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Scale up possibilities for microwave leaching of chalcopyrite in ferric sulphate

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Abstract

This paper presents a study on the effect of reactor size on the microwave leaching outcome of copper from chalcopyrite in $Fe_2(SO_4)_3{-}H_2SO_4$ solution. Microwave leaching experiments were carried out in single mode cavity using reactors of two sizes (20 and 50 mm in diameter). The results of microwave experiments were compared with those obtained under conventional conditions. It was found that the copper recovery obtained under microwave conditions in the large reactor is comparable to those obtained conventionally. On the other hand, the copper recovery was higher when leaching was carried out in small reactor. It is suggested that the enhanced recovery in the small reactor is due to the selective heating of chalcopyrite coupled with the effect of microwave penetration depth. Computational results also suggest that the portion of reactor volume affected by the high power density is higher in the small reactor. Furthermore, microwave heating of ferric sulphate leaching solution in vessels of different sizes suggests the presence of a super heated layer close to the vessel walls caused by a small penetration depth. Based on experimental and modelling evidence the implications for the scale up for microwave leaching of chalcopyrite are discussed.

Keywords: microwave leaching; selective heating; chalcopyrite leaching; hydrometallurgy; scale up

1. Introduction

Over the past few decades, microwave heating have been employed in various technological processes. One area of interest is the application of microwaves in extractive metallurgy. The first attempt to use microwave energy to improve copper recovery from its ores was conducted by Kruesi and Frahm (1982). Later, a number of reports have been published where it is suggested that microwave energy has a potential application in mineral processing and extractive metallurgy. Several review papers can be found in this area (Al-Harahsheh and Kingman, 2004; Haque, 1999; Kingman, 2005; Kingman and Rowson, 1998; Xia and Pickles, 1997). It was indicated that microwave energy could have potential applications in comminution, drying, pretreatment of refractory gold ores, coal desulphurisation, leaching, roasting, carbon reactivation, carbothermic reduction of oxides and waste and slag management. The above authors concluded in most cases that microwaves may have the potential to reduce the energy cost of comminution, enhance mineral surface chemistry and facilitate new forms of metal extraction in a controlled environment.

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Several advantages make microwaves a distinctive source of energy compared to conventional heating including short processing time, selective heating and better control. Selective heating is particularly important in catalytic reactions and heterogeneous reaction systems where one phase is heated selectively over the other leading to an increased temperature at reaction interface.

Hydrometallurgical systems compose of both liquid and solid material, each of which has its own behaviour in a microwave field and it is very important for better extraction efficiency under microwave conditions to know the properties of each of the component of that system. A recent study regarding the influence of microwaves on the leaching kinetics of chalcopyrite has been reported (Al-Harahsheh et al., 2005). It has been shown that the enhancement observed in the copper recovery is linked to the limitation of microwave penetration depth of ferric sulphate solution as well as the selective heating of chalcopyrite particles within the leaching solution.

This study reports further more detailed work to investigate the reactor size on the leaching recovery of copper from chalcopyrite when leached in a single mode cavity. It has been proposed previously that the enhanced recovery of copper from chalcopyrite is due to the selective heating of chalcopyrite particles over the leaching solution and due to the limitation on penetration depth. In this paper, the scale up potential of microwave leaching of chalcopyrite is discussed.

The behaviour of material when placed in microwave field largely depends on its permittivity (ε, F/m), permeability (μ, H/m) and conductivity (σ, S/m). Materials with low values of conductivity are classified as dielectrics, whereas, those with high values of conductivity are called conductors (Meredith, 1998). The permittivity of a dielectric material is composed of a real part (ε', dielectric constant) and an imaginary part (ε'', dielectric loss factor). Dielectric constant and the loss factor are used to express the dielectric response of materials in microwave fields. The dielectric constant measures the ability of the material to store microwave energy or in other words it measures the ability of material to be polarised. The latter measures the ability of material to dissipate the stored energy into heat (Metaxas and Meredith, 1983). Permittivity (ε^*) can be expressed as:

$$\varepsilon^* = \varepsilon_0(\varepsilon_r' - j\varepsilon_{\mathrm{eff}}'') \tag{1}$$

where ε_0 is the permittivity of free space (8.86×10^{-12} F/m), ε_r' is the relative dielectric constant, $\varepsilon_{\mathrm{eff}}''$ is the effective relative dielectric loss factor, $j = \sqrt{-1}$.

The propagation of electromagnetic wave through the dielectric material depends on its dielectric properties as well as microwave frequency and can be characterised by the penetration depth (D_p) according to the following equation.

$$D_p = \frac{c}{2\pi f\sqrt{2\varepsilon'}[\sqrt{1+\tan^2\delta} - 1]^{1/2}} \tag{2}$$

where c is the speed of light (3×10^8 m/s), f is frequency, Hz, ε' is dielectric constant, $\tan\delta$ is the loss tangent ($\tan\delta = \varepsilon''/\varepsilon'$).

2. Experimental

Chalcopyrite material used in this study was 100% passing 38 μm. Similar sample preparation was described previously (Al-Harahsheh et al., 2005). Chalcopyrite was found to be of high purity with a composition very close to the theoretical one containing 33.5 ± 0.3% Cu, 29.6 ± 0.2% Fe and 35.0 ± 0.5% S as evident from the ICP-AES (Inductively Coupled Plasma Atomic Emission Spectroscopy) analysis.

Conventional leaching experiments were carried out in a 500 ml reactor in a water bath as described in Al-Harahsheh et al. (2005). Microwave leaching experiments were carried out in a single mode cavity which supports only one mode at the source frequency compared with the multimode cavity. The attraction of single mode cavity is that the electromagnetic field pattern is well defined inside the cavity which enables the reactor to be placed in the position of maximum field strength.

A schematic of the single mode cavity apparatus is shown in Fig. 1. It consists of a microwave generator operated at 2.45 GHz with adjustable power in the range of 0–1 kW; a WR340 standard rectangular waveguide and a cylindrical applicator located within the waveguide. Three manually adjustable stub tuners inserted in the waveguide section and a short circuit tuning plunger were used to maximise microwave power absorption by minimising the reflected power. The latter is measured at the circulator.

The microwave system was equipped with a temperature controller system designed for the purpose. It consisted of a FISO® fiber optic temperature sensor connected to a FTI-10® signal conditioner which allowed the measurement of the temperature inside the leaching vessel located in the microwave cavity with an accuracy of ±1 °C. The measured temperature was sent to a control box where it was compared to a set temperature. A signal from the control box (programmed chip) was then sent to the magnetron power supply to