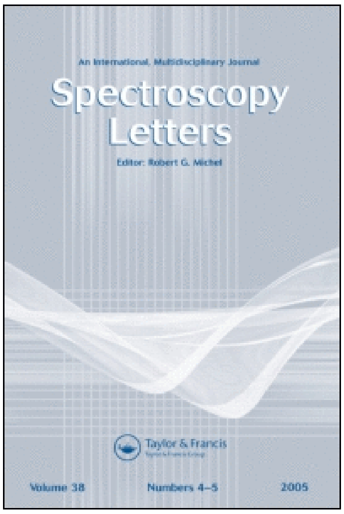

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Expression Dewatering of Mixed Sludges

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EXPRESSION DEWATERING OF MIXED SLUDGES

Keywords: expression, filtration, creep effect, mixed sludges

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ABSTRACT

Filtration followed by expression characteristics of mixtures of clay and activated sludge are first reported in this study. Experimental results indicate that the average specific resistance of the mixed sludge exhibits an ideal-solution like behavior, that is, a linear combination of pure clay and activated sludges with the weight percentage as a parameter. In expression stage, nevertheless, the influence is highly nonlinear. The presence of a little amount of activated sludge can significantly increase both the expression creep effect and the portion of secondary consolidation. The consolidation stage data are interpreted by the Terzaghi-Voigt combined model, from which the model parameters are evaluated accordingly. As the activated sludge is added, both the difficulty of creeping of constituting particles within the sludge cake and the fraction of moisture attributed to the secondary consolidation increases rapidly, revealing a highly nonlinear characteristics. The dewatering efficiency of mixed sludge is discussed.

INTRODUCTION

Owing to the relatively low energy consumption rate when compared with the thermal dewatering methods, expression is widely employed in industries to separate the liquid from a cake by a mechanical pressure (1), with one of the major applications on the water and wastewater sludge treatments. A brief review of literature work can be found in refs. (2,3).

In the past three decades, most of the research works on constant-pressure expression have been accomplished by Japanese researchers Profs. Shirato and Murase of Nagoya University (4-9), and Professor Tiller of Houston University (1, 10). The investigation under constant pressure can provide basic understanding to the detailed mechanisms involved, and the implications to the sludge characteristics. The application of expression on sewage sludge treatment is recently reported (11,12).

In dewatering of water and wastewater sludges the filtration followed by expression process is often employed, such as in the belt filter press or in the screw press. The detailed understanding about the filtration followed by expression characteristics of sludges, nevertheless, is far from satisfactory. In practice, for the sake of lower investment cost and, hopefully, the operational cost as well, sludges from different sources are often pre-mixed and dewatered in a single dewatering device. This paper aims at discussing the filtration followed by expression characteristics of mixed clay and activated sludges. To the authors' best knowledge, this is the first report concerning the expression on mixed sludges.

EXPERIMENTAL

Materials

The particle size distribution of clay sample was determined by Sedigraph 5100C (Micromeritics) as a monodispersed distribution with a mean diameter of approximately 4.6 μm. The true solid density was measured by Accupyc Pycometer 1330 (Micrometritics), giving a measure of 2584 kg/m^3 with a relative deviation of less than 0.5%.Two independent activated sludge samples were taken from

Neili Bread Plant, President Enterprise Co., Taoyuan, Taiwan, and were tested within 2 hours after sampling. The weight percent of the solid phase was measured by weighting and drying.

A constant head piston press (Triton Electronics Ltd., type 147) was employed for all the tests. A schematical drawing of the experimental setup was depicted in Fig. 1. The sludge was placed in a stainless steel cylinder of diameter 7.62 cm and of height 20 cm equipped with a free piston. The cylinder is coated with chrome, at one end of which there is a port. The high pressure fluid with a hydraulic pressure of 1000 psi was exerted through the port onto the free piston, which pressed directly the sludge to force the moisture out. The time evolution of filtrate weight was automatically recorded by an electronic balance connecting to a personal computer. The residue moisture content of cake was determined via weighing and drying. This portion of moisture should include some physically adsorbed and other chemically bounded water contents (13). With the filtrate weight versus time data and the true solid density data, the time evolution of cake porosity can be subsequently obtained. In each condition three independent tests were conducted to check the data reproducibility.

