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Full Length Research Paper

Enhanced electroforced sedimentation of various solid-liquid systems

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This study presents the results of experimental work carried out to evaluate the role of polyacrylamide as dewatering aid in electroforced sedimentation. Electroforced sedimentation experiments under constant electric current density of zinc oxide and kaolin suspended in aqueous media with and without polyacrylamide were carried out and comparison was made between the experimental results and model predictions. The model solution of basic differential equation was used to measure the progress of electroforced sedimentation, represented by an average consolidation ratio U_c as in mechanical expression. The addition of polyacrylamide as a dewatering aid enhanced the electroforced sedimentation.

Key words: Electroforced sedimentation, consolidation coefficient, electro-osmotic pressure.

INTRODUCTION

In the process of sludge handling, disposal and re-use of biosolids is one of the most significant challenges in wastewater management. Dewatering by conventional belt press filters can achieve only small solids contents leading to high expenditure for the transport and disposal of these materials. Another option is the incineration of sludge. But since the water content of the sludge is usually very high, energy consumption is the major concern. That is, such sludge is usually highly compressible, and mechanical dewatering is impeded due to a very high hydrodynamic resistance of the sludge.

Application of electric field, to enhance the separation, is one of the techniques studied recently. Electrokinetic effects play a large role in such separations. In elecro-forced sedimentation, the separation of liquid from a solid-liquid mixture is achieved between two electrodes. Its principal use would be in reducing water content in environmental sludge and biosolids, thereby reducing the volumes to be disposed through landfills, incineration or other means. In electroforced sedimentation with moderate electric field strength, the moisture of a solid-liquid mixture remains unchanged at the surface of the sediment, while it decreases drastically near the bottom of the sedimentation column. This fact is widely known; to date however, due to paucity of analytical method, it has not been successfully explained. Previously, some works which were related with electroforced sedimentation were done (Shirato et al., 1979; Iwata and Yi, 1995; Iwata et al., 1991). In our previous report, the solution of the basic differential equation that describes the progress of an electro-osmotic dewatering was presented (Mohammed and Iwata, 2008).

In this study, electroforced sedimentation experiments under constant electric current density of zinc oxide and kaolin suspended in aqueous media were carried out. The effects of the addition of polyacrylamide on the dewatering during electroforced sedimentation were examined.

MATERIALS AND METHODS

Experimental

A sedimentation column, 45 cm high and with 4.5 cm internal diameter made of acryl was used (Figure 1). As an experimental

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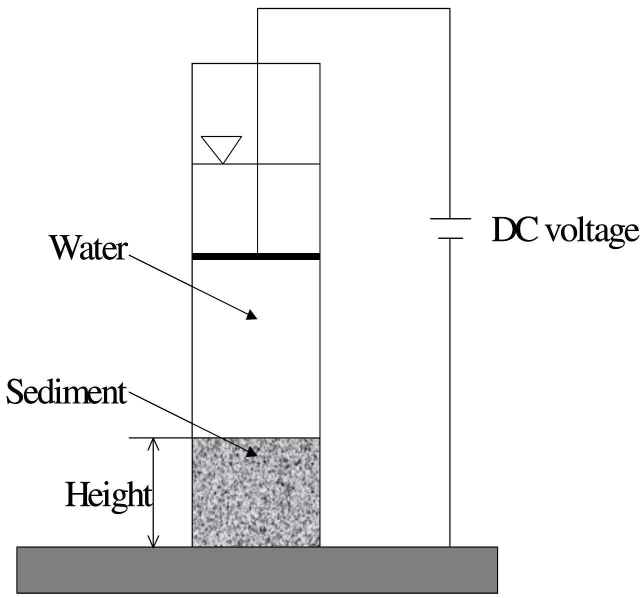

Figure 1. Experimental set up.

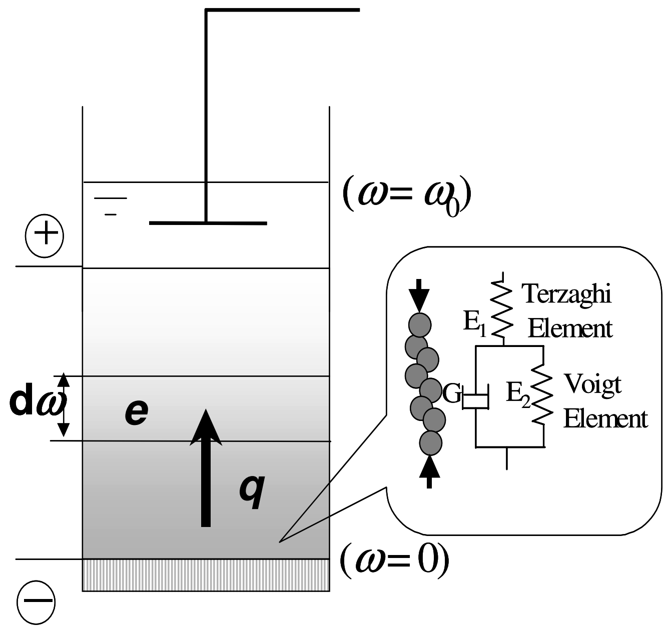

Figure 2. Terzaghi-Voigt combined model.

