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RECYCLING OF COLEMANITE TAILINGS USING THE JAMESON FLOTATION TECHNOLOGY

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Abstract: In this study, beneficiation of colemanite minerals from tailings of the Emet Boron Processing Plant using a laboratory scale Jameson flotation cell was investigated in detail. Effect of some working parameters of the Jameson cell such as jet length, plunging depth of downcomer, and bias factor was studied for the flotation performance of colemanite. The results showed that all parameters showed a significant effect on colemanite flotation using the Jameson cell which was the first time used in boron flotation with a negative bias factor. The results also indicated that a high recovery could be obtained with a worthy grade values by the negative bias factor. According to the results obtained at the bias factor of -0.3, jet length of 3 cm, and plunging depth of 20 cm, B_2O_3 content of the sample increased to approximately 46% from 36.8% with a recovery of 98.47%.

Keywords: *colemanite tailing, flotation, Jameson cell*

Introduction

Boron is a very important raw material for more than 200 different industries. Boron concentrates, by-products and refined products are widely used in many sectors. Major boron reserves in the world are located in Turkey, and this includes about 72% of the total world's boron reserves of colemanite, tincal and ulexite (Helvacı and Alonso 2000). These reserves provide a significant economic potential for Turkey when boron content of concentrate is increased by various techniques including physical and physico-chemical methods. Therefore, it is necessary to produce a clean product by removal of gangue minerals, and also prevent loss of boron to slurry ponds. Particularly, montmorillonite type of clay is a major source of gangue minerals in boron reserves (Ozdemir and Celik 2010). Therefore, separation of boron minerals from montmorillonite is the most significant beneficiation process for increasing the quality of concentrate.

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Boron beneficiation process conventionally includes a series of steps: washing, scrubbing, and classification. In Turkey, these series of methods have been utilized together to obtain concentrate with high boron content depending on the particle size. Moreover, the performance of the beneficiation methods for coarse particles is relatively high. On the other hand, the performance of physical methods decreases as the feed size gets finer. Therefore, particles finer than 150-200 μm are directly discharged to the slurry pond, and these particles have 20-26% of B_2O_3 (Gul et al. 2006; Kerenciler 2008; Ucar and Yargan 2009). Unfortunately, this causes not only economical loss but also environmental problems. For this reason, many studies have been performed to beneficiate boron minerals from the slurry ponds (Ucar and Yargan 2009). According to these studies, flotation is one of the most suitable methods for the beneficiation of the boron minerals from the slurry pond.

Previous studies indicated the importance of two points which must be taken into a consideration for boron flotation. The first one is the high possibility of slime coating on fine size particles (Yarar 1971; Celik et al. 2002; Ozdemir and Celik 2010; Ozkan and Acar 2004). The second one is the using suitable equipment having a high-performance for flotation of relatively fine particles (Ucar and Yargan 2009). According to the flotation mechanism and its theory, there is definitely a need for fine air bubbles in the flotation of fine and coarse particles (Sahbaz 2010). In this context, slime removal should be performed before flotation is carried out, and, the Jameson flotation cell will be a suitable device due to its high performance in processing of many ores because it produces fine sized air bubbles (400-1000 μm) (Sahbaz et al. 2012; Evans et al. 1995).

The aim of this study is to investigate the beneficiation of colemanite minerals from tailing of the Emet-Espey Boron Processing Plant (Kutahya-Turkey) using a Jameson flotation cell, and to investigate the effects of bias factor, jet length, and plunging depth for the flotation performance.

Materials and methods

Materials

The sample used in this study was obtained from fine tailings (-3 mm) of Emet Etibor Genaral Directorate of the Concentration Plant located in Kutahya-Emet, Turkey. The main mineral of these boron deposits is colemanite, and has a reserve of approximately 1.6 petagram with the B_2O_3 content from 28 to 30% (Eti Mine 2011). The Emet-Espey Boron Processing Plant has a capacity of 300 gigagram/year, and a total concentrate production of 120 Gg/year with a grade of 41% B_2O_3. The tailings from the plant is divided into two groups: coarse (+3 mm) and fine (-3 mm) sized. The tailings of -3 mm, collected as of 150 Gg, have a grade of approximately 26-33%.

The sample was taken from different locations of the tailing, and representatively separated and bagged using sampling methods. The chemical analysis of the sample tailing is presented in Table 1. As seen in Table 1, the B_2O_3 content of the tailing is determined as 26.33%. Besides boron mineral colemanite, montmorillonite, illite, quartz, calcite, dolomite, and sanidine were found as gangue minerals in the tailing sample (Ucar and Yargan 2009). In addition, arsenic (yellow colour), realgar (red colour), and orpiment minerals were detected in the macroscopic and microscopic examinations.