RESULTS AND DISCUSSION

General.

Typical experimental data for the sample #1 are summarized in Fig. 2. Notably, since the bound water of sludge should be considered as a part of solid phase, the final equilibrium porosity of activated sludge cake is taken as 0. The weight percentage of clay is 10%. The dewatering is more difficult for activated sludge, while the dewatering easiness for mixed sludges decays as the activated sludge amount increases. If taking the time required for removal of 90% of the "removable" moisture in sample #1 as a sludge dewaterability index, the results read: 1500 s (100%), 3900 s (96.3%), 4200 s (90.9%), 5500 s (81.6%), 6400 s (63.5%) and 6800 s (0%), where the numerical values in parentheses are the

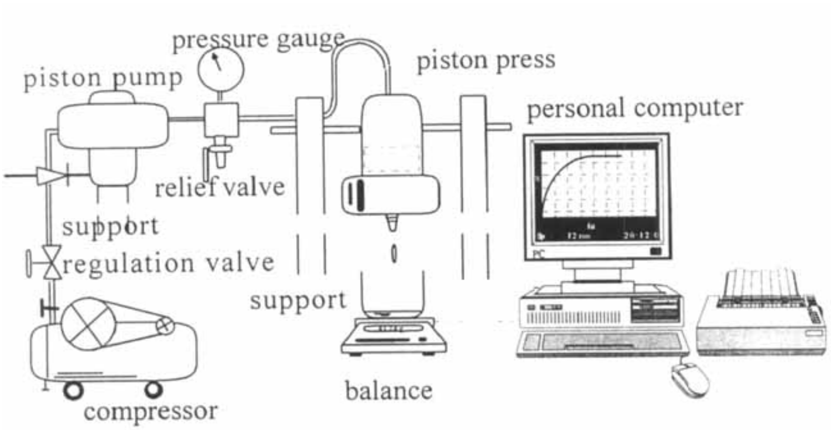

Fig 1 Experimental setup.

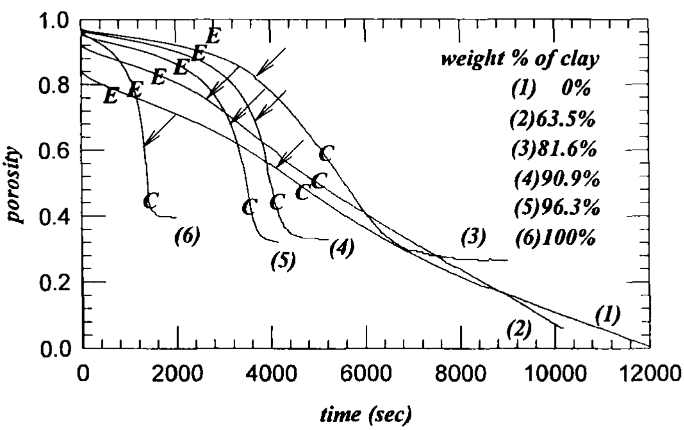

Fig 2 Time evolution of cake porosity. 1000psi. Clay+activated sludges. Arrows indicate the transition point.

weight percentage of clay sludges. The addition of activated has thereby a nonlinear effect on the overall dewatering efficiency of the mixed sludges.

A complete test includes the filtration and the expression stages, which are discussed separately in the following sections. Shirato et al. (4) had proposed a simple, graphical method to locate the transition point between these two stages, which has been adopted in this work. Some examples are depicted in Fig. 3. With the data before the separating point (indicated as region F in Figs 2 and 3), which correspond to the filtration stage, the average specific resistance to filtration under 1000 psi can be estimated according to procedures proposed by Leu (14). With the data after the separation point (region C in Figs 2 and 3), which correspond to the expression stage, the mechanisms governing primary and secondary consolidation processes can be identified (discussed later).

