



An investigation into the flotation of muscovite with an amine collector and calcium lignin sulfonate depressant



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ABSTRACT

Muscovite mica is a naturally occurring phyllosilicate mineral with a wide range of industrial applications. This work investigated the separation of muscovite from unwanted gangue minerals in a mica ore. Electroacoustic zeta potential measurements and single mineral flotation tests were used to determine the effect of Custamine 8113 (collector) and Norlig-H (depressant) on muscovite. These results were then compared to those of gangue minerals (feldspar and quartz). Muscovite showed an isoelectric point (IEP) at pH 3.5. Feldspar and quartz did not have an IEP, having negative zeta potentials over the pH range investigated (pH 3–10). This suggests that effective separation using a cationic amine collector, which relies on electrostatic attraction as the basic mechanism of adsorption onto mineral surfaces, would not be possible without the use of a depressant. Zeta potential measurements and single mineral flotation tests in the presence of both Custamine 8113 and Norlig-H indicate that reagent adsorption is controlled by Custamine 8113 in the case of muscovite and by Norlig-H in the case of feldspar and quartz. This suggests that effective separation of muscovite from the gangue minerals present in the mica ore is possible. These results were used to determine optimal flotation conditions of the ore. Concentrates from the ore flotation were examined by QEMSCAN analysis, which showed that muscovite was effectively separated from gangue minerals.

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1. Introduction

1.1. Muscovite

Micas are a group of phyllosilicate minerals distinguished by their close to perfect basal cleavage. They are widespread in igneous, sedimentary and metamorphic rocks and their crystal structure incorporates a large number of elements, leading to a large and diverse mineral group. Of the many different minerals in the mica family, muscovite ($\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$) is the most common, and its physical properties render it useful in a wide range of applications, such as: insulators; condensers; plastics; cosmetics; and paints [1–3]. Muscovite is primarily separated from common gangue minerals such as quartz and feldspar, taking advantage of differences in physical properties [3]. These methods, however, prove to be ineffective when dealing with small particle sizes and therefore froth flotation is used [1,3]. Froth flotation may

also be used as a scavenger step on gravity tailings to recover some of the remaining muscovite.

1.2. Surface chemistry

In froth flotation, the electrical double layer at the mineral-water interface governs the adsorption of flotation reagents [4,5]. An important mineral property in characterizing the electrical double layer is the isoelectric point (IEP), which is the pH value where the zeta potential is zero [6]. The IEP can aid in predicting the sign of the charge on a mineral surface in a given pH range [6]. Understanding the zeta potential of a mineral can help understand mechanisms of collector adsorption and select optimal flotation conditions to effectively separate a valuable mineral from gangue minerals [3,5–7]. In systems where electrostatic attraction and hydrophobic bonding are major driving forces in collector adsorption, the adsorption process is characterized as physical and the extent of reagent adsorption is controlled by the sign and magnitude of the surface charge [4,6]. Chemically adsorbing (chemisorbing) collectors form strong covalent or coordinate bonds with surface species and are able to adsorb onto the surface

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of similarly charged minerals, however a high surface charge can inhibit the adsorption of chemisorbing collectors via electrostatic repulsion [4]. For an introduction to the concept of surface charge and zeta potentials and their application in flotation, interested readers should consult Riley (2009) [8] and Fuerstenau and Pradip (2005) [4].

Zeta potential measurements may be conducted using different methods, with the most widely used technique being electrophoresis [9–12]. Although electrophoretic techniques are well-established, they are restricted in their applicability by the requirements for very fine particles in suspension and very dilute (<1%_{w/w}) dispersions [9,11–15]. The electroacoustic method offers distinct advantages over electrophoresis. As it is a non-optical measurement technique, electroacoustic methods are free of the limitations associated with optical electrophoretic measurements, and have been shown to be effective in analysing sizes ranging from a few nanometers to several micrometers [13,14,16,17], concentrated and complex mineral suspensions [13,14] in excess of 60%_{w/w} [16–18], opaque or photosensitive materials [9,14] and flowing streams [14]. Electroacoustic zeta potential measurements are based on the application of high-frequency alternating electric fields to a suspension of particles, causing charged particles to oscillate and produce a sound wave of the same frequency. The zeta potential of the sample can be calculated from the phase and magnitude of the resulting sound wave. More details of the electroacoustic technique can be found in O'Brien (1990) [19], O'Brien (1995) [20] and O'Brien, et al. (1990) [21]; and a review of the applications can be found in Hunter (1998) [13] and Greenwood (2003) [17].