Table 1. Chemical analysis of the sample

Components	Content, %
B_2O_3	26.3
CO_2	11.3
Na_2O	0.191
MgO	6.29
Al_2O_3	8.3
SiO_2	25.7
P_2O_5	0.128
SO_3	0.953
K_2O	2.38
CaO	13
Fe_2O_3	2.85
As_2O_3	0.448
SrO	0.612
TiO_2	0.33

A 150+38 μm size fraction was used in this study in order to prevent the negative impact of slime in flotation experiments. After the removal of slime, B_2O_3 content of the tailing increased to 36.8% from 26.3%. In the case of the flotation experiments, a commercial corn starch, R801 (Cytec Co), and MIBC were used as depressant, collector (sulphonate type), and frother, respectively. Additionally, tap water was used in these experiments.

The flotation studies were carried out using a Jameson cell (Fig. 1) which was designed by Prof. Dr. Bahri Oteyaka with the help of Prof. Dr. Graeme Jameson in 2003. In this system, there is a centrifugal type pump to feed from conditioning tank through downcomer with pulp pressure (90-150 kPa), a peristaltic pump for washing water, a manometer to measure the pressure, an air flow sensor (anemometer) to measure feed, tailing flow-meters, and the amount of air entering to the system.

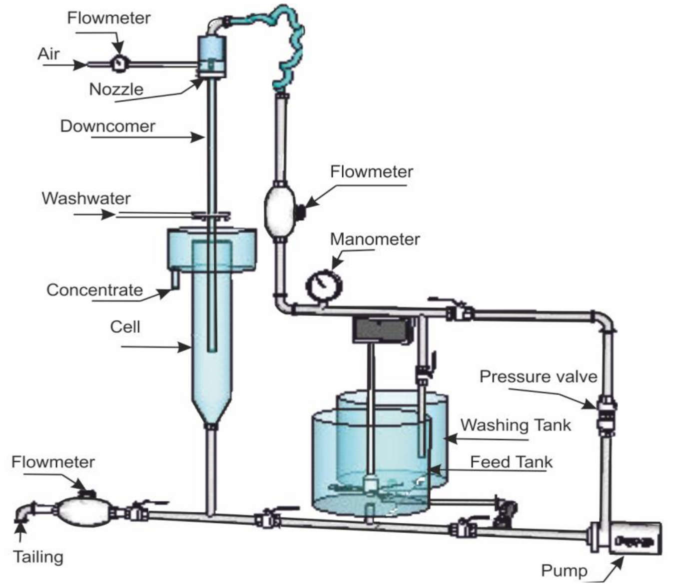

Fig. 1. Jameson flotation cell and equipments

The technical properties of the Jameson flotation cell are given below:

- cell (transparent plexiglas) diameter (D_C): 20 cm
- owncomer diameter (D_D) and length (L_C): 2 cm and 180 cm
- nozzle (stainless cast steel) Diameter (D_N): 0.4 cm.

In the experimental studies, the sample was first conditioned in a conditioning tank by adding the required reagents. In the meantime, 80 dm^3 of washing water tank was filled with the water. Then, the pulp was mixed with frother, and fed to the device where the operating parameters were set (such as a flow rate of feed and waste with by-pass system, air flow, and jet length). Then, the pulp supply valve was opened (by closing the valves between washing water tank and feeding pump), and the cell was fed with pulp approximately for 1 min. A minute later, pulp supply valve was closed, and the washing water tank valve was opened again to get the remaining floating and sinking particles in the cell. Finally, the system was fed only with water, and then the feeding was terminated until clean foam (demineralised air bubbles) came from the top of the cell.