Filtration stage.

The average specific resistances under 1000 psi constant-pressure filtration are shown in Fig. 4. A nearly linear relationship between the average specific resistance and the activated sludge addition amount presents. This result is somewhat surprising, since the activated sludge flocs are usually of a loose, fractal-like structure into which the clay particles can easily penetrate. However, the linear relationship in Fig. 4 suggests that the feasibility of applying Carman-Kozeny law onto this mixed sludge system. That is, the resistance to filtration is basically proportional to the surface area available for the sludge cake, which is a linear function of the percentage for the two sludges.

The fraction of residue moisture not removable during filtration stage is shown in Fig. 5. A higher residue moisture in cake after filtration is not preferable for the final sludge disposal sake. As the activated sludge addition amount is small (less than 10%), the fraction of moisture removal is nearly a constant or changes a little. That is, during this stage, the activated sludge flocs can not largely influence the original cake structure of clay. Further addition of activated sludge can significantly increase this fraction, reflecting a dominating role of activated sludge flocs. When the addition amount is greater than 40%, the fraction is

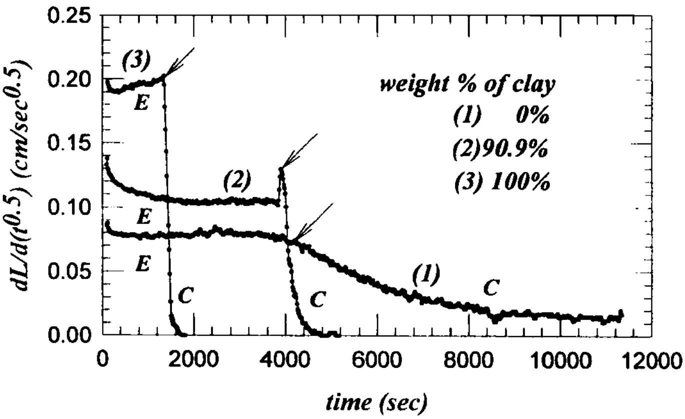

Fig 3 Transition between filtration and expression stages. Arrows indicate the transition points.

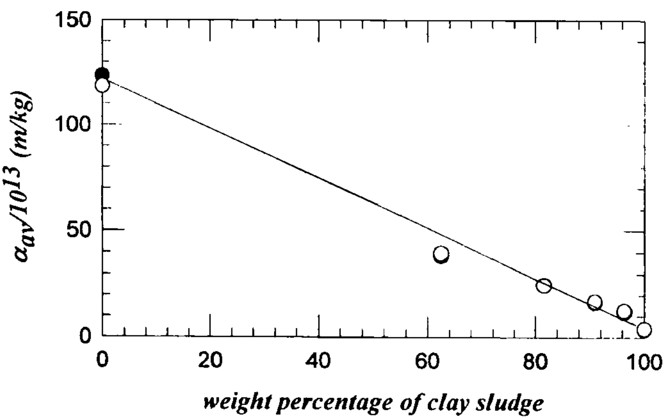

Fig 4 α_{av} versus weight percentage of clay sludge(10%,w/w). Closed and open symbols are for sample #1 and #2, respectively.

