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Inhibiting the amine flotation of magnetite through aggregation with uniform low magnetic fields and no chemical depressants

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ABSTRACT

The depression of magnetite in cationic flotation has been investigated using external 3D uniform low magnetic flux densities up to 0.015 T, in a laboratory Jameson-type flotation cell and in the absence of chemical depressants. In addition, the magnetic susceptibility and agglomeration of pure magnetite particles have been evaluated. The motion, size and morphology of magnetite aggregates and bubbles-magnetite aggregates in the flotation cell have been monitored by video microscopy. The cationic collector dodecyl amine and an iron concentrate with 65.1% total Fe, mainly as magnetite, were used for the flotation studies. In the absence of a magnetic field, the magnetite particles were fully dispersed and the iron flotation recovery linearly increased with the amine concentration. The 3D uniform magnetic flux density led to aggregation of magnetite particles as chains and chain columns whose sizes increased as the magnetic flux density increased. These magnetite aggregates rapidly settled by the action of the gravitational force and were removed easily from the flotation cell as tailings. The high amine flotation recovery of iron was significantly impaired by the magnetic field. Magnetite depression was associated with the large mass of the magnetite aggregates, which could not be floated by attached air bubbles so that they passed out as tailings.

1. Introduction

The concentration of iron ores by flotation is a proven technique consolidated worldwide (Houot, 1983; Filippov et al., 2014). Iron ore flotation began in 1931 and followed two routes: (1) flotation of iron oxides with anionic collectors and (2) reverse flotation of quartz and silica-bearing minerals using cationic collectors. Of these two routes, reverse flotation with cationic collectors (amines) remains the most popular approach used by the iron ore industry.

Adsorption of amines at pH higher than 8 is more favorable on quartz and silica-bearing minerals than on magnetite due to differences in their surface electrical properties (Peres and Correa, 1996). Even low amine adsorption promotes flotation of magnetite, however, so that depressants are used to inhibit the flotation of the iron oxide. Starches are the universal depressants due to their high affinity towards the surface of iron oxides (Araujo et al., 2005; Filippov et al., 2014; Shrimali and Miller, 2016). Quartz and iron oxides adsorb more amine in the presence of starch and adsorb more starch in the presence of amine (Lima et al., 2013; Shrimali et al., 2017). Although starches significantly impair the flotation of iron oxides, they also hinder the floatability of quartz, when added in excess, leading to a high silica content in the iron concentrate. In addition, separation of iron oxides from iron-bearing silicates is difficult by reverse cationic flotation because of the high affinity of the starches towards the iron-bearing silicates (Dogu and Arol, 2004; Filippov et al., 2014). Besides starches, other depressants have been considered for the iron oxides, namely carboxymethylcellulose (CMC), lignosulfonates, humic acid and Guar gum (Deng et al., 2013; Turrer and Peres, 2010; Martins et al., 2012).

Magnetic energy has been applied to flotation in order to diminish the floatability of paramagnetic and ferrimagnetic minerals. Yousef et al., (1971) used the magnetic field generated by the coils of a Davis tube equipment to impair the flotation of magnetite while floating

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chromite. Yalcin et al. (2000) applied a high intensity magnetic field to the froth phase as it leaves the flotation cell to remove pyrrhotite from nickel concentrates in the processing of the Falconbridge nickel ore. Birinci et al. (2010) applied a vertical magnetic field gradient in a microflotation column to prevent the flotation of magnetite in the cationic flotation of quartz. They reported that the flotation recovery of magnetite decreased as the magnetic field increased. However, the vertical magnetic field gradient caused the magnetite agglomerates to migrate towards the wall at the bottom of the flotation column where the magnetic field was highest (Corona-Arroyo, 2015). This makes the download of the magnetite difficult from the flotation column. Using an external magnetic field will avoid the use of chemical depressants, such as polysaccharides, in the concentration of iron ores by silica reverse flotation. Along this line, Martins et al. (2012) found that magnetites with a low zeta potential value did not float with amine so that polysaccharides were not needed to inhibit the magnetite floatability.

This work aimed at studying the application of 3D uniform low magnetic fields for the depression of magnetite in reverse cationic flotation systems without the use of chemical depressants. Dodecyl amine ($CH_3(CH_2)_{11}NH_2$) was used as the cationic collector. The flotation tests were carried out at pH 8.5 where the dodecyl amine (DDA) is as $CH_3(CH_2)_{11}NH_3^+$. A laboratory Jameson-type flotation cell was used in this work. The uniform external magnetic field configuration would overcome the difficulties encountered in the design of Birinci et al. (2010) as the magnetite agglomerates will not migrate towards the wall at the bottom of the column flotation cell, but they will settle vertically to the bottom exit of the flotation cell. This will facilitate the download of the magnetite from the flotation cell.