1.3. Physico-chemical properties of muscovite

Muscovite has been shown to have permanently negatively charged basal planes [22–27] and edges with an IEP in the pH range 5–7.5 [23,25,27]. The edges account for approximately 5–10% of the overall surface charge [28], resulting in an overall mineral IEP commonly occurring at pH <4 [22–24,29,30]. Due to the negative surface potential at pH >4, muscovite is expected to show much greater affinity for cationic collectors than anionic collectors, if electrostatic attraction is the mechanism of adsorption. Many papers on the application of collectors in the flotation of muscovite have been published, focusing primarily on cationic amine collectors [5,22,24,31–42]. Electrostatic attraction is the basic mechanism involved in the adsorption of amines onto mineral surfaces, and thus it has been suggested that at higher pH values greater adsorption is observed. However, increasing the pH to a point where the amine solubility limit is exceeded may be detrimental to flotation [36,39,43]. Conversely, some researchers have found that amine precipitation onto a mineral surface at an elevated pH can occur and improve flotation, but in either case at pH >12 flotation does not occur [43]. In the published literature focusing on muscovite flotation, the maximum flotation response with dodecylamine, a widely used collector, has been shown to occur around pH 8 [36,44]. Adsorption of anionic and mixed cationic/anionic collectors on muscovite and the corresponding flotation response has also been examined [5,24,33,45,46]. Using sodium oleate as an anionic collector no adsorption was observed, however in mixed amine/oleate systems the adsorption of anionic and cationic collectors is enhanced due to co-adsorption, although the underlying mechanism of this co-adsorption has not yet been identified [24,33].

The zeta potential of common gangue minerals in mica ores, such as feldspar and quartz, have been shown to be negative at pH >3. [22,47–53]. The lack of an IEP in this range means that silicate minerals will be electrostatically attracted to a cationic collector and it may not be possible to selectively concentrate

muscovite from these minerals. Examples of quartz and feldspar flotation with cationic amine collectors indicate that these minerals must be effectively depressed for selective flotation to occur [54–60]. Calcium lignin sulfonate (Goulac), a silicate depressant, is commonly used in muscovite flotation [61,62].

The objective of this work was to effectively separate muscovite from gangue minerals present in a mica ore through the use of froth flotation with an amine collector and calcium lignin sulfonate depressant. The surface chemistry of the ore minerals in the presence of various flotation reagents was investigated followed by flotation tests on both pure mineral samples as well as the ore itself.

2. Experimental

2.1. Materials

Pure muscovite and feldspar used in this work were provided by an industrial minerals operation; quartz was purchased from Daubois (Canada). The muscovite ore used for flotation experiments was obtained from a muscovite mine.

In order to obtain a size fraction small enough for zeta potential measurements the muscovite ($d_{50} = 20 \mu\text{m}$) was passed through a 2" Mozley hydrocyclone with a cut size of approximately $10 \mu\text{m}$ and operating pressure of 35 psi. The overflow of the hydrocyclone was then wet screened at $25 \mu\text{m}$ to produce a feed ($d_{50} = 5.0 \mu\text{m}$) for electroacoustic zeta potential measurements. The underflow of the hydrocyclone was used directly for single mineral flotation experiments. Particle sizes, unless otherwise noted, were determined using a LA-920 particle size analyser (Horiba).

Feldspar ($d_{50} = 8.7 \mu\text{m}$) was used as provided for electroacoustic measurements. The sample was determined by X-ray diffraction (Bruker D8 Diffractometer) to be a mixture of both Na-feldspar and K-feldspar.

Quartz was prepared for single mineral flotation experiments by wet grinding in a rod mill to produce a 80% –106 μm feed. For electroacoustic measurements quartz was milled in a Pulverisette 6 planetary monomill (Fritsch, Germany) to produce a particle size with a d_{50} of $4.1 \mu\text{m}$.

The muscovite ore was ground wet in a laboratory rod mill at 50% solids for 22.5 min to produce an 80% –106 μm flotation feed. The rod mill had an inner diameter of 180 mm and length of 230 mm. A total of 22 rods were used with a length of 190 mm as grinding media, weighing 10,724 g and varying in diameter from 164 mm to 339 mm (14 of 164 mm, 6 of 227 mm and 2 of 339 mm). The mill speed was 61 rpm.

Reagents obtained from the mica mine are shown in Table 1. Hydrochloric acid (at a concentration of 1 mol/L), used for pH modification in both zeta potential and flotation experiments, was purchased from Fisher Scientific.

2.2. Electroacoustic zeta potential measurement

Electroacoustic zeta potential measurements were carried out using a FieldESA (PartikelAnalytik, Germany) equipped with a large volume (220 mL) cell and an automatic titration unit. Samples

Table 1
Reagents from the mica mine.

Reagent name	Reagent type	Manufacturer
Custamine 8113	Collector/Frother	ArrMaz
Norlig-H	Depressant	LignoTech
Cp-102a	Frother	ArrMaz
Caustic	pH Modifier	OxyChem

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