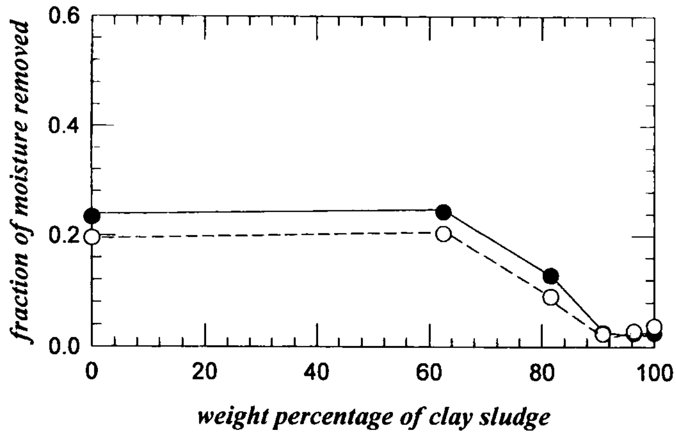

Fig 5 Fraction of residue moisture not removable in filtration stage versus weight percentage of clay sludge(10%,w/w). Closed and open symbols are for sample #1 and #2, respectively.

almost the same as that for pure activated sludge, suggests the clay particles may have been trapped into the floc structure. However, when consulting the linear dependence of filtration resistance data shown in Fig. 4, all particles are still able to expose their surface area to fluid phase owing to the quite loose structure of the activated sludge flocs (19).

Expression stage.

The expression stage can be differentiated from the filtration stage and the results for sample #1 are redrawn in Fig. 6. The presence of activated sludge has a substantial effects on the expression dewatering.

Shirato et al. (5) had adopted the combined Terzaghi-Voigt rheological model for describing the expression process. Several other works had proven the validity of Shirato's approach (6-9, 11, 15-17). The Terzaghi-Voigt combined model has been shown in Fig. 7 for illustration purpose. Notably, the spring in Terzaghi model accounts for the elastic behavior of cake, whose action under pressure is referred to as the "primary consolidation"; while the dashpot and spring in the

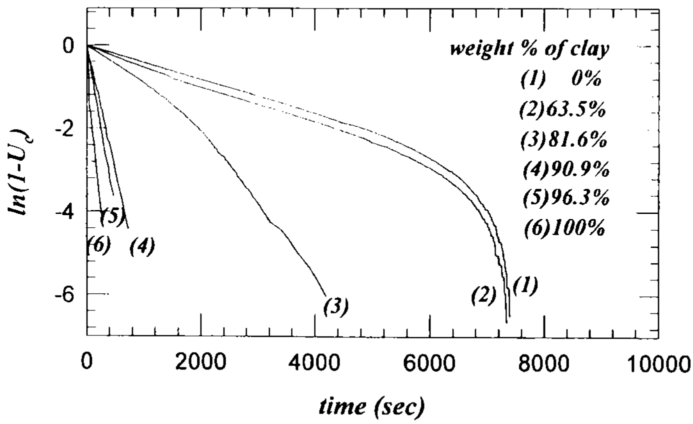

Fig 6 ln(1-U_c) versus expression time.

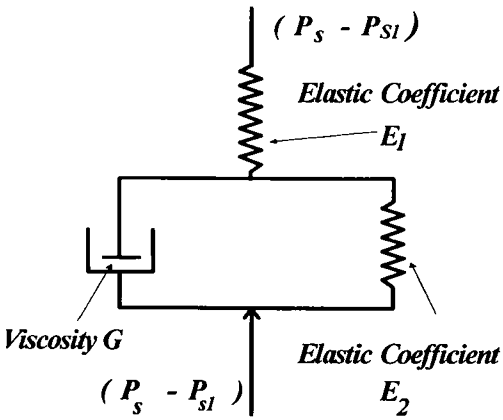

Fig 7 Schematics of the Terzaghi-Voigt combined rheological model.
P_S: expression pressure; P_{s1}:initial pressure distribution in cake.