material, zinc oxide and kaolin were used. The slurry was kept until gravitational sedimentation was completed and equilibrium height was achieved. Then, D.C. voltage was applied between the electrodes, both made of stainless steel. Experiments were conducted under various current densities and total solid volume per unit cross-sectional area. The change in height of sedimentation was visually monitored continuously. The slurry used in the experiments was prepared by mixing a predetermined quantity of dry solid and deionized water to form a suspension of known total solid volume per unit cross-sectional area. The slurry was then poured into the sedimentation column and left until gravitational sedimentation was completed and equilibrium height was achieved. The electric field was provided by a D. C. power supply through the top anode and bottom cathode under constant-voltage condition.

Basic differential equation

Kobayashi et al. (1979) solved the Navier-Stokes equation to describe an electro-osmotic flow through a capillary tube, taking into account the applied electric field strength and the electric field strength in the electric double layer caused by the contact potential difference. They extended the result to describe an electro-osmotic flow through porous media the same way as in the derivation of the Kozeny-Carman equation. The apparent liquid velocity q through the porous material is defined as the flow rate per unit cross-sectional area of the material and represented by:

$$q = \frac{\varepsilon^3}{kS_0{}^2(1-\varepsilon)^2\mu}\left(\rho_e E - \frac{dp_L}{dx}\right) \quad (1)$$

Where, k is the Kozeny constant; ε and S_0, are the porosity and specific surface of the material respectively; μ, is the viscosity of the liquid; ρ_e, is the volumetric charge density of the liquid and p_L, is the liquid pressure. x and E in Equation (1) are the spatial coordinate and the electric field strength in the direction of material thickness, respectively. The first term of the right-hand side of Equation (1) represents an electro-osmotic flow in a porous material, while the second term shows a pressure flow in the material including both the tortuosity and size of flow path. If E = 0, then Equation (1) is reduced to the Kozeny-Carman equation which represents the apparent flow rate through a porous material under a liquid pressure gradient. Kobayashi et al. (1979) examined Equation (1) by using incompressible sintered glass beads. In finding the solution to the basic differential equation, it is assumed that the Terzaghi-Voigt combined model shown in Figure 2 expresses mechanical property of the solid network.

RESULTS AND DISCUSSION

The average consolidation ratio U_c, which is a measure of the progress of electroforced sedimentation is given by:

$$U_c = \frac{H_1 - H}{H_1 - H_\infty} = (1-B)\left[1 - \frac{32}{\pi^3}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{(2n-1)^3}\exp\left\{-\frac{(2n-1)^2\pi^2}{4}\frac{C_e}{\omega_0{}^2}\theta\right\}\right] + B\left[1-\exp(-\eta\theta)\right] \quad (2)$$

Where, H_1 and H are the initial and instantaneous height of the sediment; H_∞ is the final height of the material, respectively. B represents the ratio of the creep deformation to the total deformation. U_c is zero at the beginning and becomes unity at infinite electroforced sedimentation time. ω_o is the total solid volume per unit cross-sectional area; ω the net solid volume per unit cross-sectional area extending from the bottom up to an arbitrary position in the material; C_e the modified consolidation coefficient and θ time. Detailed solution of the basic differential equation is available in Mohammed et al. (2008).

Figure 3 represents the time course of the average consolidation U_c during electroforced sedimentation of zinc oxide. The theoretical values were calculated using

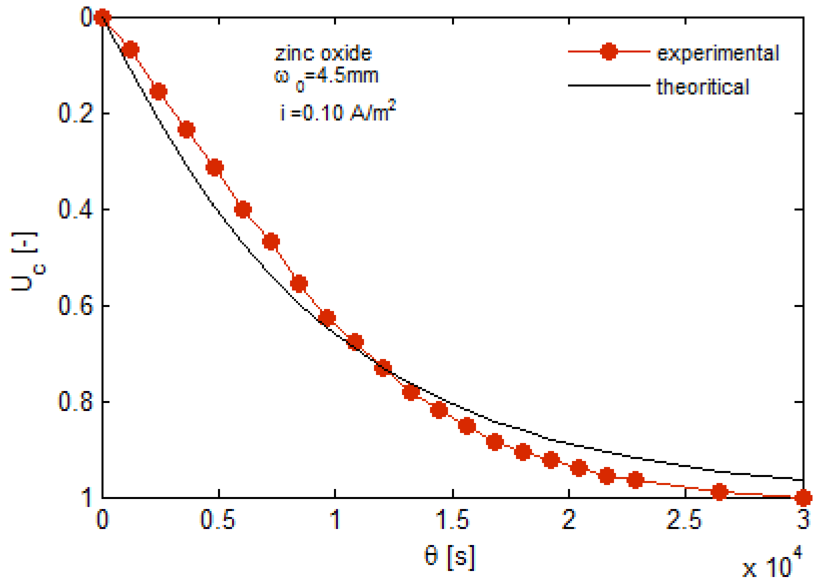

Figure 3. Comparison of the rate of consolidation ratio of theorical and experimental sedimentation of zinc oxide.

