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Selective depression of silicates in phosphate flotation using polyacrylamide-grafted nanoparticles

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ABSTRACT

In this study, novel in-house synthesized hybrid polyacrylamide-grafted nanoparticles (Hy-PAM) were used to enhance the recovery of phosphorus bearing minerals from plant tailing by the froth flotation process. Characterization assays, including X-ray diffraction (XRD) and mineral liberation analysis (MLA) indicated that apatite, fluorapatite and quartz are the major crystalline phases in the tailing sample. Flotation experiments were performed using a bench scale Denver flotation cell with 1 L capacity in the presence of sodium oleate, which was used as a collector. Several influencing parameters such as polymer dosage, pH, and the flotation time were investigated to optimize the flotation outcomes in terms of recovery and grade of phosphorus pentoxide (P_2O_5). Results indicated that the P_2O_5 content in the plant tailings can be enriched from 21.6% to 28.6% at a recovery value of 80.5% in the first 4 min of flotation without the need to add a pH modifier. Moreover, flotation kinetics was investigated using classical first order kinetic model which was evaluated based on the flotation rate constant, the ultimate phosphorous recovery and the correlation coefficients obtained by non-linear regression analysis. Results indicated that the ultimate recoveries and the flotation rate constant values were affected by the change of the pulp's pH.

1. Introduction

Froth flotation of mineral ores is considered as one of the most selective techniques to enhance the separation of particulate matter in aqueous suspensions (Matis et al., 1993; Shean and Cilliers, 2011; Ata, 2012). Froth flotation utilizes the differences in wettability of minerals in a three-phase system: solid, gas, and water (Ata, 2012). In this process, hydrophobic particles attach to air bubbles to form a froth (concentrate) which is basically solid-air aggregates containing entrapped water. The hydrophilic minerals tend to stay in the pulp as flotation tailing. Surface wettability of particles can be altered using task-specific chemical reagents (Liu et al., 2017; Wen et al., 2017; Khodakarami and Alagha, 2017). For example, surfactants called "collectors" are added to promote surface hydrophobicity and thus flotability of a particular mineral. Modifiers, such as pH regulators, activators or depressants may also be added to modify the interfacial characteristics of certain minerals to promote or hinder the adsorption of collector compounds. Thus, froth flotation process is heavily dependent on applied surface chemistry and is extensively used in several industries such as mineral processing, food processing, pulp/paper manufacturing, and water purification. (Taseidifar et al., 2017; Vashisth et al., 2011; Yoo and Hsieh, 2010; Wang et al., 2015).

There are three closely related components in any flotation system (Klimpel, 1995) that are typically investigated to improve the separation efficiency with respect to the recovery and the grade of the final concentrate product: chemical (e.g. reagents and pH), mechanical (e.g. cell design), and operational (e.g. pulp density, temperature). Among all the aforementioned factors, chemical reagents have gained more attention (Urbina, 2003; Marabini et al., 2007, Laskowski, 1993). Development of chemical reagents is considered as an effective approach to improve the flotation performance in terms of economic and technical efficiency.

Among the different categories of chemical reagents used in froth flotation, both natural and synthetic polymers have received considerable attention due to their tunability and the opportunity they provide to enhance the flotation performance at a low cost (Chen et al., 2003; Liu et al., 2000; Bulatovic, 1999). Polyacrylamide-based polymers (PAMs) are widely used in minerals flotation processes as multifunctional reagents. Depending on the integrated functional groups, polyacrylamides and their derivatives are being used as collectors,

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depressants, activators or modifiers (Bulatovic, 1999; Liu et al., 2007; Beattie et al. 2006; Farrokhpay and Filippov, 2017).

Organic-inorganic (hybrid) polyacrylamides have shown promising separation efficiency in mineral processing and have been successfully applied to enhance the flotation of fine coal, dewatering of oil sand tailings and flocculation of fine kaolinite dispersions (Alagha et al., 2011; Molatlhegi and Alagha, 2016; Khodakarami et al., 2017; Alagha et al., 2016; Liu et al., 2016; Klein et al., 2013; Wang et al. 2014; Molatlhegi and Alagha, 2017). The polyacrylamide-grafted-nanoparticles used in this study is one type of the organic/inorganic hybrid polymers in which the polyacrylamide organic chains are grafted on inorganic $Al(OH)_3$ nanoparticles (50 nm in diameter). In a previous study, Alagha et al. (2011) reported the capability of organic-inorganic hybrid polymers to adsorb on the surface of ultrafine silica particles, flocculate them and enhanced their sedimentation in solid-liquid separation processes (Alagha et al., 2011). The successful use of these polymers in the previously mentioned research work along with its unique structural characteristics have brought the motivation to examine this polymer as a silicate depressant in the flotation of phosphate-bearing tailing samples.