Methods

Flotation experiments

Flotation is a complex beneficiation process realized in three-phase system using physicochemical surface property differences of minerals. For understanding flotation, physicochemical properties of particle surface and interface between phases must be known very well. One of these features is zeta potential profile of colemanite and its zero point of charge (zpc). As known from the literature, the zpc of the colemanite was found between pH 10-10.5 (Yarar 1971; Celik et al. 2002; Ucar and Yargan 2009; Ozdemir and Celik 2010). Meanwhile, colemanite showed a buffer feature at around pH 9. Moreover, sulphonate as a collector was used at this pH in these studies (Yarar 1971; Gul et al. 2006). It is important to note that the flotation behaviour of the colemanite was examined using a mechanical flotation cell in these studies. However, in this study, the Jameson flotation cell was used for the flotation experiments. Additionally, R801 and starch was used as a sulphonate type collector and depressant, respectively. Other parameters and values are given below. The flotation experiments were carried out in a single-stage and open-circuit. The parameters and the values used for the flotation experiments were: conditioning time (t_k) 2 +5 min, pulp flow 11.4 dm^3/min, washing water flow rate (Q_{ys}) 1.9 dm^3/min, solid ratio (%N) 2.5%, air velocity (V_h) 27 cm/sec, amount of frother (Q_K) 60 ppm, amount of collector (Q_T) 3.500 g/Mg, depressant 800 g/Mg, jet length (L_j) 2-9 cm, plunging depth 20 - 50 cm.

Results and discussion

Results

Effect of jet length

Jet length is defined as a distance between point where pulp jet starts to mix with air in the downcomer and tip of the nozzle. This parameter determines the amount of air entrained to the cell referred as gas hold-up. It varies depending on the entrained air volume, and hold-up changes in the downcomer. The hold-up values from the various jet lengths were determined as 41% (3 cm), 45% (6 cm), and 48% (9 cm) by the use of the procedure given by Harbort et al. (2002). The flotation experiments were carried out at these values, and the results are shown in Fig. 2.

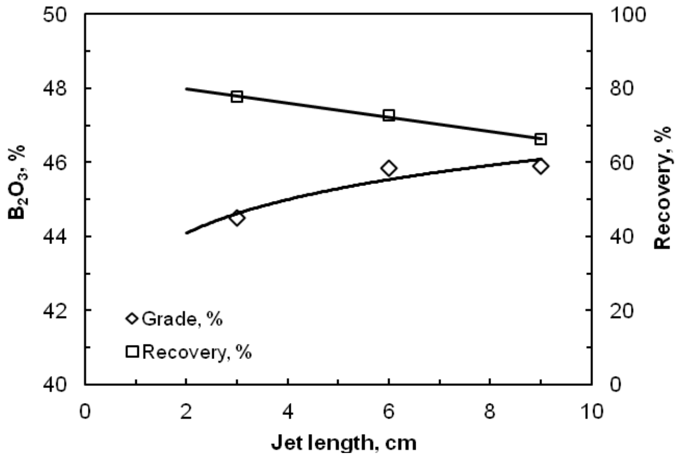

Fig. 2. Effect of jet length on grade-recovery (solid ratio: 2.5%, collector amount: 3500 g/Mg, plunging length: 40 cm, bias factor: +0.3, frother amount: 60 ppm)

As seen in Fig. 2, the flotation recovery decreased with the increase in the jet length. This can be attributed to the increase of the hold-up which caused the turbulence increase in the downcomer, hence this negatively affected the recovery (Oteyaka and Soto 1995; Sahbaz 2010). In addition, it is thought that the average bubble size increased with the increase in the hold-up, and hence probability of collision between particle and bubble started to decrease. Moreover, the turbulence at the end of the downcomer in the separation tank increased with the increasing of hold-up (Sahbaz 2010). Therefore, bubble-particle aggregate which occurred in the downcomer detached, and recovery decreased. The suitable jet length was found to be 3 cm for the colemanite sample.

Effect of plunging length

One of the other important parameters for the colemanite flotation using the Jameson cell is the plunging length of the downcomer at the separation tank. As the plunging length increases, water pressure applied in the cell increases on cross-sectional surface area of the pulp (aggregates + hydrophilic particles) coming out of the downcomer. In order to investigate the effect of this pressure on the recovery and grade, the flotation experiments were carried out at 4 different plunging lengths of the downcomer (e.g. 20 cm, 30 cm, 40 cm, and 50 cm), and the results are shown in Fig. 3.

As shown in Fig. 3, depending on the increase of plunging length, the recovery decreased while there was no noteworthy change in the grade. The reason for this could be related to a reduced flotation probability due to a poor stability of the bubble-particle aggregate because relatively coarse particles are easily affected any change in turbulence (Cinar et al. 2007). As clearly seen in Fig. 3, the most suitable plunging length for the downcomer is in the range between 20 and 30 cm. At this depth, a concentrate with B_2O_3 grade of 43.4% was obtained with a recovery of 92.78%.

