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Depressing effect of flocculants on molybdenite flotation ☆

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ABSTRACT

The quality of recycled process water is an important issue in the flotation of Cu–Mo ores. Processing of Cu–Mo ores includes two steps: a bulk flotation where molybdenite is recovered together with Cu sulfides, and a subsequent selective flotation step where molybdenite is separated from depressed copper sulfides. Flocculants are usually employed in the middling thickeners in the copper plant, and in the Cu–Mo bulk concentrate ahead of the molybdenite plant. However, the floatability of molybdenite, similarly to other naturally hydrophobic minerals, is highly sensitive to the presence of both natural and synthetic polymers. In this work flotation tests demonstrate that conventional flocculants, high-molecular weight anionic polyacrylamides (PAM), are strong molybdenite depressants. Low-molecular weight shear degraded polyacrylamides in spite of losing flocculation efficiency maintain depressing ability for molybdenite. Also a non-ionic flocculant, polyethylene oxide (PEO), has been studied in this project. Our results indicate that PEO is an efficient flocculant for molybdenite suspensions in a wide pH range. However, similarly to polyacrylamides, the PEO flocculant also depresses molybdenite flotation.

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1. Introduction

Modern processing plants must have closed water circuits in which process water is recycled back after removal of solids in the solid/liquid separation unit operations. With the present trend towards higher flocculant levels in the thickening (e.g. paste technology) and filtration dewatering the likelihood of flocculants build-up in recycle streams over time is very large. The possible presence of residual flocculants or degraded derivatives in water which is recycled back to a flotation process raises the question about the effect of flocculants on flotation of Cu–Mo ores, and in particular on flotation of molybdenite which is an inherently hydrophobic mineral. These effects were studied in coal flotation, and since coal along with graphite, molybdenite and talc belongs to the same group of inherently hydrophobic solids there is a lot

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of to learn from these results and to apply directly to the case of molybdenite flotation.

In many flotation processes, for example in rejection of pyrite from coal, rejection of talc and graphite in the flotation of sulfide ores, polymeric agents are commonly applied as depressants. At one point, dextrin was implemented at the Utah concentrator as molybdenite depressant in the selective flotation of Cu sulfides from molybdenite (Shirley, 1979).

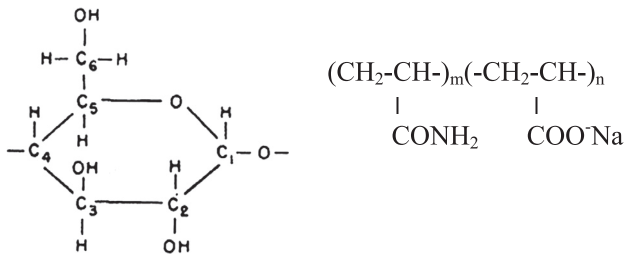
In the Cu–Mo sulfide ore processing plants, the stage of bulk flotation of copper sulfides and molybdenite (and depression of pyrite) is followed by the second stage (moly plant) which includes selective flotation of molybdenite and depression of copper sulfides. It has been a common practice that the Cu–Mo bulk concentrate is stored in thickeners in which also flocculants can be applied to increase solids content in the feed to the moly plant. In doing so it is often assumed that the use of low molecular weight flocculants minimizes flocculation and so does not affect much flotation. However, Shirley (1979) pointed out that in plant practice "most of commonly used flocculants are excellent depressants for molybdenite even if it has been collected with an oil. Therefore, flocculants should not be used on middling thickeners in the copper circuit or the molybdenite plant feed thickener unless absolutely necessary".

The objective of this paper is to discuss the effect of anionic polyacrylamide flocculants and their degradation products – which are polymer segments of low-molecular weight – on the floatability of molybdenite. Polyethylene oxide (PEO), a non-ionic flocculant and its ability to depress molybdenite flotation has been studied, too.

2. Use of polymers in mineral processing

Various polymers – low molecular weight dispersants/depressants and high molecular weight flocculants – are utilized in mineral processing circuits. Since they must be water soluble, these polymers are highly hydrophilic macromolecules. Common examples in the former group are dextrins, low molecular weight polyacrylates (e.g. Cataflot, Dispex, etc.), polystyrene sulfonate (PSS10 used in coal–water slurries), and in the latter group polyacrylamides are the best known. Also starch is in the group of high molecular weight polymers used as flocculants (by the way starch in combination with lime was the first flocculant patented in 1928 for the clarification of a coal's mine effluents (Kitchener, 1978). It is to be pointed out that from the chemical point of view both dextrin and starch are the same polysaccharides which differ only by molecular weight (Fig. 1).

