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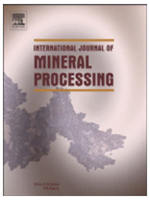

Improving thickener bed density by ultrasonic treatment

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ABSTRACT

We report here the effect of 28 k Hz ultrasonic on dewatering of mineral tailings in conjunction with a mechanic rake. It is found that when a moderate level of ultrasonic energy (2.01 W/L), which will not disperse the settled bed in thickener but enough to open the closed network structure, is delivered to the transition settling zone for 2.5 min, the bed density in a lab bench top thickener improves from 33.72 wt.% to 37.48 wt.%, which is an 11% improvement on bed density. Cryo-SEM is used to image and analyse settled bed aggregates structure changes which clearly demonstrates a denser settled bed after ultrasonic treatment. The combination effects of ultrasonics and rake in the transition zone rearrange the settled bed structure from mainly E-E to mainly F-F clearly shown by the cryo-SEM images. This indicates that the ultrasonication in the transition zone could break up the E-E and E-F associations, which allow loose aggregates to be compacted into much denser F-F aggregates. In situ shear stress measurement also confirms these findings. This technology will be beneficial for tailings' management where the improvement in thickener bed density is environmentally and economically crucial.

1. Introduction

Tailings are the waste minerals slurry produced from mineral processing operations for valuable minerals. More than 10 billion tonnes of tailings is estimated to be produced globally in the mineral processing industry every year (Taylor, 2002). The tailing stream is significantly larger than the mineral concentration stream and contains more than 90 wt.% recyclable water. The modern continuous gravity thickener normally consists of a cylindrical tank with a top-drive rotating rake. Conventional gravity thickeners generally produce underflow solids ranging from 40 wt.% to 55 wt.% for clay-rich tailings due to a significant amount of water being trapped between and within the aggregates. Tailings represent uneconomic materials but can consume significant capital and operating costs in their disposal and lead to loss and delay in water recovery. Mwale et al. (2005) reported the water recovery rate of three mine sites in South Africa were ranging from 20% to 58%, which indicates 0.64 to 0.40 tonnes of fresh makeup water was consumed for each tonne of ore ground. The Kennecott tailing storage facility in Magna Utah, USA, has a footprint of 8,700 acres to accommodate the tailings stream. Improving thickener underflow density will recover more water from tailings' processing and ease the pressure on water demand, reduce tailings storage footprint, maximise capacity of tailings storage facility and minimise the risk of stope barricade failure; therefore, the improved thickener under flow bed density is environmentally and economically crucial. It was estimated that a 2 wt.% improvement of the thickener underflow solid at one of Rio Tinto's business unit would save more than 3 million tonnes of water and reduce operating cost by more than 5 million Australian dollars each year.

It was well established that the presence of clay minerals, particularly kaolinite and smectite, was a major factor in limiting thickener settling rates, underflow densities and water recycling availability (McFarlane, 2006). Kaolinite was commonly found in many tailings. For instance, we found the kaolinite contents were in the range of 1.9 to 3.8 wt.% by X-ray diffraction analysis in three thickener feeds at Kestrel, Bengalla and Hunter Valley coal mines in Australia,. These clay-rich tailings produced low settling rates and poor thickener underflow density. Kaolinite platelets generally had typical basal face surface length of less than 2 μm and edge face surface of less than 0.5 μm thick (Taylor, 2002). Due to complex surface characteristics of the kaolinite, low-density aggregates formed even without flocculant addition by electrostatic and van der Waals forces (Zbik and Horn, 2003). Edge-edge (E-E), edge-face (E-F) and face-face (F-F) model aggregate structures had long been suggested by Lambe and van Olphen (Lambe, 1953; Olphen, 1977). It was apparently that the aggregate structures are dominating the final sediment density, with F-F interaction would produce denser settled bed than E-E and E-F interactions (Castro and Martins, 2005; Nasser and James, 2006).

Flocculant polymers were commonly added and mixed with the mineral tailings in the thickener to bridge or bind dispersed small particles into larger aggregates. After the flocculation process, the flocculated

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aggregates settled to the bottom section of the gravity thickener. The rake was thought to primarily assist transportation of the sediment out of the gravity thickener (Rudman et al., 2008; Warden, 1981); however, there were some studies showing that the post-flocculation raking action also remarkably improved the final solid loading by releasing trapped water in the settled bed. Farrow et al. (2000) showed that higher agitation intensities during flocculation resulted in lower bed densities through measurements of the steady-state bed density profile. The authors suggested that the rake action, not bed compression, dominated dewatering. The dewatering induced by the rake action occurred not only by the removal of inter-aggregate liquor but also by the densification of the aggregates (i.e. removal of intra-aggregate liquor). Owen et al. concluded that the low density of the aggregates (E-E, E-F) may readily collapse under relatively low shear in the compression zone, and the intensity and duration of the applied shear were critical factors (Owen et al., 2007). Our previous study (Du et al., 2009) showed that the raking behaviour in the consolidation zone significantly released inter-aggregate water by breaking the honeycomb structure. The shear stress introduced by raking overcame the relatively weak bridging bonding between the flocculant and kaolinite edge interaction. The shear stress then appeared to push the largely E-E aggregate to allow the basal faces to slide over and form more F-F structures. As a result, rearrangement of E-E aggregates to denser F-F aggregates was observed in some selected areas. There was a dramatic improvement in bed density from 12 wt.% to 36 wt.% by raking action; however, a significant amount of water was still trapped in inter- and intra-aggregates. It was this part of trapped water triggered our interests on how to further improving settled bed density by applying ultrasonic energy.

