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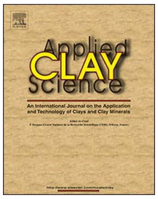

Research paper

Microstructure of clay fabric in electrokinetic dewatering of phosphatic clay dispersions

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ABSTRACT

Electrokinetic dewatering is considered a promising method for separation of water from clay dispersions in the mining industry. Numerous studies over the past few decades have been conducted on electrokinetic dewatering process in order to identify potential performance improvements. However, little is known about the impact of process on clay microstructure that determines its water content. Here, for the first time, scanning electron microscopy (SEM) was utilized to study the impact of electrokinetic dewatering process on clay fabric microstructure. The studies were conducted on three experimental platforms including 1) a gravity settling experiment to determine the clay structure in the absence of an electric field, 2) a cylindrical tank in which a static electrokinetic separation process was conducted under an electric field applied along the tank height and 3) a continuous dewatering system in which electrokinetic separation took place in two stages along a conveyer belt. The studies suggested that formation of honeycomb microstructures was responsible for poor settling and an acidic environment promoted a more voluminous honeycomb with a higher water content. Under an electric field, a less-ordered structure than a honeycomb was formed during the electrophoresis separation process near the region where the pH was above the point of zero charge. The less-ordered structure was later compressed (i.e. the structure partially collapses) in the 2nd stage of the continuous system in which an already formed clay cake was dewatered through the electro-osmotic process. The insight provided in this study can help improve the performance of electrokinetic separation process.

1. Introduction

Clay minerals (e.g. montmorillonite and kaolinite) are common waste products in the mining industry and have diverse structural and physical properties, such as anisotropic shape, large surface area, and varying types of charges (McFarlane et al., 2005). When dispersed in an aqueous media, the clay minerals exhibit a low dewatering rate due to formation of porous structures by inherently charged clay layers in which a large amounts of water is retained (Kotlyar et al., 1998; Morris and Zbik, 2009).

The poor dewatering characteristic of phosphate clay dispersions is a major challenge for the phosphate mining industry. For example, in Florida (USA), large amounts of water (mostly groundwater) is consumed for the beneficiation process (i.e. separating phosphate rock from clay and sand); the volumetric flow rate of phosphate clay dispersions produced from beneficiation is about 130,000 gal per minute (GPM) (i.e. 8.2 m^3/s) at a solid content of 2–3 wt%. The dispersions are pumped into large man-made ponds for natural settling, occupying 30% of mine land. This settling process takes approximately 25 years to consolidate the solid content to 25 wt%, for which water recovery becomes possible (Kong and Orazem, 2014; Mckinney, 2010). In order to reduce both the land area occupation and water consumption for the settling process, different methods have been proposed by researchers (Dentel et al., 2000; Mahmoud et al., 2010; Rahman, 2000). However, complexity, cost and energy consumption of these methods have prevented their on-site implementation.

Among the different techniques is electrokinetic process that relies on separation based on the particle's inherent charge properties. In this process, an external electric field is applied across the dispersion driving the negatively charged clay particles to the anode (electrophoresis). Once a porous structure is formed, the electric field further induces the migration of water out of the porous media to the cathode (electro-osmosis) (Shang and Lo, 1997). These two phenomena together contribute to create a condensed clay structure and clear water. Over the past several years, researches on improving the separation efficacy of electrokinetic process are implemented with the efforts culminating into development of a fully continuous prototype and its successful testing (Kong, 2015). The best prototype could achieve a cake solid

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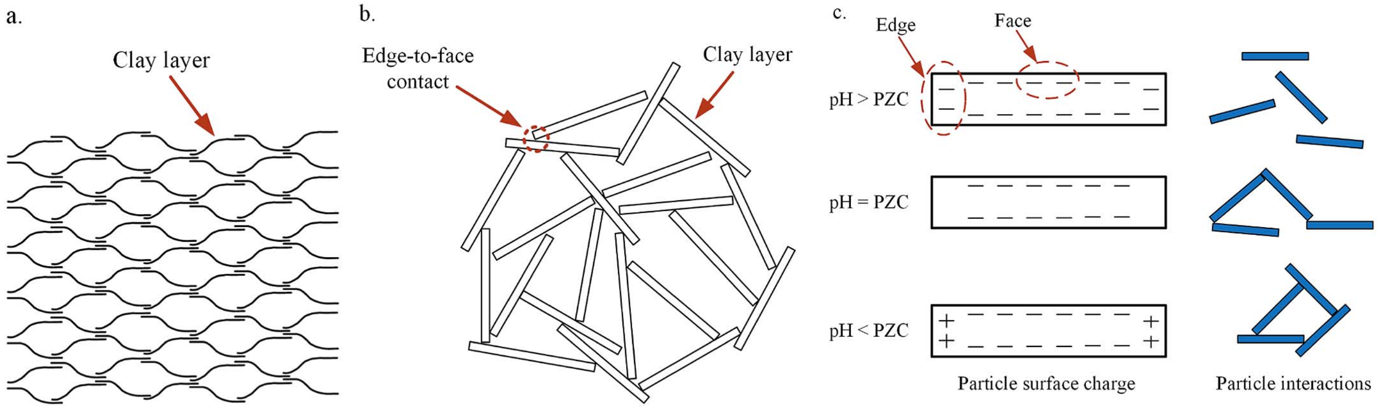

Fig. 1. Schematic model of clay microstructure: (a) honeycomb structure (reproduced from (Morris and Zbik, 2009)); (b) "card house" structure (reproduced from (Lambe, 1958)); and (c) schematic model of clay particle surface charge and interactions at different pH conditions (PZC represents of point of zero charge).