2. Experimental

2.1. Materials

A magnetite concentrate from the magnetic concentration plant of Consorcio Benito Juárez Peña Colorada, México was used. The iron concentrate had a P_{80} of 38 μm and graded 65.1% total Fe, 60.45% magnetic Fe, 4.1% SiO_2, 0.80% CaO, 0.36% S. The iron concentrate was constituted by 83.4% magnetite (Fe_3O_4), 3.7% hematite (Fe_2O_3), 0.7% pyrite (FeS_2) and 12.2% diamagnetic gangue. The hematite was locked to the magnetite, so that it was recovered along with the magnetite. Analytical grade dodecyl amine (DDA) from Aldrich was dissolved in aqueous solutions at pH 2. Then, this DDA acid aqueous solution was added to the magnetite slurries at the desired DDA concentration. HCl and NaOH aqueous solutions were used to adjust the pH of the DDA aqueous solutions and magnetite slurries. MIBC frother from Cytec-Mexico was added to the magnetite pulp for froth stability. The MIBC concentration was 10 mg/L and kept constant in all tests. Tap water was used to prepare the magnetite slurries for all the flotation experiments, which were carried out at pH 8.5.

Magnetic characterization and agglomeration of magnetite particles were carried out with magnetite crystals from Colima, México. The crystals were hand crushed with a hammer, then ground using a corundum mortar and pestle. The −53 + 45, −45 + 38, and −38 + 25 μm size fractions were collected for agglomeration and magnetization studies. In this work, the particle size is reported as the geometric mean of the size fraction.

2.2. Laboratory Jameson-type flotation cell with external uniform magnetic field

Fig. 1 shows a schematic diagram of the flotation column set-up used in this work (Corona-Arroyo et al., 2015). The main components are: (1) a riser of constant slurry level, (2) a vertical plexiglass column (downcomer) with its base extending 2 cm below the surface of the riser, (3) a storage tank for the feed, riser underflow and riser overflow, (4) a peristaltic pump to feed the slurry to the downcomer, (5) a video digital camera for collecting images of magnetite agglomerates. The downcomer consisted of a plexiglass tube of 13 mm inner diameter and 600 mm length, while the riser had an inner diameter of 100 mm and 1 L total volume. The magnetite slurries were pumped into the downcomer through a cone-type nozzle of 1 mm inner diameter. A calibrated peristaltic pump was used to control the slurry flow to the downcomer. A superficial feed velocity (Ja) of 11 cm/s was used in all tests. Air was fed at the top of downcomer at a fixed flow rate of 200 cm^3/min, measured by a calibrated rotameter. This air flow corresponded to an air superficial velocity (Jg) of 1.32 cm/s, which was kept constant in all tests. In this work, Jg and Ja refer to the volumetric air flow rate and volumetric water flow rate per unit cross section of the downcomer, respectively (Majumder et al., 2005; Corona-Arroyo et al., 2015).

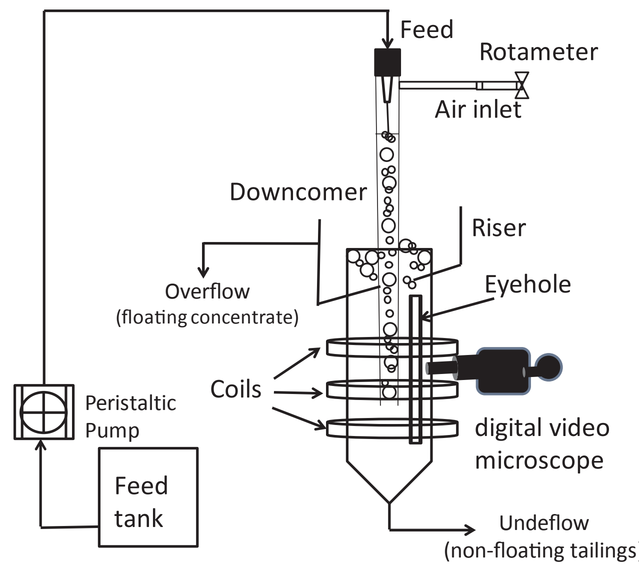

Fig. 1. Schematic diagram of laboratory Jameson-type flotation cell set-up.

Magnetic fields were applied to the flotation column through three coils. The coils were placed in the Helmholtz configuration to achieve a uniform magnetic field (Trout, 1988). The magnetic field intensity varied from 0 to 0.0150 T by adjusting the electric current through the coils using a DC power supply (RSR Variable DC Power Supply Model HY5003). A 410 Gaussmeter Model from Lake Shore Company was used to measure the magnetic field intensity.

2.3. Methods

Magnetite agglomeration studies were carried with a monolayer of pure magnetite particles laid on the bottom cross sectional area of a Petri glass dish. This monolayer of magnetite particles was covered by water. Then, the Petri dish was placed between two coils in a Helmholtz configuration and magnetic field was gradually applied. The experimental set up has been reported by García-Martínez et al. (2011) and involved an optical microscope coupled with a video-camara to capture images of the particles under the magnetic field. The captured videos were downloaded to a PC for their analysis using the free ImageJ 1.48b software. The length distribution of the chains formed at various magnetic fields was determined.

Magnetic characterization of the pure magnetite particles was carried out using a Princeton Research Instrument magnetometer and an alternating gradient magnetometry. The maximum applied magnetic field was ± 0.6 T.

Flotation tests were performed with 20%w solid slurries. The slurries were conditioned with DDA and MIBC at pH 8.5 for 10 min. Flotation tests started by first filling the flotation column with tap water and injecting air at the top of the downcomer. Then, the magnetic field was applied to the desired value. Afterwards, the slurry was pumped to