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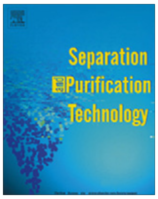

Investigation of shear flocculation behaviors of colemanite with some anionic surfactants and inorganic salts

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ABSTRACT

The variations of shear flocculation of colemanite mineral with sodium oleate and sodium dodecyl sulfate (SDS) as anionic surfactants with suspension pH, surfactant concentration, stirring speed, and flocculation time have been investigated. It was determined that sodium oleate was more effective in the flocculation than SDS and the colemanite particles could be flocculated by oleate in the broad pH range. Also, a stirring speed of 500 rpm and a flocculation time of 3 min were required to achieve the maximum flocculation degree of colemanite particles. The effects of magnesium, barium, aluminum, and ferric chlorides as inorganic salts on the shear flocculation of colemanite suspension were also studied. In the presence of these cations, the flocculation degrees of colemanite suspension reached high values at particular conditions. However, some differences in the behavior of flocculation of colemanite mineral were observed depending on pH, cation concentration, type of surfactant and inorganic salt.

1. Introduction

Colemanite ($Ca_2B_6O_{11}\cdot 5H_2O$), one of the most important boron minerals, is a hydrated semi-soluble salt and has a large portion in the boron mineral deposits of Turkey. Boron compounds are used in the manufacture of a variety of industrial products, such as soaps, washing powders, glasses, ceramics, specialty alloys, fillers, and advanced technological materials [1–3]. The friable nature of colemanite mineral tends to produce a large amount of fines in mineral processing operations. Flotation appears to be a promising technique to recover colemanite from such fines [2,3]. However, the recovery of the mineral particles by froth flotation decreases for particle size of slime [4]. Therefore, size enlargement processes may be beneficial for mineral processing operations. One way to recover valuable minerals from fines is to increase their size by selective aggregation and then to float the aggregates. Secondly, one of the selective aggregation techniques is used to separate valuable minerals from fine particle mixtures, with the aggregation of the desired mineral [5,6]. One of these selective aggregation methods in fine particle processing is shear flocculation. In this technique, the aggregation of fine particles is provided at a convenient stirring regime after hydrophobization by the adsorption of surfactants. Hydrophobic electrically charged fine particles can also form stable suspensions. Therefore, the shear flocculation process requires mechanical energy to overcome the energy barrier, arising from the electrical charge on the particle surfaces [5,7]. To provide hydrophobization of hydrophilic particles, surfactants known as flotation collectors are often used. The advantage of shear flocculation is the production of stable hydrophobic flocs which should be tough enough to withstand the turbulence in mineral processing operations. Also, the hydrophobic flocs produced in the flocculation process can be separated from the remaining hydrophilic dispersed particles by flotation [7].

Although there have been various studies on the flotation behaviors of colemanite mineral, there has not been any investigation on the shear flocculation properties of this mineral in the literature. Therefore, this paper aims to determine those characteristics experimentally. Determination of such properties regarding to colemanite mineral will also support fine particle processing of colemanite ores.

2. Experimental

2.1. Materials

The shear flocculation experiments were conducted using a high purity sample of colemanite mineral from Bigadic, Turkey. The chemical composition of the sample consists of 41.18% B_2O_3, 30.06% CaO, 4.76% SiO_2, 0.2% MgO, 0.12% Fe_2O_3, 0.07% Na_2O, 0.06% SO_3 and 0.01% Al_2O_3. The colemanite sample was dry ground by a steel ball mill and the particle size distribution of the ground sample was determined by an Andreasen pipette. As seen in Fig. 1, the ground colemanite sample has 70% passing 17 µm. Sodium oleate ($C_{17}H_{33}COONa$) and sodium dodecyl sulfate ($C_{12}H_{25}SO_4Na$) were used as anionic surfactants for hydrophobization of

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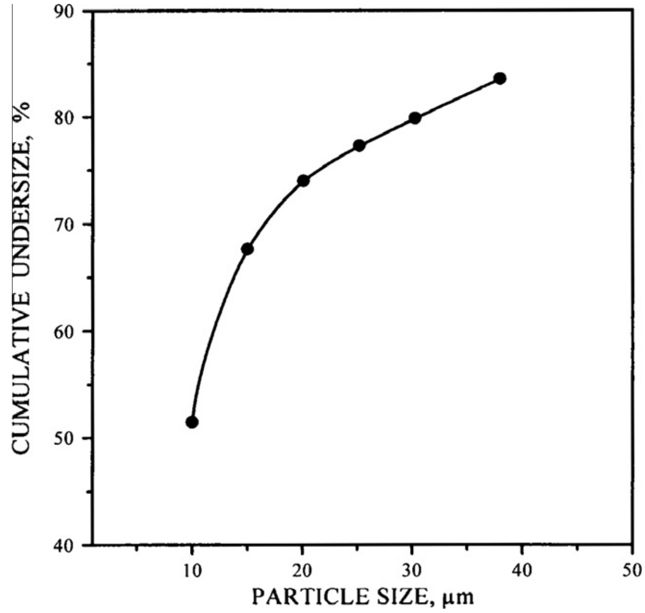

Fig. 1. Particle size distribution of the colemanite sample used in the experiments.

colemanite mineral. Sodium oleate was prepared from oleic acid ($C_{17}H_{33}COOH$) (Carlo Erba) and sodium hydroxide (Merck). Sodium dodecyl sulfate (SDS), magnesium chloride ($MgCl_2·6H_2O$), barium chloride ($BaCl_2·2H_2O$), aluminum chloride ($AlCl_3·6H_2O$), and ferric chloride ($FeCl_3$) were also purchased from Merck. Sodium hydroxide and hydrochloric acid (Merck) were prepared as 1% and 5% solutions for modification of pH values of the suspensions and the control of pH was also provided by a digital pH meter. The chemicals used in the experiments were of analytical grade and mono distilled water was employed for all experimental work.

