), gypsum (B), and limestone (C)*

reported in literature (Masindi et al. 2018). The synthesized calcium carbonate (Figure 2C) shows the presence of spherical and nodular linked structures that are consistent hence depicting that the synthesized material is uniform.

Mineralogical composition of synthesized materials

The mineralogical properties of Fe-based mineral, gypsum and calcium carbonate are shown in Figure 3.

As shown in Figure 3, Fe-based mineral was characterised of hematite, jarosite, magnetite, and hexahydrate. Quartz was observed as an impurity. Gypsum was observed to be characterised of basanite, brucite and gypsum. Quartz and montmorillonite were also observed to be present. The presence of magnesium is attributed to lime addition and an increase in pH. The limestone was observed to contain the calcite, brucite, quartz and hydro-magnesite. The obtained results are in agreement with the water quality results.

Water quality

The product water qualities of acid mine drainage treated using pre-treated magnesite, lime, soda ash, and reverse osmosis are shown in Table 1.

As shown in Table 1, the initial pH of acid mine drainage was observed to be 2.4 and it was observed to increase to 10, 11, 10 and 7 after contacting the pre-treated magnesite, lime, soda ash, and RO purification respectively. The major component of this mine water was observed to be Fe and Sulphate hence indicating that this mine water origi-

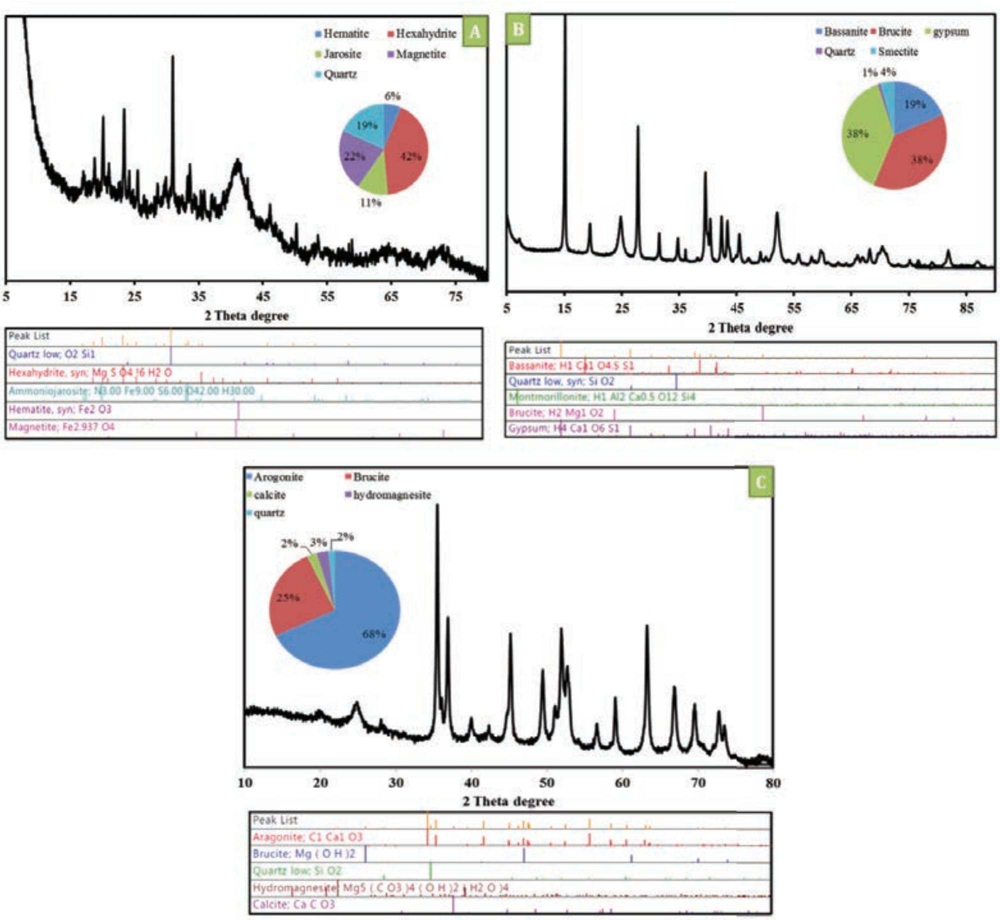

Figure 3: Mineralogical properties of Fe-based minerals (A), gypsum (B) and calcium carbonate (C).

