International Journal of Mineral Processing 144 (2015) 90–96

Contents lists available at ScienceDirect

International Journal of Mineral Processing

journal homepage: www.elsevier.com/locate/ijminpro

Utilisation of residue gas sludge (BOS sludge) for removal of heavy metals from acid mine drainage (AMD)

A. Jafaripour [a,*], N.A. Rowson [a], G.S. Ghataora [b]

[a] School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom
[b] School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom

ARTICLE INFO

Article history:
Received 11 March 2014
Received in revised form 13 June 2015
Accepted 5 October 2015
Available online 14 October 2015

Keywords:
Heavy metals
Acid mine drainage (AMD)
BOS sludge
Adsorption

ABSTRACT

This investigation employed waste gas sludge (BOS sludge) which is an end-waste from steelmaking process as a novel adsorbent to study adsorption phenomena on real acid mine drainage. BOS sludge was used to treat Wheal Jane mine (Cornwall, UK) AMD in this work. Batch experiments were conducted as function of initial solution pH, adsorbent loading, regeneration and thermal treatment to study the performance of BOS sludge in removing manganese, copper, iron, and zinc.

Kinetic studies indicated that the rate of adsorption of the heavy metals by BOS sludge was rapid. A high pH promoted adsorption and removal of the heavy metal ions was not only due to ion exchange or adsorption but also partly due to co-precipitation effect. The treatment of Wheal Jane mine AMD demonstrated that about 100% of Cu and Fe, 97% of Zn and 94% of Mn were removed from solution. The results show that BOS sludge has great potential as an alternative material in the treatment of real waste water streams. Thus BOS sludge could be used as a sustainable sorbent for the more expensive materials in AMD treatment technologies due to its adsorptive properties, high availability, large quantities and low cost.

1. Introduction

Acid mine drainage (AMD) is an environmental pollutant resulting from a combination of weathering and mining activities. Acid mine waters have low pH-values and high concentrations of toxic and heavy metal contaminants (Pb^{2+}, Cu^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+}/Fe^{3+}, Cd^{2+}) which are not biodegradable and thus tend to accumulate in the environment causing various threats in nature (Skousen and Ziemkiewicz, 1996; McGinness, 1999; Skousen et al., 2000).

Britain has a long history of mining for coal, metal ores and other minerals. The number of mines is enormous, reports suggest in Wales, the South West and Northumbria over 3700 sites exist. No significant metal mines are still in use; the last large tin mine in Cornwall closed in 1998. Monitoring and studies have shown that a large number of abandoned metal mines are significant contributors to heavy metal and toxic pollution into rivers and seas (Environment Agency, 2008).

There are a number of acid mine drainage (AMD) treatment technologies and these fall into two broad categories, passive and active treatments. However conventional methods such as lime based chemical precipitation, ion exchange and other processes have a number of shortcomings; which are extensive land utilisation, production of large secondary solid waste, high capital and operating costs. Overall, AMD treatment processes depend highly upon many factors; for example type and concentrations of the dissolved metal ions in AMD solutions.

Adsorption is becoming a popular method for the removal of heavy metals from the AMD (Omer et al., 2003). Natural materials, waste and residue products from industrial or agricultural activities have excellent potential as an economic adsorbent for heavy metal removal from AMD solution. It is believed that such materials may be considered as alternative adsorbents to activated carbons and ion exchange resins (Ahmaruzzaman, 2011; Bailey et al., 1999; Barakat, 2011; Kurniawan et al., 2006; Sud et al., 2008).

High metal adsorption capacity and efficiency involving steel slags in single and binary adsorbate systems have been investigated, and the mechanisms of adsorption and the effects of variables on metal adsorption have also been assessed. For silicate based materials such as slags, many authors believe metal adsorption process to occur through ion exchange and metal hydroxide/silicate precipitation (Dushina and Aleskovski, 1976), physical adsorption based on ion exchange (Lopez et al., 1995), primarily sorption through ion exchange and some form of metal silicate precipitation (Dimitrova and Mehanjiev, 1998). However the studies are limited, inconsistent and the adsorption mechanisms are yet to be understood fully in detail.

Integrated steel plants generate large amounts of different solid wastes such as blast furnace slag, steel slag, mill scales and many others. The fine solid particles recovered after wet scrubbing of the gas generated from basic oxygen furnace (BOF/BOS) in the sludge form are known as waste gas sludge (BOS sludge). A newer approach of utilising this

* Corresponding author.
E-mail addresses: axj953@bham.ac.uk (A. Jafaripour), n.a.rowson@bham.ac.uk (N.A. Rowson), g.s.ghataora@bham.ac.uk (G.S. Ghataora).

http://dx.doi.org/10.1016/j.minpro.2015.10.002
0301-7516/

waste material (BOS sludge) deserves attention as a potential and alternative solution to recycling routes.

BOS sludge has not previously been studied or examined under adsorption purposes for acid mine drainage treatment, hence very limited literature and data are available on this particular material. However due to its adsorptive properties, presence of exchangeable cations (neutralising potential ability) and its high availability, BOS sludge can be considered as a novel adsorbent for the removal of heavy metal ions. Thus employing BOS sludge in an efficient and cost effective manner would solve two environmental problems simultaneously.