Voigt model accounts for the viscous behavior and is the so-called "secondary consolidation". If further assume that the rate of primary consolidation is much higher than the secondary consolidation, which is usually the case in practice, a reduced form of solution is found under infinite expression time limit as follows:

$$U_c = \frac{L_1 - L}{L_1 - L_f} = 1 - B\exp(-\eta\theta_c). \qquad (1)$$

In eq. (1), U_c is the consolidation ratio, L the cake thickness, L_l and L_f respectively the initial and final cake thickness, B the ratio of moisture removal by the secondary to total consolidation, η the creep factor, demonstrating the easiness of the relative mobility of constituting particles, and θ_c, the expression time. Consequently, if the $\ln(1\text{-}U_c)\text{-}\theta_c$ plot exhibits a linear relationship, the parameters B and η can be found subsequently.

As indicated in Fig. 6, for all mixed sludges, after a decrease in U_c in the initial stage of expression follows a linear $\ln(1\text{-}U_c)\text{-}\theta_c$ region. This confirmed the validity of employment of eq. (1) in describing the expression characteristics for these conditioned clay sludges. The best fitting coefficients B and η are shown in Figs. 8 and 9. Notably, the addition of activated sludge has a substantial effects on these two coefficient. The B value and η can changed from 0.45 to 1, and from 0.02 to 0.0008, respectively, both are mostly accomplished in the low activated sludge addition amount region. The physical meaning of the change in these parameters can be interpreted separately.

In expression theories, the primary consolidation had been proposed as the escape of pore liquid and the cake structure collapse; while for the secondary con solidation, the disturbance of the structural bonding of particles, or the creeping of the particles (18). Notably, the presence of activate sludges particles tend to strengthen the expressed cake toughness to resist instant shape deformation when loading is first employed, and to "freeze" their neighboring particles to prevent fast creeping. This can be satisfactorily explained by the usually existing large amount of bound water in activated sludges, whose erosion would be highly vis-

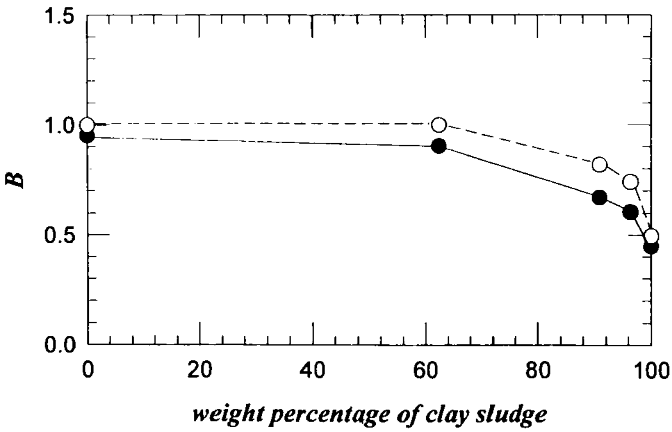

Fig 8 Parameter *B* versus weight percentage of clay sludge(10%,w/w).Closed and open symbols are for sample #1 and #2, respectively.

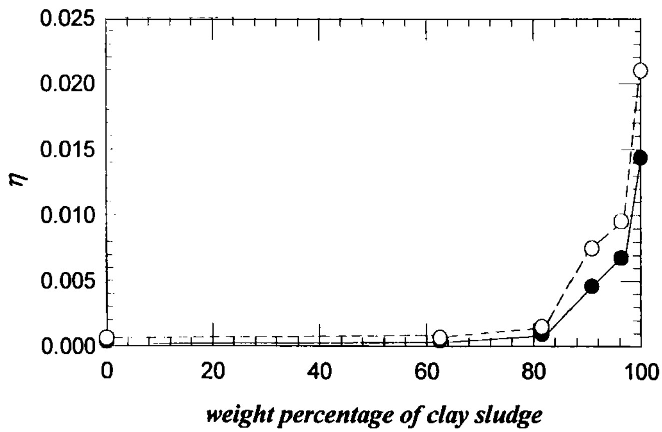

Fig 9 Parameter η versus weight percentage of clay sludge(10%,w/w). Closed and open symbols are for sample #1 and #2, respectively.

cous, thereby markedly enhancing the secondary consolidation stage (17). The fractal-like floc morphology should have contribution as well (19). It is surprising, however, to find the rapid growth (decay) of B (η) during the low activated sludge amount region. This reflects the predominating role of the activated sludge than the clay particles. The filtration stage data shown in Fig. 4 reveal that the resistance to filtration is governed by the surface area of the constituting particles. The expression stage data show a totally different mechanisms for mixed sludges. This further supports the suggestions by Moudgil and Shah (20) that the so-called "optimal" sludge floc characteristics are different for various sludge treatments. This is especially true for the mixed sludge considered here.