Ultrasound, sound frequency higher than 20 k Hz, is also a form of mechanical vibratory energy. Ultrasonic energy transmits through all material mediums at different velocities depending on the elastic and inertial properties of the mediums. When ultrasonic wave travels through a medium, very high compression and rarefaction forces are generated locally due to the high frequency. When the medium is a mixture of two different phases, such as liquid and solid, the compression and rarefaction forces between these two phases are likely to be even higher. These high compression and rarefaction forces are likely to break the surface tension and promote separation of liquids from solids (Onal et al., 2003). Chu applied ultrasonics to a waste-activated sludge and found that, at the first stage of sonication at a power input exceeding a critical level (at 0.33 W/ml), the porous flocs can be readily restructured into a more compacted structure. Both ultrasonic vibration and bulk temperature rise contributed to the change (Chu et al., 2001). However, there have been no significant studies reported for the application of the ultrasound on bed density and statistical analysis of the changes in aggregate structures induced by the ultrasonic treatment. This correlation with exploration of the ultrasonic and surface chemical mechanisms forms the central theme of this paper.

2. Materials and methods

2.1. Kaolinite slurry preparation, flocculation and bed density test

The anionic polyacrylamide copolymer FLOPAM AN-910 (10 mol% of acrylic acid monomer content, medium molecular weight 12 million Daltons) is provided by SNF (Melbourne, Australia) Pty. Ltd. The stock solution (0.5 wt.%) is prepared in Milli-Q water and rotated gently for 24 h in a bottle tumbler at 12 rpm. The stock solution is stored in a refrigerator for at least 24 h before dilution with Milli-Q water into a 0.025 wt.% working solution and blending in the bottle tumbler at 12 rpm for 1 h. The working solution is used within 4 h after dilution to avoid aging. Analytical-grade KCl and Milli-Q water are used in all the sample preparations.

Kaolinite Q38 is provided by Unimin Limited Australia. According to the technical data provided by Unimin, Q38 is a dry milled kaolinite with food white colour, with specific gravity value of 2.63×10^3 kg/m^3. The pH of 20% slurry is 7.2, and a specific surface area of 21.1 m^2/g. 99% of the particles was smaller than 38 μm. Kaolinite slurry (50 wt.%) is prepared in 0.01 M KCl solution and stored in a refrigerator for overnight before use. This concentrated slurry is diluted to 2 wt.% in 0.01 M KCl and blended by a six blade stirrer at 800 rpm for 30 min to ensure a good mixing; 2.25 L of this sample is then distributed into an acrylic cylinder (90 mm OD × 84 mm ID, 616 mm long) to 440 mm height. A blunger consisting of a round perspex disc (80 mm ID) with six holes (15 mm ID) cut at 60° angle interval is attached to a steel rod. This blunger is attached to one end of a rotational arm by a steel wire, which goes through a crown block; the other end of the rotational arm is driven by a motor with a speed controller. As the motor drives the arm rotating in a circle, the plunger moves up and down at a constant speed. This design is to eliminate human plunging errors when mixing the slurry and flocculant. The rotational speed is optimised at 3 s per blunge for ten times to achieve completed mixing slurry. The slurry is blunged ten times before adding the flocculant working solution. Another four times of blunging is introduced to mix flocculant thoroughly after flocculation was induced. A single rectangular rake (6 cm width × 25.5 cm length) made of 3 mm stainless steel wire is inserted into the settled bed after 2.5 min of settling and rotates at a constant speed of 3 rpm for 1 h. The final bed height is recorded for bed density calculation.

2.2. Cryo-vitrification and cryo-SEM

The cryo-vitrification/cryo-SEM technique has been well described and illustrated in the literature (Du et al., 2010; Rosenqvist, 1959; Zbik, 2006). It involves snap-freezing a small amount of flocculated sample in liquid nitrogen–solid nitrogen slush at around 80 K. The rate of cooling is such that the water is not able to crystallise before solidification and becomes an amorphous, glassy (vitrified) background in which the real structures of aggregate and flocs are retained. The sample holder consists of two hollow and thin-wall brass tubes super glued together; each tube is 1 mm in inner diameter and about 3 mm long. This sample holder was immersed into sediment and an open end pipette was used to suck sample into the holder. This sample was immersed into liquid nitrogen for vitrification. The two-part sample holder was then transferred into the preparation chamber where the top part of brass tube was knocked off to expose a fresh surface for SEM. The frozen sample is then transferred under vacuum to a cold stage at 105 K and imaged by Philips XL30 Field Emission Scanning Electron Microscope, which is equipped with an Oxford Cryo-transfer and fracture stage.

2.3. Ultrasonic post-treatment setup

After analysis of the dynamics of mud line height versus settling time, we identify four different settling zones (Fig. 1). Settling zone 1

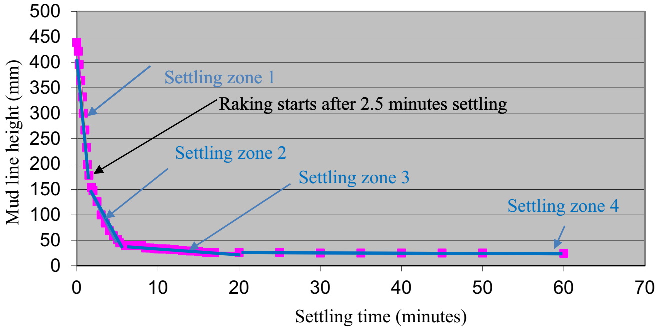

Fig. 1. Kaolinite slurry mud line height versus settling time after flocculation.