2.2. Shear flocculation experiments

Shear flocculation experiments were carried out in a 400 cm^3 cylindrical cell with four baffles using 1 g solid and 300 cm^3 water. The mixture of mineral–water suspension was pre-conditioned for 1 min in order to obtain a well-dispersed suspension. The dispersed suspension, adjusted to the desired pH, was first conditioned at 500 rpm for 5 min and the surfactant was added into the suspension at an impeller speed of 500 rpm. After 3 min, the stirring speed was reduced to 160 rpm for 2 min to allow floc growth. After a settling time of 2 min, the supernatant was siphoned off, at a fixed distance of 4.5 cm below the air–liquid interface, by a special system. The settled material was filtered, dried, and weighed in order to determine the % shear flocculation degree [% shear flocculation degree = (settled weight/weight of feed) × 100]. The pH of the colemanite suspensions was continuously controlled in the experiments. It was determined that the shear flocculation degrees were obtained within the experimental error of ±5%.

2.3. Zeta potential measurements

The zeta potential measurements were made by a ZetaPlus apparatus from Brookhaven. The ZetaPlus is an automatic instrument designed for use with suspensions of particles from 10 nm to 30 μm. The ZetaPlus system, also known as Laser Doppler Velocimetry (LDV), has a laser beam which passes through the sample in a cell which carries two electrodes to provide the electric field. In the zeta potential measurements, 1 g of mineral in 100 cm^3 of water was conditioned for 5 min during which the pH was adjusted, followed by 5 min of conditioning after adding appropriate reagents. The suspension was kept still for 5 min to let larger particles settle. Thereafter, 10 cm^3 of supernatant was taken out and transferred into the clear disposable cells. The clean platinum electrodes were inserted into the cell. Thereafter, the cell inserted into the ZetaPlus and the zeta potential was automatically calculated using the average velocity and direction of the particle within this electric field. An average of 10 runs was recorded for the measurement of zeta potential of each sample. Three measurements were made for each data point and the average values were reported. All measurements were made at 22 °C and the zeta potential values were obtained within the experimental error of ±4%.

3. Results and discussion

Fig. 2 shows the zeta potential of colemanite mineral as a function of pH in the presence of sodium oleate and sodium dodecyl sulfate (SDS). It can be seen that the isoelectric point (i.e.p.) of the colemanite sample occurs at pH 10.2 in the absence of the surfactants. This i.e.p. value is very close to that reported by Celik and Yasar [8]. The colemanite mineral had a negative potential in the presence of the anionic surfactants at pH values below the i.e.p. and the negative surface charge of the mineral also increased at pH values above the i.e.p. value. Celik et al. [2] stated that flotation of colemanite with anionic sodium dodecyl sulfate and cationic dodedcylamine hydrochloride collectors in the absence of salt was attributed to electrostatic interactions in the system. In other studies, the adsorption of sodium oleate and SDS onto the colemanite surfaces was attributed to electrostatic and chemical adsorption mechanism [9–11]. Because of the chemical adsorption, $Ca(DS)_2$ and $Ca(Oleate)_2$ compounds form on the colemanite surfaces and the zeta potential of colemanite became largely negative at pH values higher than pH 10.2, as seen in Fig. 2. At pH values below the i.e.p, the electrostatic interaction between the anionic surfactants and the positively charged colemanite surfaces could be possible.

The variations of zeta potential of colemanite in the presence of 10^{-4} M concentration of Mg^{2+}, Ba^{2+}, Al^{3+}, and Fe^{3+} ions with pH are

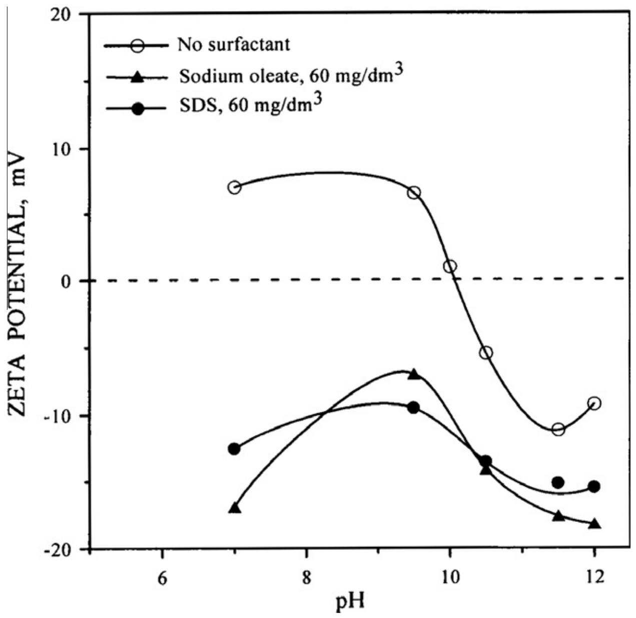

Fig. 2. Zeta potential of colemanite as a function of pH in the absence and presence of surfactants.