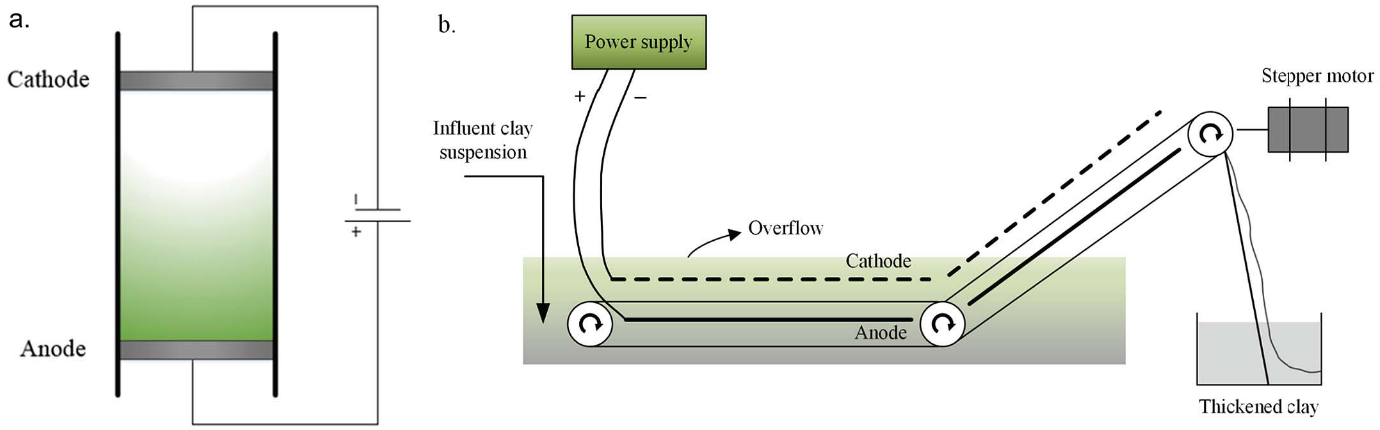

Fig. 2. Schematic of electrokinetic dewatering experimental setup: (a) benchtop cylindrical cell for static electrokinetic dewatering test, and (b) fully continuous electrokinetic dewatering system.

Table 1
Characteristics of clay dispersion from the Four Corners mining plant in central Florida.

Parameters	Value
Solid content (wt%)	8.84–12.33
pH	6.99–7.23
Electric conductivity (S/m)	0.09–0.11
Zeta potential (mV)	−20.1 to −19.9
Particle size (μm)	1.25–4

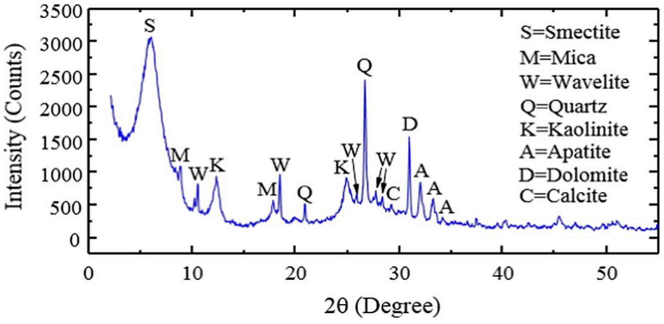

Fig. 3. X-ray diffraction (XRD) pattern of the clay sample.

content of 35 wt% under 1 V/cm electric field, with an energy consumption of 47 W-hr/kg of solid. Although compared to static electrokinetic separation (i.e. batch processing), the fully continuous prototype consumed significantly less energy and improved solid content, it is desirable to further improve the process through enhancing the understanding of the electrokinetic process on the clay cake microstructure.

As mentioned earlier, the clay fabric retains water in its porous structure. Physical insight into the construction and formation mechanism of the structure can pave the way for further improvement of the dewatering process. The first theoretical study of clay microstructure was conducted by Terzaghi (Terzaghi, 1925) who proposed formation of a honeycomb structure in which clay particles formed chain-like arrangements of flocs, as depicted in Fig. 1a. Lambe (Lambe, 1958) indicated that the undisturbed marine clay had a random, open structure dominated by edge-to-face particle contacts. This structure was subsequently termed as "card house" structure (Fig. 1b), later adopted by other researchers (Olphen, 1977). Rosenqvist (Rosenqvist, 1953) proved the existence of the "card house" structure by transmission electron microscopy (TEM) of Scandinavian quick clay; Bowles (Bowles, 1968) and Pusch (Pusch, 1966) confirmed the presence of honeycomb structure in wet clay sediments by scanning electron microscopy (SEM). In another study, McFarlane et al. (McFarlane et al., 2005) proved the presence of highly networked honeycomb structure in smectite dispersions by cryo-SEM imaging.

The structure morphology depends on properties of its constituent material. Smectite, a major component of the clay mixture, is a layered structure consisting of two tetrahedral sheets of silica sandwiching a central octahedral sheet of alumina, which has a large surface area of hundreds of square meters per gram (Bailey, 1980; Bergaya and Lagaly, 2013). The smectite surface consists of two different facets: basal face and edge. The basal faces exhibit permanent negative charge due to ion isomorphous substitution (e.g. Al (III) replacing Si (IV) in the silica