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Optimization of coagulation-flocculation process for treatment of a colloidal suspension containing dolomite/clay/borax

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ABSTRACT

This study statistically investigated the turbidity removal of a dolomite/clay/borax-containing colloidal suspension that had a high degree of stability. During the destabilization experiments, the mixing intensity, the dosage of the coagulant and the flocculant was tested at fixed pH 9.40 due to the buffering property of dissolved borax. Then, the performance of the coagulation/flocculation process was evaluated with Response Surface Methodology (RSM) by using Box-Behnken Design. For the collected experimental data set, the different models were formed. However, the logarithmically transformed model (R^2: 99.75%; Adj-R^2: 99.30%) was selected as the most capable one for the physicochemical process. By using this enhanced statistical model, the optimum turbidity removal was acquired with the help of the design variables as follows: the mixing intensity of 265.138 s^{-1}, calcium chloride dosage of 305.585 mg/L and the flocculant dosage of 218.619 g/ton-solid. Based on this result, it can be concluded that the treatment of the tailings of borax concentrators can be feasible if the physical and the chemical parameters of the solid/liquid separation process are properly implemented all together.

1. Introduction

Natural salts or esters of boric acid, containing the radical B_2O_3, are called as borates. A large number of minerals contain boric oxide in their crystal structures however the widely used commercial borates are borax, ulexite and colemanite. Borax, also known as tincal, is one of the economically most important boron minerals with a general formula of $Na_2B_4O_7 \cdot 10H_2O$ (Kistler and Helvaci, 1994). This sodium borax mineral has been used in many different areas ranging from manufacturing of ceramic and pottery to metallurgical applications for thousands of years (Önal and Burat, 2008). Nowadays, due to the improvement in the boron technology, the existing demand for borax continues to increase (Wang et al., 2006). To meet this demand, the capacities of the borax processing plants in the world have been gradually expanded since 1970s (Garret, 1998). The Kırka borax concentrator is an important example for these expansion projects owing to its high production capacity.

The Kırka plant processes the run-of-mine ore, which is extracted from the largest borax deposit located in Eskişehir/Turkey (Lyday, 2006), and produces 800,000 ton borax concentrate per year with 34.5% B_2O_3 content (Özdemir and Kıpçak, 2003). This plant uses a simple and effective mineral processing technique including crushing, screening, washing/scrubbing and classification circuits for the enrichment of borax (Acarkan et al., 2005; Özbayoğlu and Poslu, 2007) as stated in Fig. 1. In the plant, the run-of-mine ore is firstly comminuted to −2.5 cm with hammer mills and then to −6 mm with the roll mills (Ergin et al., 2004). The crushed material is screened at a 1 mm size. The two products of this screen are sent to the different attrition scrubbers and completely dispersed in water. The overflow of the screen is classified with spiral classifier and its coarser fraction is directly sent to the product bin. On the other hand, the underflow of the screen is subjected to the two-staged classification with spiral classifier and hydrocyclone. The underflow of this latter stream is sent to the product bin and mixed with the former product. This final concentrate can be used in the production of boron derivatives or it can be directly sold to the market (Kahraman, 2010). In conclusion, the aim of this whole process is to separate coarser fraction, which mostly contains the economically valuable borax particles, from the finer gangue minerals and obtain a sellable concentrate.

The remaining fine gangue minerals, which form very stable aqueous suspensions, are contained in six different tailings ponds located near the Kırka concentrator. Although the total capacity of these tailings ponds is 16,980,000 m^3, only 13.2% of this volume is currently available for the further usage (Ekonorm, 2013). This limitation in the storage of the tailings creates a borax-processing bottleneck. Furthermore, in the near future, the annual discharge rate of the concentrator will increase from 700,000 m^3 to 1,000,000 m^3 following the completion of the expansion projects (Ekonorm, 2013). This capacity improvement will significantly intensify the already existing tailings management problem of

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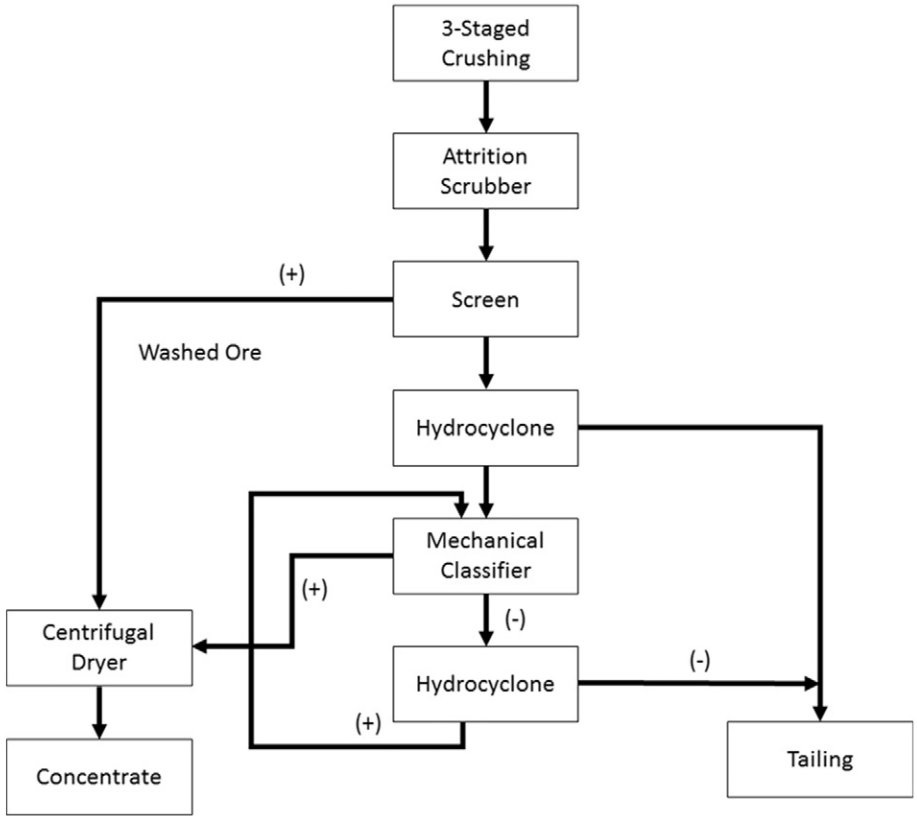

