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Two-stage shear flocculation for enrichment of fine boron ore containing colemanite

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ABSTRACT

The enrichment of fine boron ore containing colemanite mineral was investigated using shear flocculation, two-stage shear flocculation, column flotation and floc flotation techniques. In these fine particle processing methods, sodium dodecyl sulfate (SDS) and Aero 801 were used as surfactant for colemanite. Also, sodium pyrophosphate and sodium hexametaphosphate were employed to improve the selectivity of the processes. The highest grade of the colemanite concentrate was obtained with two-stage shear flocculation method using Aero 801 and sodium hexametaphosphate. Under the optimum conditions, a concentrate of 38.65% B_2O_3 could be recovered by two-stage shear flocculation from the ore containing 26.98% B_2O_3.

1. Introduction

In present day society, boron, an important element of both chemical and biological interest, has a variety of uses. Modern uses of boron-bearing minerals and boron derivatives include heat resistant glass (e.g., Pyrex), fiberglass, ceramics, washing products (e.g., detergents and soaps), special alloys, fertilizers, fire retardants, wood treatment agents, insecticides, and microbiocides [1]. Boron reserves in the world are estimated to be 1241 million tons of B_2O_3 [2] and Turkey has about 70% of total boron reserve of the world [3]. Colemanite ($Ca_2B_6O_{11}\cdot 5H_2O$), a major source of boron mineral, is semi-soluble calcium-borate hydrate that is found in massive beds with other calcium containing minerals such as calcite and gypsum, and a variety of clays. In Turkey, colemanite is usually concentrated using scrubbing, washing and classification following the size reduction step [4]. Mining and processing steps increase the fine particle concentration continuously. These fine particles cause several problems in dewatering, drying, transportation and storage. These problems also lead to considerable environmental pollution. Therefore, the mineral matter must be removed from these fine particles. Because of the losses of valuable minerals in the fine size range, there is interest in devising new processes and in improving the existing processes for the recovery of fine particles.

Flotation appears to be a promising technique to recover valuable minerals from fines [5,6]. However, the recovery of the mineral particles by froth flotation decreases for particle size of slime [7]. Therefore, size enlargement processes may be beneficial for mineral processing operations. One way to recover valuable minerals from fine ores is to increase their size by selective flocculation and then to float the flocs (floc flotation). Secondly, one of the selective polymeric flocculation, selective shear flocculation techniques is used to separate valuable minerals from fine particle mixtures, with the aggregation of the desired mineral [8,9]. In the shear flocculation 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 [8,10]. 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 [10]. A successful industrial example of the application of the shear flocculation technique to mineral processing was the Yxsjoberg scheelite plant in Sweden. In this plant, the scheelite ore was conditioned with fatty acid as surfactant and the scheelite was selectively flocculated and then floated by flotation [11]. A pilot plant test of scheelite ore from King Island suggested that pre-treatment of the fine particles by shear flocculation improved subsequent flotation recovery of scheelite mineral. Also, it has been shown that

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scheelite flocs formed by shear flocculation effect float 10 times faster than the original particles [10,12]. The application of shear flocculation as a pre-treatment before flotation to the Rey de Plata sulfide ore of Mexico showed that shear flocculation not only reduced the losses of the valuable minerals in the tailing through recovering more valuable mineral fines, but also considerably increased the separation efficiency in the flotation through increasing the flotation rate of valuable minerals, in comparison to conventional flotation [11].

Column flotation was developed as an alternative to the conventional, mechanically agitated flotation machines. The main advantages of column flotation compared to conventional cells are a better product without sacrificing recovery, a reduction in the number of stages of operation, ability to handle a finer feed, savings in collector requirements and simplicity in design for construction without any moving parts and less floor space requirements. However compared to conventional cells the water requirement per ton of feed processed and consequently the frother requirement may be more. In many studies, it has been claimed that column flotation gives a higher recovery with better grade [13].

The friable nature of the colemanite leads to produce a large amount of fines in mineral processing operations. Although there have been various studies on the conventional flotation behaviors of colemanite mineral, there has not been any investigation on the column flotation, two-stage shear flocculation and floc flotation properties of fine boron ores containing colemanite mineral in the literature. Therefore, this paper aims to determine those characteristics experimentally. Determination of such properties regarding to boron ores containing colemanite will help improving the alternative processes for the recovery of fine boron ores. On the other hand, the vast majority of the studies made on the shear flocculation technique have been carried out using high purity samples of minerals. Therefore, this paper also purposes to reveal the applicability of the shear flocculation process on fine ores.

