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Comparative study on different steel slags as neutralising agent in bioleaching

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ABSTRACT

A comparative study on bioleaching of a pyrite concentrate using five different steel slags as neutralising agent has been performed with reference to a commercial grade slaked lime. The acid produced during oxidation of pyrite was neutralised by regular additions of neutralising agent to maintain a pH of 1.5. Bioleaching was conducted as batch in 1-L reactors with a mixed mesophilic culture at a temperature of 35 °C. The different steel slags used were Argon Oxygen Decarbonisation (AOD) slag, Basic Oxygen Furnace (BOF) slag, Electric Arc Furnace (EAF) slag, Composition Adjustment by Sealed Argon Bubbling–Oxygen Blowing (CAS–OB) slag and Ladle slag, representing slags produced in both integrated steel plants and scrap based steel plants. The aim of the study was to investigate the possibility to replace normally used lime or limestone with steel slags, considering their neutralising capacity and eventual toxic effects on the bacterial activity.

The bioleaching efficiency was found to be equally good or better, when steel slags were used for neutralisation instead of slaked lime and the extent of pyrite oxidation of pyrite was in the range 75–80%. Some of the slags used contained potentially toxic elements for the bacteria, like fluoride, chromium and vanadium, but no negative effect of these elements could be observed on the bacterial activity. However, slags originating from stainless steel production are less environmentally friendly due to the presence of chromium. The neutralising potential of the slags was high, as determined by the amount needed for neutralisation during bioleaching. The range of additions of neutralising agents required to control the pH at 1.5 for all the experiments ranged from 16–27 g, while 22 g was needed in the experiment with slaked lime.

Hence, it was concluded that considerable savings in operational costs could be obtained by replacement of lime or limestone with steel slag, without negative impact on bioleaching efficiency. Recycling of steel slags would render an eco-friendly process and provide a means for sustainable use of natural resources.

1. Introduction

Stirred tank biooxidation of refractory gold concentrates utilising mesophilic microorganisms is one of the processes successfully commercialised today. Mineral decomposition in temperature and oxygen controlled stirred tank reactors normally takes 5 days in contrast to heap bioleaching of secondary copper sulphides, which takes months or even years. Stirred tank bioleaching is the most effective bioleaching process though it is restricted to high value minerals due to its limitations on solid concentration and higher process costs (Rawlings et al., 2003). Approximately ten operational units have successfully established stirred tank reactor biooxidation using Gold field's proprietary BIOX® process for commercial application with three more plants upcoming in the near future (van Aswegen et al., 2007).

The mineral dissolution process in bioleaching follows either the polysulphide or thiosulphate pathway (Schippers and Sand, 1999; Tributsch, 2001; Sand et al., 2001; Rohwerder et al., 2003; Rawlings et al., 2003). The thiosulphate mechanism applies to acid insoluble disulphides like FeS_2 and MoS_2, while the polysulphide mechanism applies to acid soluble sulphides like ZnS, $CuFeS_2$, NiS etc. The present study deals with bioleaching of pyrite following the thiosulphate pathway in which, Fe^{3+} ions attacks the FeS_2, producing thiosulphate and ferrous iron as intermediate products (Eq. (1)). The ferrous iron is then oxidised to ferric iron by the iron oxidising microorganisms (Eq. (2)), while thiosulphate is oxidised by Fe^{3+} ions to produce sulphate (Eq. (3)).

$$FeS_2 + 6Fe^{3+} + 3H_2O \rightarrow 7Fe^{2+} + S_2O_3^{2-} + 6H^+ \qquad (1)$$

$$Fe^{2+} + 1/4O_2 + H^+ \rightarrow Fe^{3+} + 1/2H_2O \qquad (2)$$

$$S_2O_3^{2-} + 8Fe^{3+} + 5H_2O \rightarrow 2SO_4^{2-} + 8Fe^{2+} + 10H^+ \qquad (3)$$

The thiosulphate can alternatively also be oxidised into sulphate by sulphur oxidising microorganisms. The overall reaction based on the primary oxidant is given in Eq. (4).

$$FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \qquad (4)$$

From the equations given above it is seen that bioleaching of pyrite is an acid producing process and further acid is produced due to the