However there are a number of challenges, two major restrictions associated with BOS sludge usage could be that the sorbent must remain submerged during treatment. The BOS sludge will harden into a concrete-like substance, thus leading to reduced surface area and porosity. Another challenge could be the disposal of used BOS sludge (spent sorbent) which was not dealt with in this particular study and this could be a potential area of further study which could ultimately may result in increase of environmental concerns associated with AMD treatment. Before this technology is implemented on an industrial scale, the construction of an optimised pilot plant using BOS sludge to treat different real AMD solutions would be a constructive plan forward, as this could generate more options on how to treat the spent sorbent with different solvents prior to discharge. Further research and investigations must be carried out in order to determine different operating conditions and flow regimes which simulate real plant operation and to assess the longevity of the treatment.

This study investigated the adsorption efficiency and removal rates of copper, iron, zinc and manganese ions using waste gas sludge (BOS sludge; as received). The aim of this present work is to assess the effectiveness of BOS sludge as a sorbent in treating AMD solutions from Wheal Jane disused mine (Cornwall, UK).

2. Materials and methods

2.1. Adsorbent and adsorbate

In this study BOS sludge samples from Tata Steel plant in Port Talbot (South Wales) were used, provided by Harsco Metals & Mineral Ltd., UK. The samples were used in their natural state ("as received") with no chemical modifications, unless stated. The particle size distribution of the samples was determined using screens and a sieve shaker.

The particle size range of the BOS sludge used in this study was +1 mm, −1.4 mm. Real AMD from Wheal Jane mine was collected in sealed containers. Concentrations of copper, iron, manganese and zinc were determined by the atomic absorption spectrometer (AAS).

The results presented in Table 1 show the oxide composition of BOS sludge as determined by XRF. The high lime (13.1% CaO) content means that the material has a potentially high neutralising capacity for acidic effluents. The other characteristics of BOS sludge that were investigated are also listed in Table 1.

The density of BOS sludge was determined using a helium gas PYCNOMETER from Micrometrics, model AccuPyc Ц 1340. The porosity of BOS sludge samples were measured using a mercury porosimeter. Surface area measurements were also determined by Nitrogen adsorption fitted to the BET equation (Brunauer, 1943), using the TRISTAR 3000 apparatus from Micrometrics.

Table 1
Properties of untreated BOS sludge.

Chemical composition		Physical properties	
Oxide	% w/w	Parameter	Value
FeO	23.95	Porosity (%)	74.2548
SiO_2	2.60	Surface area; m^2g^{-1}	16.95
Al_2O_3	1.62	Surface area of thermally treated sample; m^2g^{-1}	12.92
H_2O	12.9	Density; g/cm^3	4.2693
MnO	1.41	Average pore dia. (μm)	1.665
CaO	13.11	Moisture content (%)	19.21
MgO	1.7	Physical form	Black slurry

2.2. Batch sorption studies

Batch adsorption tests/studies provide information on adsorption equilibrium characteristics and adsorption kinetics, which are important in determining the effectiveness of the adsorbent in removing solute from solution. Specified masses of BOS sludge samples were mixed with 200 ml solution of Wheal Jane AMD for a predetermined time period and agitated over tumbling mill at 110 rpm. The initial concentrations of copper, iron, zinc and manganese in AMD from Wheal Jane mine collected were 1.1, 74, 23 and 4 mg/l respectively and these were measured using the AAS. The pH of Wheal Jane water was in a range of about 2.7–2.9 ± 0.1. The final concentrations of the heavy metal ions in the aqueous phase were determined using AAS from which efficiency and adsorption capacities for each sample was calculated.

The percent adsorption (%) was calculated using the equations:

$$\%\text{Adsorption} = (C_i – C_t)/C_i \times 100, \quad (1)$$

where, C_i and C_f are the concentrations of the metal ions in the initial and final solutions respectively.

The amount of metal adsorbed from aqueous solution at time t, was determined by the following equation:

$$q_t = m_s/m = (C_o – C_t)(V/m), \quad (2)$$

where q_e is the amount of heavy metal ions adsorbed at any time, mg/g adsorbent; m_s is the mass of metal adsorbed, mg; m is the adsorbent mass, g; C_o is the initial concentration of heavy metal ions, mg/l; C_t is the liquid- phase concentration of heavy metal ions at any time, mg/l; V is the volume of solution from which adsorption occurs, L.

The equilibrium amount of metal adsorbed from aqueous solution was determined by the following equation:

$$q_e = m_s / m = (C_o - C_e)(V/m), \quad (3)$$

where q_e is the amount of heavy metal ions adsorbed at equilibrium, mg/g adsorbent; m_s is the mass of metal adsorbed, mg; m is the adsorbent mass, g; C_o is the initial concentration of heavy metal ions, mg/l; C_e is the liquid- phase concentration of heavy metal ions at equilibrium, mg/l; V is the volume of solution from which adsorption occurs, L.

2.2.1. Effect of adsorbent dosage on adsorption process

Different masses were used in this study, ranging from 8 g, 16 g and 24 g of BOS sludge and these were contacted with Wheal Jane solution.

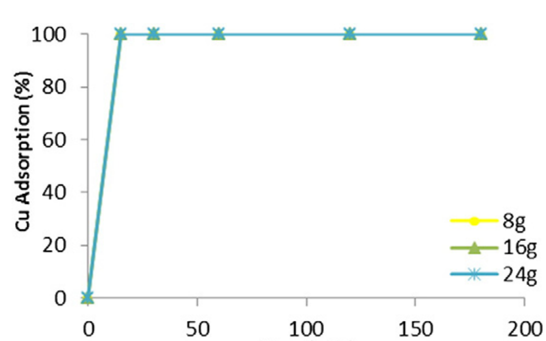

Fig. 1. The effect of mass of BOS sludge on the adsorption of Cu from Wheal Jane solution (particle size: +1 mm, −1.4 mm; initial: pH ~2.8).