Polyacrylamides, the most common commercial flocculants, as shown in Fig. 1, are to some extent anionic (expressed as degree of anionicity), and so they can also be treated as co-polymers of polyacrylamide and polyacrylic acid. High molecular weight PAMs with a degree of anionicity in the range 20–30 are claimed to be the most efficient in thickening tailings (Michaels, 1954; Xu and Cymerman, 1999).



$$(CH_2\text{-}\underset{\displaystyle CONH_2}{CH}\text{-})_m(\text{-}CH_2\text{-}\underset{\displaystyle COO^-Na}{CH}\text{-})_n$$

Fig. 1. α-D-Glucose structural unit of dextrin and starch, and chemical formula of polyacrylamide.

The main function of flocculants used in solid/liquid unit operations is to produce large and strong flocs. It is generally accepted that polymers used as flocculants aggregate suspensions of fine particles by a bridging mechanism. The bridging is considered to be a consequence of the adsorption of the segments of the flocculant macromolecules onto the surfaces of more than one particle. The optimum flocculation occurs at flocculant dosages corresponding to a particle coverage that is significantly less than complete. Incomplete surface coverage ensures that there is sufficient unoccupied surface available on each particle for the adsorption of segments of the flocculant chains during collision of the particles. Thus, at low polymer coverage, the adsorbed polymer can destabilize the suspension by bridging flocculation, but since these macromolecules are hydrophilic the polymer adsorbed layers cause repulsion at a high coverage (high polymer dosage). These results in stabilization of the suspension, the phenomenon referred to as steric stabilization.

There are many direct contact angle measurements which show that hydrophobic solids become less hydrophobic and loose floatability in aqueous solutions of water-soluble polymers. Klassen in his monograph on coal flotation (Klassen, 1963) listed many polysaccharides as depressants for coal flotation. The use of dextrin to depress coal and float pyrite with xanthate was patented by DOE for desulfurizing flotation of fine coal (Miller and Deurbrouck, 1982). Pradip and Fuerstenau, 1987 tested the effect of various polymers on the wettability of anthracite and showed that the anthracite becomes less hydrophobic in their presence. Similar results were reported by Moudgil (1983). Wie and Fuerstenau (1974) reported strong depressing effect of dextrin on the wettability of molybdenite in acidic solutions; such a depression has recently been confirmed by Beaussart et al. (2012).

Polymeric substances known as humic acids often appear in process waters (obtained from lakes or rivers). These are poorly defined anionic polymers with phenolic and carboxylic groups, which were shown to affect strongly wettability of graphite (Wong and Laskowski, 1984) and also wettability of molybdenite (Laskowski and Yu, 1994). These effects were particularly significant in acidic solutions where humic acids become less soluble and precipitate. Pawlik et al. (1997) confirmed that very hydrophobic bituminous coal can become totally hydrophilic at relatively low concentrations of humic acids. One of the important gangue minerals in the South African sulfide ores that contain platinum is talc. Since it is naturally hydrophobic it tends to float well and it is common to depress it using guar gum (or other polysaccharides such as starch or carboxymethyl cellulose).

3. Effect of flocculants on coal flotation

This important aspect of coal flotation has been extensively discussed in the book by Pikkat-Ordynsky and Ostry (1972). In their tests they used slightly anionic polyacrylamide (PAM) with molecular weight of 3×10^6 and non-ionic polyethylene oxide (PEO) with molecular weight of 7×10^6. Flotation tests were carried out in a 1.5 L lab flotation cell, at 150 g solids/L pulp density.

Both flocculants were found to strongly depress coal flotation: the higher the flocculant dosage, the smaller the yield of the concentrate, higher its ash content, and lower ash content in the flotation tailings. These effects begin to be visible at a dosage of 1 g/m^3 of PAM and were more pronounced for the flotation feeds with a high yield of very fine particles. Fig. 2 shows the results of their flotation tests on the effect of PAM on flotation of bituminous coal. As seen, at 150 g/m^3 of PAM, depression is total. The lower yields of clean coal were explained by the adsorption of hydrophilic macromolecules onto coal particles that makes these particles hydrophilic and higher ash contents of the concentrate results