The purpose of the current study is to evaluate the performance of hybrid polyacrylamide-grafted-nanoparticles (Hy-PAM) as a novel aid for phosphate enrichment by conventional flotation. Influencing parameters such as polymer dosage, pulp pH and flotation time were examined for the purpose of process optimization. Advanced characterization techniques were carried out to acquire fundamental knowledge about the flotation feed characteristics, the polymer characteristics and the interaction modes of the polymer with mineral surfaces. A conceptual view of the hypothesized role of the polymer in phosphate flotation process is depicted in Fig. 1. The positively charged $Al(OH)_3$ are anticipated to adsorb on the surface of silicate particles via electrostatic attraction mechanism which results in consequent charge neutralization followed by bridging flocculation which inhibits their flotation. Furthermore, the kinetics of phosphate flotation in the presence of Hy-PAM was investigated using the classical first order kinetic model which was evaluated based on the flotation rate constant, the ultimate phosphorous recovery and the correlation coefficients obtained by non-linear regression analysis.

2. Experimental

2.1. Materials

Representative tailing samples were provided from a phosphate production plant located in USA. All chemicals used in this study were purchased from Fisher Scientific Company, USA. This includes: sodium oleate which was used as collector, methyl isobutyl carbinol (MIBC) which was used as frother, and sodium carbonate (Na_2CO_3) which was used to adjust the pH of the flotation pulp as needed. In addition, the pure apatite and quartz mineral samples used in the zeta potential experiments were purchased from Ward's Science Company, USA.

2.2. Characterization

2.2.1. The X-ray powder diffraction (XRD)

XRD was conducted on the flotation feed and products to investigate the crystallinity of the associated minerals in the samples. The intensities of XRD pattern of an individual mineral are known to be proportional to the concentrations of the different minerals present. The XRD spectra were obtained by scanning in the 2θ range of 5–90°. A Philips XRD apparatus with Cu-Kα radiation was used to obtain the X-ray diffraction patterns.

2.2.2. Mineral liberation analysis (MLA)

Prior to MLA, the particle size distribution (P_{80}) of the flotation feed was determined using ASTM C136-14 protocols (Kemper and Rosenau, 1986). MLA data was obtained by the XBSE method where the acquired backscattered electron (BSE) image is used to differentiate the mineral phases based on the gray level as the gray level intensity varies, dependent on the phase composition. The acquired X-ray spectrum obtained from each phase was compared to the X-ray mineral database to qualitatively determine mineral phases and the surface area data for each mineral was used for quantitative determination of the minerals identified. The MLA results were provided by the Center for Advanced Mineral & Metallurgical Processing in Montana Tech of the University of Montana, Missoula, MT, USA.

2.2.3. Polymer preparation and characterization

The hybrid polyacrylamide grafted nanoparticles (Hy-PAM) were

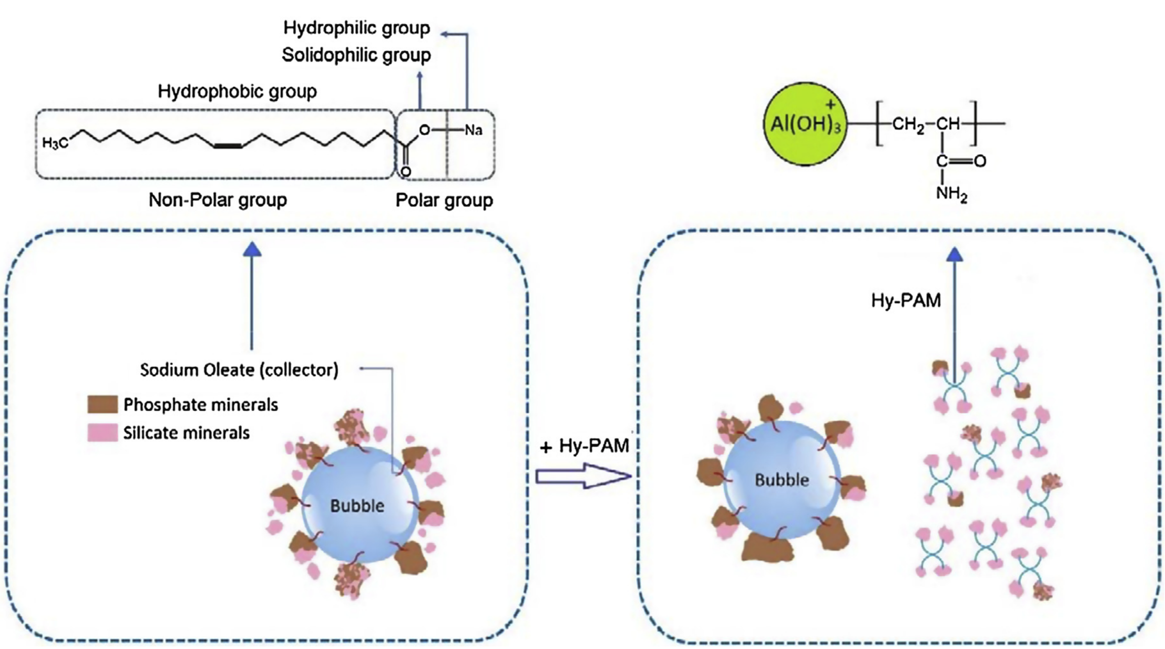

Fig. 1. A conceptual view of the proposed role of Hy-PAM as a silicates depressant.