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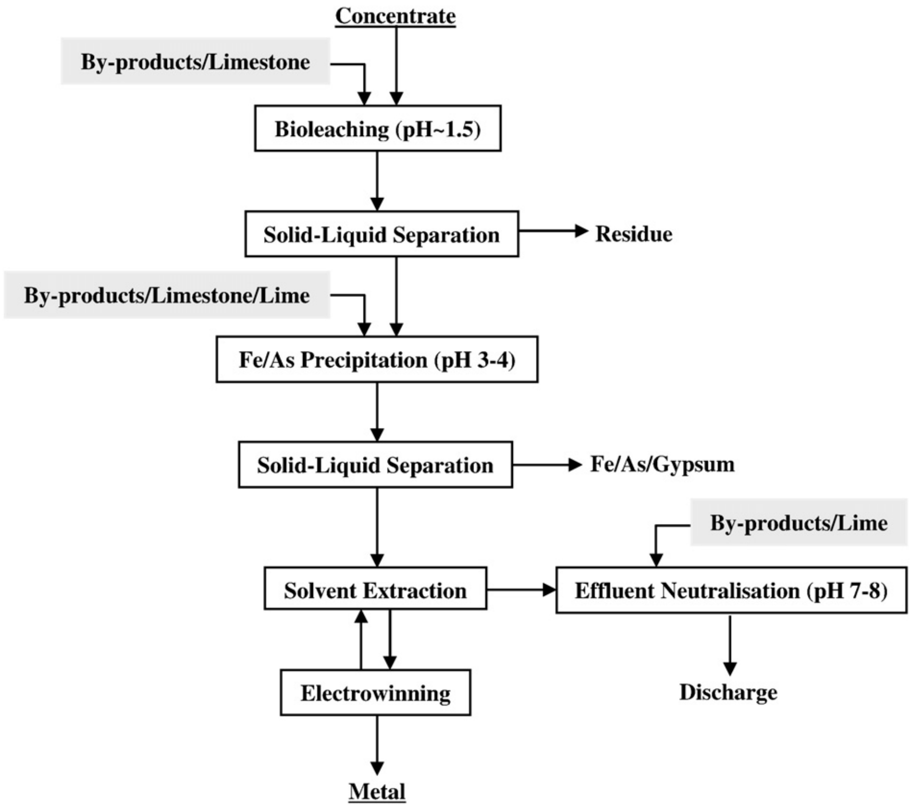

Fig. 1. Example of a process for base metal production with points of neutralisation highlighted.

hydrolysis of ferric iron. The microorganisms used in bioleaching processes are chemolithotrophic and acidophilic having optimum activity at a pH around 1.5, therefore, depending on the reactor configuration, addition of neutralising agents is required to maintain the desired pH.

Neutralisation of the acid produced during bioleaching of sulphide minerals is generally practised using limestone. In a bioleaching process, neutralisation is required at different stages (Fig. 1). Primary neutralisation to pH ~ 1.5 using limestone during the bioleaching process, secondary neutralisation to pH 3–4 using lime/limestone for precipitation of iron and arsenic, and finally to pH 7–8 for effluent neutralisation by lime (Fig. 1). Controlling pH at a proper level is important to the operation efficiency in bioleaching processes and generally, a pH range of 1.0–2.0 is maintained. Operating a bioleaching process at a pH above 1.85 may cause excessive iron precipitation as jarosite, while operation at a pH below 1.0 may result in foam formation, as observed at the BIOX® process at Fairview and Wiluna (Dew, 1995; Chetty et al., 2000). Neutralisation of the ferric iron (Fe^{3+}) and arsenate (AsO_4^{3-}) containing leachate at a pH of 3–4 with limestone or slaked lime precipitates arsenic as a ferric arsenate ($FeAsO_4$) (Stephenson and Kelson, 1997). The ferric arsenate obtained is stable and environmentally acceptable according to the US EPA (Environment Protection Agency) TCLP testing procedure (Cadena and Kirk, 1995; Broadhurst, 1994). Studies on the possibilities to use oxidic by-products, like steel slags, for precipitation of Fe/As at pH 3 in comparison to slaked lime proved promising, due to the presence of high concentrations of oxides and silicates in those materials (Cunha et al., 2008).

The cost for neutralisation is normally the second largest operation cost in BIOX® plants and the limestone cost is directly proportional to the distance between the deposit and the operation plant (van Aswegen and Marais, 1999). Therefore, to save operation costs it is important to find substitutes such as dolomite, ankerite or calcrete (a low-grade limestone) deposits located close to the plant.

Table 1
Elemental composition of the pyrite concentrate

Material	Composition (%)													
Pyrite concentrate	Si	Al	Ca	Fe	K	Mg	Mn	Na	S	Ba	Cu	Cr	Mo	Zn
	12.9	4.5	1.9	25.7	2.3	0.7	0.2	0.7	23.9	0.6	0.2	0.01	0.01	0.01

Table 2
Elemental composition of the neutralising agents

Neutralising agents	Si (%)	Al (%)	Ca (%)	Fe (%)	K (%)	Mg (%)	Mn (%)	Na (%)	S (%)	Ba (mg/kg)	Cr (mg/kg)	Mo (mg/kg)	Pb (mg/kg)	V (mg/kg)	Zn (mg/kg)	F (mg/kg)	Cl (mg/kg)
$Ca(OH)_2$	0.1	0.0	53.6	0.0	0.1	0.4	0.0	<0.004	0.02	<2	<10.0	<6.0	1.9	<2.0	27.3	30.9	1047
AOD slag	12.9	2.5	37.5	1.6	0.1	3.7	0.7	0.09	0.12	101	13,100	232	19.4	205	251	23,600	695
Ladle slag	5.9	13.4	29.9	2.4	0.1	8.6	0.2	0.04	0.34	85.1	2350	174	16.3	347	476	5273	1738
EAF slag	7.0	3.0	31.2	19.8	0.1	1.9	2.3	0.13	0.06	243	2200	11.5	2.9	227	91.9	63.1	1617
BOF slag	3.9	0.7	28.2	18.9	<0.1	7.3	2.9	<0.04	0.09	66.1	1500	<6.0	10.5	25,100	90.8	97.0	883
CAS–OB slag	3.4	18.7	17.0	12.7	0.1	2.7	8.2	0.05	0.03	41.3	2930	<6.0	6.8	5060	112	119	1205