2. Experimental

2.1. Materials

The experiments were carried out using boron ore sample containing colemanite from Bigadic, Turkey. The chemical composition of the sample consists of 26.98% B_2O_3, 24.26% CaO, 14.71% SiO_2, 5.69% MgO, 0.36 SO_3, 0.09% Fe_2O_3 and 0.01 Al_2O_3. The sample was dry-ground to 38 μm by a steel ball mill. The particle size distribution of the ground sample was determined by an Andreasen pipette and the obtained results showed that the ground material has 70% passing 20.5 μm. Sodium dodecyl sulfate (SDS, $C_{12}H_{25}SO_4Na$) (Merck) and Aero 801 (petroleum sulfonate) (Cyanamid Company) were used as surfactant/collector for hydrophobization of colemanite. Flotenal D-13 was employed as frother for column flotation and floc flotation experiments. 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. For increasing the selectivity of the processes, sodium pyrophosphate ($Na_4P_2O_7{\cdot}10H_2O$) and sodium hexametaphosphate $(NaPO_3)_6$, purchased from Merck, were used as dispersant/depressant. The chemicals used in the experiments were of analytical grade and mono distilled water was employed for all experimental work.

2.2. Shear flocculation and two-stage shear flocculation experiments

The 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 solid-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 3 min and the dispersant was added into the suspension. After 2 min, the suspension was also conditioned with surfactant for 3 min at an impeller speed of 500 rpm. Thereafter, the stirring speed was reduced to 160 rpm for 2 min, to allow floc growth. After a settling time of 2 min, the top 4.5 cm of supernatant was siphoned off with a syringe system. The sediment remaining in the cylindrical cell was filtered, dried, weighed and analyzed by GBC Atomic Absorption Spectrophotometer (AAS) for their B content. The grades of B_2O_3 of the materials were also calculated. In the two-stage shear flocculation experiments, the concentrate, i.e. flocculated material, obtained with the shear flocculation was re-flocculated under the same experimental conditions given above.

2.3. Column and floc flotation experiments

The column and floc flotation studies were carried out in a laboratory scale flotation column having a square cross section of 5×5 cm^2 with a height of 40 cm and a volume of 1 dm^3. Initially, the mixture of 10 g solid and 100 cm^3 water was preconditioned in a separate cell for two min at the desired pH. Thereafter, the depressant was added into the suspension. After 3 min, the suspension was conditioned with collector for 3 min and then the system was stopped. Frother was also added into the column. The suspension conditioned with the reagents was fed to column with a constant speed at approximately 2/3 of the column height, travelled downwards against the rising air bubbles. Air bubbles were generated using an air compressor and an air sparger located at the bottom of the column (air-flow rate 279 cm^3/min). The froth was washed by a spray of water and the clean froth was collected at the top of the column. After that, the obtained concentrate was filtered, dried and analyzed for their B content. In the floc flotation experiments, the flocs provided by the shear flocculation experiments performed under the desired experimental conditions were transferred into the flotation column. The experimental procedure of floc flotation tests was also similar to that of column flotation experiments.

3. Results and discussion

3.1. Enrichment of the ore with shear flocculation and two-stage shear flocculation

Fig. 1 shows the effect of pH on the enrichment of boron ore containing colemanite with shear flocculation method. The experiments were carried out in the presence of 60 mg/dm^3 concentration of sodium dodecyl sulfate and Aero 801 as surfactant. As seen in Fig. 1, the B_2O_3 grades of the concentrates recovered by shear flocculation reached high values at the natural pH of the suspension, i.e. pH 9.3. Also, the B_2O_3 recovery values of the concentrates showed slight increases in the pH range of 9.3–12. On the other hand, Aero 801 was more effective than sodium dodecyl sulfate in the enrichment of colemanite ore by shear flocculation. While a concentrate having a grade of 28.13% B_2O_3 was achieved with sodium dodecyl sulfate with a recovery of 83.43%, a concentrate of 33.59% B_2O_3 was obtained with a recovery of 76.24% in the presence of Aero 801 at pH 9.3.

The effects of the concentrations of sodium dodecyl sulfate and Aero 801 on the enrichment of colemanite ore by shear flocculation at pH 9.3 are given in Fig. 2. The B_2O_3 grade of the concentrates increased rapidly towards 60 mg/dm^3 concentration of Aero 801 and thereafter did not change much. In the case of SDS, the B_2O_3