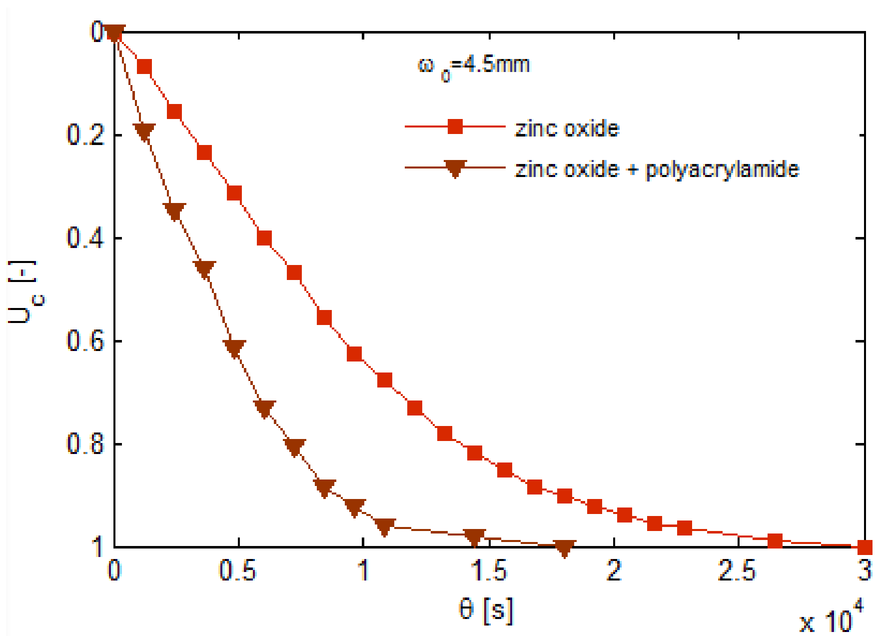

Figure 4. Rate of sedimentation of zinc oxide and mixture of zinc oxide/polyacrylamide.

Equation 2. The creep ratio *B* is zero, that is, the primary consolidation is dominant and hence the creep deformation does not exist. There is a good agreement between experimentally measured and theoretically calculated values. Figure 4 depicts the progress of electroforced sedimentation with and without the addition of polyacrylamide. The efficacy of sedimentation increases with the introduction of only 1% polyacrylamide.

Figure 5 shows the experimental results of kaolin and zinc oxide. Kaolin has better consolidation rate. This could be attributed to the fact that kaolin generally possesses a net negative charge higher than zinc oxide at the neutral pH.

Conclusions

In this study, constant current electroforced sedimenta-

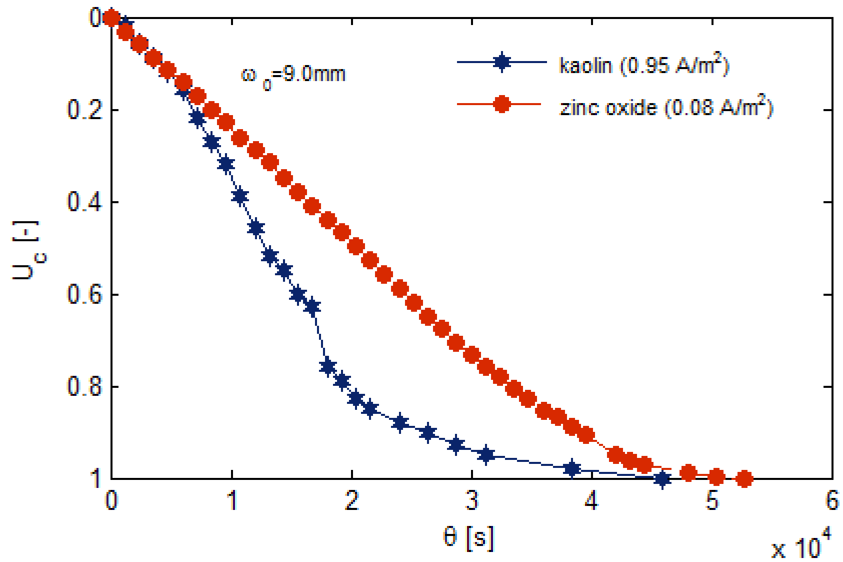

Figure 5. Comparison between consilidation ratio rate of zinc oxide and kaolin.

tion properties of kaolin and zinc oxide sediments were investigated. The basic differential equation for electro-forced sedimentation was solved analytically under the assumption that the electro-osmotic property of the material does not change during the process. The model agrees with the experimental results. The addition of 1% polyacrylamide as dewatering aid enhanced the electro-forced sedimentation. Kaolin showed higher consolidation rate than zinc oxide for a given current density. The investigation will be continued to study the effect of initial weight, current density and pH on the electroforced sedimentation.

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