Dewatering efficiency.

For the dewatering sake, a low average specific resistance, low parameter B, high η, and a as low as possible residue moisture content are desired. Since the average specific resistance of filtration exhibits a linear relationship with the activated sludge addition percentage, the mixing of clay and activated sludge has gained no benefits when considering the filtration stage alone. However, during expression stage, both the creep factor and the portion attributed to secondary consolidation reveal a highly nonlinear character when activated sludge is added. A less than 20% of activated sludge addition can decrease the creep factor by more than an order of magnitude , thereby largely retarding the expression process.

The final expressed cake thickness data are depicted in Fig. 10, which can be taken as an index for the residue moisture in the expressed cake. A minimum locating near 20% w/w activated sludge presents in the figure. This should occur owing to the filling action of the deformed activated sludge flocs into the empty space between clay particles. An approximately 50% of cake final thickness reduction is noted. Departure from this addition amount, nevertheless, will cause the thickness to increase rapidly to that for pure activated sludge test or for pure clay test.

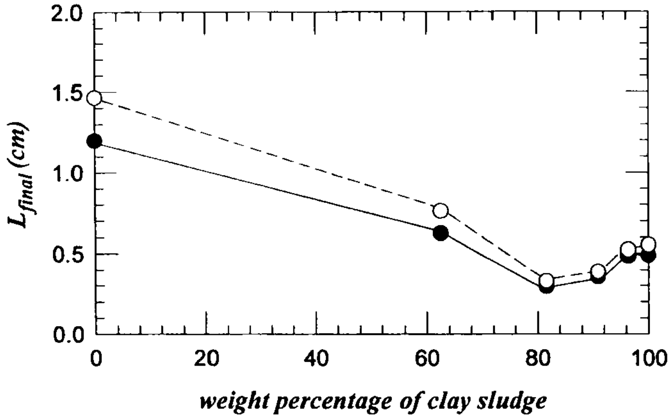

Fig 10 The final cake thickness versus weight percentage of clay sludge (10%, w/w). Closed and open symbols are for sample #1 and #2, respectively.

Based on these results, if the dewatering time is of major concern, the mixing of clay and activated sludge has gained no benefits when only filtration is considered. However, if the filtration + expression processes are considered as a whole, the presence of activated sludge becomes extremely undesired. On the other hand, if a low final residue moisture is the key issue, a mixing of 20% activated sludge and 80% clay can reduce the final cake thickness by 50%. The dewatering speed, nevertheless, has also reached a rather low level.

CONCLUSIONS

This work has experimentally evaluated the filtration followed by expression characteristics of mixed sludges (clay + activated sludges) . The average specific resistance of filtration shows a linear relationship with the amount of activated sludge amount presents, thereby suggesting an important role of particle surface area and the validity of employment of Carman-Kozeny law in such a complex system. On the contrary, during expression stage, both the creep factor and the portion attributed to secondary consolidation reveal a highly nonlinear character when activated sludge is added. The expression process is markedly retarded as merely a small amount of activated sludge is present. When consulting the dewatering speed, mixing of clay and activated sludge has gained no benefits if only filtration is considered, and is highly undesired if the expression process has been considered as well. If the final residue moisture is of major concern, mixing of a certain clay and activated sludge flocs can reduce the expressed cake thickness by 50%.

ACKNOWLEDGMENT

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