Fig. 1. Simplified flowsheet of Kırka concentrator located in Eskişehir/Turkey.

the concentrator. Such difficulties encountered in this stage of the process threaten the natural environment and the sustainable borax production cycle (Hoşten and Çırak, 2013).

The tailings of the Kırka borax concentrator contains great amount of water (97–90% water by weight), which is contaminated by solid gangue minerals and dissolved borax (Kökkılıç et al., 2005). In spite of the low solid-to-liquid ratio of the downstream of the concentrator, these solid gangue particles form very stable aqueous suspensions and hinder the dewatering process. The root cause of this dewatering challenge of the discharged waste is commonly related to the unique particle-induced problems. For this reason, the detailed characterization tests were carried out on the solid fraction of the borax tailings to reveal the physicochemical properties of the colloidal particles. The chemical and mineralogical analyses (Ataman and Baysal, 1978; Gür, 1995) of the representative samples showed that the borax tailings mostly constitute of dolomite and clay minerals. Then, the oriented clay fractions of the samples were subjected to ethylene glycolation and XRD measurements of these preparations indicated the presence of Mg-rich trioctahedral swelling-type clay mineral (Çırak, 2010). Another study (Çırak, 2014) proved that these particles in the borax tailings had an extremely negative surface charges (ζ-potential < -70.1 mV) confirming their high degree of colloidal stability in water. In addition to this uncovered strong electrostatic repulsion between particles, the authors (Çırak and Hoşten, 2015) also found out an abnormal interfacial phenomenon between these gangue particles and the flocculants with the help of the ATR-FTIR technique. When the infrared spectra of these gangue samples were analyzed by the researchers (Çırak and Hoşten, 2015), it was seen that the peaks of the surface isolated hydroxyls, which serve as an anchor point for the flocculant adsorption, were almost completely depressed. In the absence of these isolated hydroxyls, the polymer bridging mechanism fails due to the insufficient H-bonding between particles and flocculants (Moudgil et al., 1997).

The abovementioned dewatering drawbacks of the Kırka concentrator tailings were tried to be solved with different techniques. The researcher (Çırak, 2010) experimented the activation of the particle surfaces with the help of the pH adjustment prior to the flocculation procedure. According to the results of his work (Çırak, 2010), the turbidity of the borax tailings can be removed at higher adjusted pH values in a laboratory environment. Furthermore, Gür et al. (1996) compared the performances of the polyethylene oxide (PEO)- and polyacrylamide (PAM)-types flocculants. They found out that PEO-based flocculant produced clearer supernatants, particularly in the flocculation of dolomite rich suspensions. Another study (Sabah and Yeşilkaya, 2000) tested the flocculation performance of three different PAM-based flocculants on the borax-buffered suspension. Considering the results of their comparative studies, the anionic flocculants performed much better than the non-ionic flocculants. More recently, Çırak (2010) investigated the performance of 2-D (linear) and 3-D (branched) flocculants and the results showed that the linear non-ionic PEO-type flocculants reduced the supernatant turbidity better than the branched flocculants.

The previous flocculation studies of the borax tailings generally focused on the solid-liquid separation performances of the different type polymers. However, very high flocculant consumptions around 1000–2000 g/t-solid (Sabah and Yeşilkaya, 2000; Çırak, 2010) with very high supernatant turbidities (Hoşten and Çırak, 2013) were reported by different researchers for the flocculation of these suspensions. Therefore, the focus of this investigation is to statistically analyze the data obtained from flocculation trials and optimize the flocculant requirement for the effective turbidity removal of the borax tailings. For this purpose, the mixing intensity, the coagulant and the polymer dosages were determined as input variables and the supernatant turbidity was defined as response variable. With the help of the Response Surface Methodology (RSM), the different statistical models via transformation were formed considering three independent variables and one dependent variable. Upon the determination of the most capable statistical model, the physical and chemical flocculation parameters were tried to be optimized to eliminate the supernatant turbidity of the borax-containing colloidal suspension.