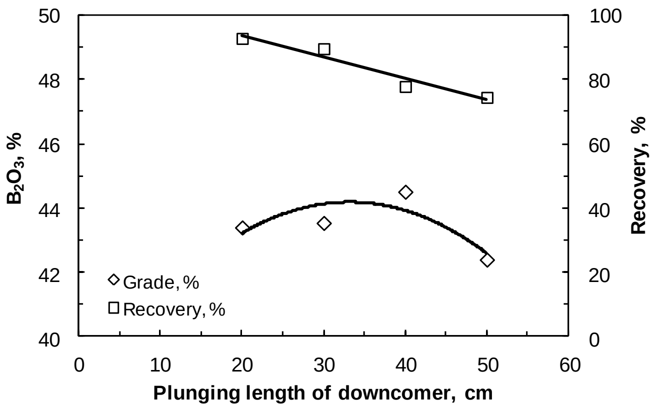

Fig. 3. Change of grade-recovery depending on the plunging depth (solid ratio 2.5%, collector amount 3500 g/Mg, jet length 3 cm, bias factor +0.3, frother amount 60 ppm)

Effect of bias factor

Fraction of the wash water flowing downward to report to the tailing stream which is called the bias factor is one of the variable contributing to the attainment of performance of the Jameson cell (Sahbaz et al. 2008). The bias factor is not only the parameter responsible for the formation of froth zone but also is maintained to limit the entrainment of fine hydrophilic particles into the froth phase. Production of a clean concentrate is greatly helped by the increased froth depth and the increasing bias factor (Cinar et al. 2007). As given in Eq. 1, the bias factor (BF) is defined as a ratio of the difference between tailing (Q_A) and the feed flow rate (Q_B) to the washing water flow (Q_{WW}) (Mohanty and Honaker 1999; Patwardhan and Honaker 2000).

$$BF = (Q_A - Q_B)/Q_{WW} \tag{1}$$

The *BF* is generally positive in the fine-grained minerals flotation (-100 μm) in order to prevent entrainment of hydrophilic minerals. For the purpose of present investigation, four different positive *BF*’s (+0.3, +0.4, +0.5, and +0.7) were evaluated for the colemanite sample. The feed and washing water rates were fixed, and tailing rate was changed during the experiments to obtain the *BF* values used in the present study. On the other hand, negative bias was used for coarse-grained minerals flotation (Oteyaka and Soto 1995). Meanwhile, the *BF* must be close to zero or negative in order to increase recovery. Therefore, flotation experiments were also carried out at negative bias factor values (–0.1, –0.2 and –0.3). The results are shown in Figs. 4 and 5.

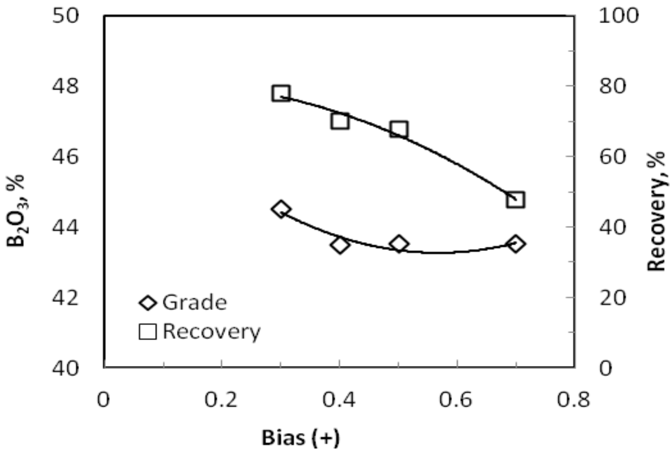

Fig. 4. Change of grade-recovery depending on the positive bias (solid ratio 2.5%, collector amount 3500 g/Mg, plunging length 40 cm, jet length 3 cm, frother 60 ppm)

Figure 4 shows the recovery and grade values as a function of positive bias values. The increase of positive BF provided the increase in the froth thickness caused the recovery decreased. In addition, there was not significant change in the grade of the float product. The thick froth zone acted as a barrier for large particles even though some of them were hydrophobic. Under the washing water and dense bubble environment, it became difficult for the particles to move up, and hence bubble particle detachment occurred. As a result of these experiments, a product with 44.51% of B_2O_3 was obtained with a recovery of 77.83% at 0.3 positive bias factor value.

In addition, the flotation results as a function of negative bias values are presented in Fig. 5. As shown in Fig. 5, the flotation recovery sharply increased with the increase in the bias values. The results indicated that a colemanite concentrate with 45.42% of B_2O_3 was obtained with a recovery of 98.47% at 0.3 of the negative bias value. Moreover, the positive role of rising water with the increase of buoyancy played a positive role for the grade and recovery increase in the absence of froth zone. Furthermore, it must be taken into a consideration that there was not any particle in slime size which may be dragged into the concentrate in the case of negative bias values. Therefore, there was no significant change in the grade while the recovery increased.