Table 1: Chemical compositions of AMD before and after treatment

Parameters	Unit	SANS 241	Raw AMD	Magnesite	Lime	Soda ash	Permeate	Brine
Aluminium	mg/L	0.03	70	0.03	0.01	0	0	0
Ammonia	mg/L	1.5	7.7	8.2	6.3	6.5	0.8	12
Barium	mg/L	0.7	0.1	0.1	0.1	0.4	0.1	0.3
Cadmium	mg/L	0.03	0.04	0.02	0.02	0.02	0.02	0.02
Chloride	mg/L	300	3.8	2.1	6.3	6.3	32	28
Chlorine	mg/L	5	1.1	0.25	0.05	0.05	0.05	0.04
Chromium	mg/L	0.05	0.04	0.02	0.02	0.02	0.02	0.02
Colour	mg/L	15	600	5	7	<5.0	6	6
Copper	mg/L	2	0.5	0.04	0.04	0.04	0.04	0.04
EC	mS/cm	170	10	19	4	4	0.1	3
TDS	Mg/L	1200	5000	9900	2100	3900	300	3500
Iron	mg/L	2	1000	2	0.02	0.02	0.02	0.02
Lead	mg/L	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Manganese	mg/L	0.4	30	0.5	0.5	0.2	0.01	0.2
Mercury	mg/L	0.06	0.2	0.02	0.02	0.02	0.02	0.02
Nickel	mg/L	0.07	1	0.04	0.04	0.04	0.04	0.04
pH	pH	5 - 9,5	2.38	10.5	11	10	7	7.5
Sodium	mg/L	<200	91	110	103	1624	100	2803
Sulphate	mg/L	<500	11681	11000	621	71	8	53
Turbidity	NTU	<5	43	66	110	75	0.62	0.88
Uranium	mg/L	0.03	0.01	0.008	0.08	0.80	0.08	0.80
Zinc as Zn	mg/L	5	2	0.05	0.05	0.05	0.05	0.05

nates from the weathering of FeS_2. Notable components of Al and Mn were also observed to be presence hence showing that these are the associated minerals. Traces of other toxic chemical components were observed to be present in significant concentration in relation to their toxicity. After contacting the pre-treated magnesite the pH had increase and significant amount of metals were removed except for sulphate. Addition of lime led to an increased removal of residual sulphate and metals. The water was much cleaner and rich in Ca ions. Soda ash was added to remove the Ca and Mg hence forming the carbonates. The water was much softer and ready to pass through an RO. The water was purified with an RO system to SANS 241 water quality specifications. This is evident because the Na ions were observed to be present in the brine stream. The water is safe for human consumption. Brine stream is going to be further treated using membrane distillation in order to attain a Zero-Liquid-Discharge (ZLD) system.

Conclusions

This pilot study successfully reclaimed drinking water and attained valuable minerals from acid mine drainage treatment process. A 3.5 KL clarifier with a return stream was used for the recovery of valuable minerals and the purification of drinking water. The plant managed to reclaim portable water that complies with SANS 241 water quality specifications. The recovered products showed good industrial quality. These materials have a number of industrial, agricultural and metallurgical applications. More so, this pilot study proved to be successful, effective and economically viable. Furthermore, it was also proven that there is feasibility of AMD valorisation. This will aid in an endeavour to minimise the environmental footprints by protecting the environment and its precious resources. Future work involves detailed costing

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