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Investigation of the role of interfacial chemistry on particle interactions, sedimentation and electroosmotic dewatering of model kaolinite dispersions

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Abstract

The influence of pulp chemistry on particle interactions and dewatering behaviour of colloidal kaolinite dispersions has been investigated under coagulation conditions. The dispersion shear yield stress, settling rate and consolidation showed strong dependence upon pH and ionic strength, indicating a maximum at ~pH 3.2 which was established as the isoelectric point (iep) by particle zeta potential analysis. A "gel point" solid concentration at which the dispersion began to be significantly networked and gravity-driven consolidation of the pulp was completely suppressed, occurred at 13 vol.% (~28 wt.%). The dewatering rates due to coagulation were significantly lower than those commonly achieved by polymeric flocculation, however the sediment consolidation was ~25% higher when compared with flocculated pulps. Electroosmosis was found to be effective in consolidating pre-sedimented pulps to spadeable pastes (~30 vol.%) at pH values away from the iep where zeta potential was higher and ionic strength low (10^{-3} M). This pulp consistency or markedly improved consolidation behavior is not achievable under coagulation and/or flocculation conditions.

Keywords: Dewatering; Kaolinite dispersions; Electroosmosis; Particle interactions; Rheology; Pulp consolidation

1. Introduction

Effective dewatering of clay mineral waste tailings is an important global issue which poses a major technological and environmental challenge to the mineral processing industries. Chemical additive (coagulants and polymeric flocculants) mediated, gravity-driven thickening processes are generally used for clay tails dewatering but these are far from being efficient. Kaolinite ($Al_2Si_2O_5(OH)_4$) is one of the minerals encountered extensively in most clay waste tailings [1–6]. To date, extant thickening methods for dewatering colloidally stable kaolinite dispersions invariably produce low solid content (e.g. 24 wt.%) pulps [1–4], warranting further development and optimisation for dramatic, rather than incremental, enhancement in pulp consolidation.

In the present work, fundamental studies focussing on new knowledge and greater understanding of the pivotal role interfacial chemistry plays in regulating particle interactions/colloid stability and improving the dewaterability of kaolinite dispersions as a function of pH, KNO_3 electrolyte concentration and particle volume fraction were carried out. Particle zeta potential, dispersion shear yield stress and sedimentation/electroosmosis are used as diagnostic characterization tools for interfacial chemistry, particle interactions and improved dewatering behaviour, respectively. The increased understanding and new knowledge that emerged will facilitate the formulation of effective dewatering method(s) needed for dramatic, rather than incremental, enhancement of the consolidation of plant clay tailings.

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2. Experimental methods

2.1. Suspension preparation

Synthetic, colloidal kaolinite crystals (K15GM, 99% pure, quartz and mica 1%, Unimin Australia) with particle sauter mean diameter, BET surface area and density of 2.7 μm, 26.1 $m^2\ g^{-1}$ and 2.60 kg dm^{-3}, respectively, was used in this work. Dispersions with percent volume fractions in the range 2–37 were prepared by thoroughly mixing known masses of dry clay in known volumes of 10^{-3} M KNO_3 solution at an agitation rate of 500 rpm for 4 h using a 4 blade, 4.5 cm, 45°-pitch turbine impeller. To study the effect of ionic strength on pulp chemistry, rheology and colloid stability, KNO_3 (99.9% pure reagents, Chemsupply, Australia) was used as a coagulant. Concentrated, analytical reagent grade KOH and HNO_3 (BDH, Australia) solutions were used for pH adjustments. All solutions and dispersions were prepared using high purity Milli-Q water (specific conductivity < 0.5 $\mu S.cm^{-1}$, surface tension 72.8 $mN.m^{-1}$ at pH 5.6).