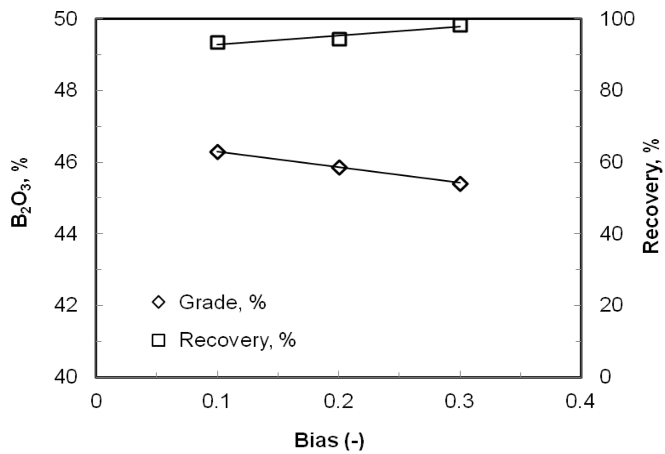

Fig. 5. Grade and recovery relation in accordance with negative bias (solid ratio 2.5%, collector 3500 g/Mg, plunging length 20 cm, jet length 3 cm, frother 60 ppm)

One of the most important indicators of flotation performance is selectivity obtained from upgrading curves such as Halbich's, Fuerstenau's, and other (Duchnowska and Drzymala 2013; Drzymala et al. 2013). In this study, Halbich's grade-recovery curve was used, and the results are seen in Fig. 6. It can be stated that it is possible to increase the flotation recovery up to 98% with no loss in the grade. In Fig. 6, the circle shows the upgrading of colemanite at the different jet lengths while triangle and square shows the upgrading at plunging depth and negative BF, respectively.

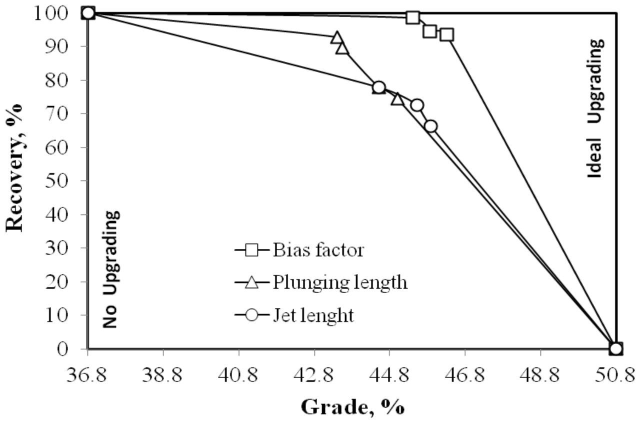

Fig. 6. Upgrading curves for effect of parameters

As seen from Fig. 6, a final concentrate with B_2O_3 of 46% was obtained with a recovery of 99%. This result indicated that a colemanite product can be beneficiated from the tailings with a grade of more than 40% which is much higher than that of product obtained using a classical physical separation including scrubbing and classification. It can also be concluded that if the plunging depth of the downcomer is reduced, and negative bias factor is chosen while jet length is reduced, the process recovery can be increased.

Conclusions

In this study, a Jameson flotation cell was applied to separate colemanite from the fine tailing of the Emet-Espey slurry pond. The final concentrate having 45.42% of B_2O_3 was obtained from the feed having 36.8% B_2O_3 content with the recovery of 98.47%. Based on the results obtained from this study we can conclude that

- operating parameters of the Jameson cell showed a significant impact on the flotation recovery. The negative bias factor has a more pronounced effect in terms of recovery. It is the operating parameter to be considered specifically for the coarse particle and the feed without slime,
- the Jameson flotation cell has been used for the first time for the colemanite flotation, and a high flotation recovery and grade were gained,
- it is convenient to use positive bias in flotation of fine-grained (- 100 µm) minerals, and the negative bias in flotation of grains over the size of 100 µm without slime problems,
- colemanite can be beneficiated from the tailings of the Emet Processing Plant with the grade of more than 40%,

- in addition, plunging depth of the downcomer should be reduced, and negative bias factor should be applied to increase the recovery of the process.

This study clearly indicated that colemanite tailings without slime can be successfully beneficiated with a high recovery using the Jameson cell with a negative bias factor. Further research will be conducted to beneficiate the finer size (-38 μm) fraction.

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