2.2. Interfacial chemistry and particles interaction determination

Particle zeta potential (ζ) was calculated from dynamic mobility measurement determined by an Acoustosizer (Colloidal Dynamics Inc., Australia). The dynamic mobility measurements were carried out on 4.1 vol.% (10 wt.%) dispersions as a function of pH, which was increased from acidic to basic values and ionic strength. Shear yield stress measurements were performed using the vane technique [7]. It involved a six-blade vane (diameter = 24 mm, height = 17 mm) which was powered by a Haake VT550 and rotated slowly at a constant rate ($\gamma = 0.021\ s^{-1}$). The shear yield stress was calculated from the maximum torque.

2.3. Dewatering behaviour tests

Batch sedimentation tests were performed in graduated, 0.5 dm^3, high density polyethylene measuring cylinders. The initial pulp settling (dewatering) rates were estimated from the slopes of linear portions of the batch sediment volume versus time curves. The final sediment bed volume was recorded after 24 h of consolidation under quiescent conditions at room temperature (22 °C). A batch, 3 dm^3 cell (cylindrical section internal diameter = 8.0 cm, height = 45 cm) with 2 porous 316 stainless steel electrodes operating at voltage of 20 V and electrode spacing of 20 cm or less for 8 h was used to conduct electroosmotic (EO) dewatering tests on 1 dm^3 dispersions. The schematic diagram of the EO cell (cylindrical section internal diameter = 8.0 cm, height = 45 cm) used is shown in Fig. 1. The current, voltage and volume of water collected as a function of time were continuously monitored and recorded by a computer connected to the cell. Slurries of volume 1 dm^3 were dewatered over a 24 h period at an operating voltage of 20 V and electrode spacing (X) of 20 cm or less. All measurements and tests were carried out at room temperature (22.0 ± 0.2 °C).

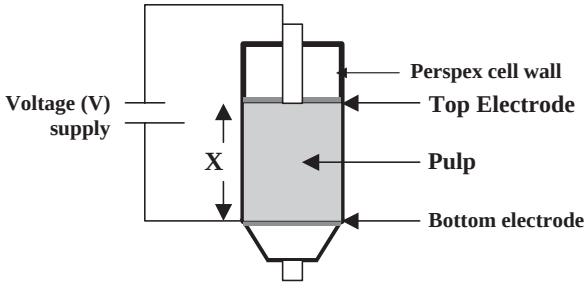

Fig. 1. Schematic diagram of the batch electroosmotic dewatering cell. (X is the electrode spacing [m] and V the applied voltage).

3. Results and discussion

3.1. Zeta potential and shear yield stress

The particle zeta potentials measured for 4.1 vol.% solid dispersions containing 10^{-3}, 0.1 and 0.3 M KNO_3 are shown in Fig. 2. Strong pH and ionic strength dependence and an isoelectric point (iep) of ~pH 3.0 are indicated. The iep value agrees well with the some of the values in the pH range 2–3 reported for kaolinite [1–3,5,6,8], although significantly higher values (e.g. pH 5.5) have also been reported in other studies [9,10]. The decrease in the magnitude of zeta potential with increasing ionic strength, with no iep shift or lack of charge reversal, is consistent with electrical double layer screening by the indifferent K^+ and NO_3^- ions. The rheology of the dispersions determined as a function of solid volume fraction at different pH values showed a non-Newtonian, pseudoplastic behaviour [11]. The shear yield stress (τ) and normalized yield values (τ/τ_{max}) (where τ_{max} = maximum yield stress) as a function of volume fraction and pH are shown in Figs. 3 and 4. The data show that a maximum in yield stress occurred at close to pH 3, regardless of the volume fraction and a dramatic scale up in particle interactions with increasing solid volume fraction. A remarkably high yield stress was produced at ~36.5 vol.% solid. Further analysis of the shear yield stress—% solid volume faction curves indicated that at 13 vol.% (28 wt.%) solid, a "gel point" at which the dispersion begun to be significantly networked occurred, reflecting a significant increase in yield stress thereafter (Fig. 4(A)). The shear/normalized yield stress versus (i) pH (Fig. 4(B)) or (ii) the square of zeta potential (Fig. 5) data were observed to collapse unto a single curve, and this demonstrates that the pair-wise interactions between the particles are constant over the volume fraction