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ASSESSMENT OF SLUDGE DEWATERABILITY USING RHEOLOGICAL PROPERTIES

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ABSTRACT

This study evaluates the feasibility of using rheological properties to assess the dewaterability of sludge. Inorganic water sludge and organic activated sludge were conditioned with fly ash and polymer. The rheological characteristics of conditioned sludge, such as sludge viscosity and rheogram, in addition to capillary suction time (CST) and specific resistance to filtration (SRF) were determined. Experimental results indicate that the sludge viscosity and rheogram peak can be used to assess inorganic water sludge dewaterability, but not that of organic activated sludge. Selecting proper rheological parameters for sludge conditioning control depends on sludge types and conditioning methods. The minimum sludge viscosity of inorganic water sludge conditioned with fly ash corresponded to the minimum CST and SRF. Additionally, the specific height of the rheogram peak is an alternative means to determine the best point of coagulation for inorganic water sludge conditioned with polymer.

Key Words: sludge dewaterability, fly ash and polymer, sludge conditioning, rheology.

I. INTRODUCTION

An appropriate dosage of sludge conditioner is essential in dewatering. Sludge rheology provides fundamental information on the characteristics of sludge for optimum conditioning. For years, several researchers have examined the application of rheology to assess dewaterability of sludge. For example, the yield strength of conditioned sludge increased with the dosage of polymer added up to the optimum dosage, which corresponded to the minimum capillary suction time (CST). The sludge viscosity could also be used as a control parameter to optimize the dosage in chemical conditioning (Campbell and Crescuolo, 1983, 1989; Abu-Orf and Dentel, 1997). Moreover, Abu-Orf and Dentel (1999) demonstrated that the mixing parameter has a considerable effect on the rheological characteristics of conditioned sludge and cast some light on floc strength as related to dewaterability. Lin and Shien (2001) showed that sludge rheograms varied as the temperature changed. The dewatering ability of sludge can be greatly enhanced by thermal conditioning in conjunction with the addition of polymers. Another manner in which rheological properties may be used for the improvement of sludge conditioning is through the monitoring of filtrate or centrate (liquid stream) viscosity. Bache and Papavasilopoulos (2000) observed the centrate viscosity in response to polymer conditioning of alum sludge. The minimum in the viscosity-dosage trend, which may be applied for prediction of optimum polymer dosage, coincides with the onset of adsorption saturation of the polymer on the sludge. Because of the evident importance of the rheological properties in determining the behavior of sludge in a variety of contexts, it is meaningful to further examine the potential uses of rheology in optimizing the dosage for sludge conditioning.

This study addresses the relationship between the dewaterability and the rheology of sludge, when inorganic water sludge and organic activated sludge are conditioned with fly ash and polymer. The application of the rheological properties of conditioned sludge to control the optimal dosage was also

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Table 1 Characteristics of water and organic activated sludge samples

Sludge	TS (%)	CST (sec)	SRF (10^{12} m/kg)	Coefficient of Compressibility	Sludge Viscosity (cp)	Temp (°C)
Inorganic water sludge	3.0	55.7	2.11	1.34	1.63	23±2
Organic activated sludge	0.6	20.9	1.33	0.94	2.81	23±2

Table 2 Composition of fly ash

Al_2O_3 (%)	Fe_2O_3 (%)	K_2O (%)	SiO_2 (%)	TiO_2 (%)	SO_3 (%)
22.27	4.48	1.86	51.01	0.96	0.30

investigated.

II. MATERIALS AND METHODS

1. Raw Sludge

Inorganic water sludge was obtained from the clarifiers of the water treatment plant in the Hsin-Chu City in Taiwan, which used PAC (polyaluminum chloride) as a coagulant. The solid concentration of the inorganic water sludge, measured by evaporation at 105°C, was around 30,000 mg/L. The organic activated sludge was collected from the wastewater treatment plant of the Neili Bread Plant of the President Enterprise Co. in Taoyuan, Taiwan. Its solid concentration was around 6,000 mg/L. Table 1 summarizes the characteristics of the sludge samples.

2. Sludge Conditioning

In this study, the raw sludge samples were conditioned both physically and chemically.

Physical conditioning of the sludge was conducted by adding fly ash obtained from the Lin-Kuo coal-fired plant in Taipei, Taiwan. Table 2 presents the composition of the fly ash. Fly ash with a fly ash to dry sludge solids ratio (weight: weight) from 0% to 12% was added to sludge samples to produce slurries of high solid content.

The sludge was chemically conditioned by adding various amounts of polymer PC-325C to sludge samples. Polymer PC-325C is a cationic polymer of polyacrylamide with an average molecular weight of 10^7 and a charge density of 25%. It was obtained from the Taiwan Polymer Company. Polymer solution (1% w/w) was prepared following the instructions of the polymer manufacturer. The polymer solution was vigorously mixed with the sludge sample at 100 rpm for 60 seconds, using a standard jar test stirrer. The sludge sample was then flocculated at a slower mixing rate of 60 rpm for 15 minutes.

3. Dewatering Experiments

This study characterized the dewaterability of the conditioned sludge by the dewatering indices, specific resistance to filtration (SRF) and CST. The optimum dosage of the sludge conditioner generally occurs at minimum SRF or CST.

SRF was determined in a Buchner funnel that contained a 200 mL sample. This sludge sample was filtered under a pressure drop of 15 in-Hg, using Whatman #1 filter paper as the porous medium (Coackley and Jones, 1956).

CST is the time for water from a small sludge sample (4 mL) to flow through filter paper between two fixed points (1 cm). CST was recorded directly in seconds (Baskerville and Gale, 1968; Vesilind, 1988).

4. Measurement of Sludge Rheology

Rheology is the science of the relationships between stress and deformation (strain). The shear rate of Newtonian fluids is linearly related to the shear stress. Newtonian viscosity can be considered to be a constant at a specific temperature or pressure. Sludge, however, is a non-Newtonian fluid, because the relationship between the shear rate and the shear stress is non-linear. The rheological behavior of the sludge before conditioning can be described by the Bingham model with the following equation (Hiemenz, 1986; Spinosa and Lotito, 1989):

$$\tau = \tau_0 + \mu(\frac{dv}{dy})$$

where τ is the shear stress; τ_0 is the yield stress; μ is the viscosity and dv/dy is the velocity gradient

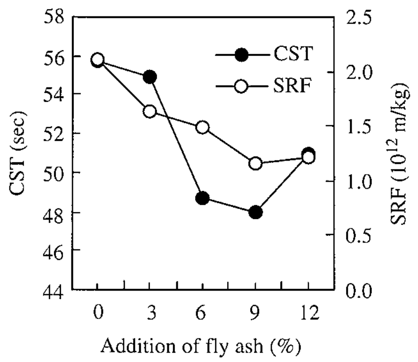

Fig. 1 Response of SRF and CST to various fly ash dosages in physical conditioning of inorganic water sludge

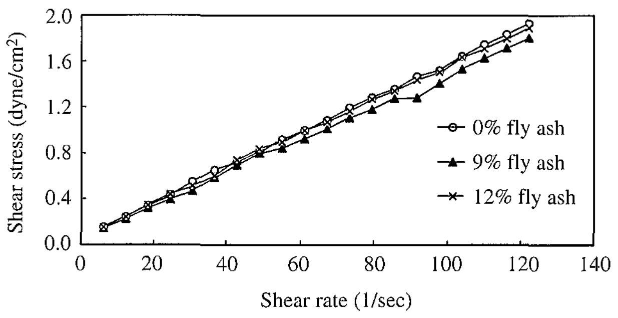

Fig. 2 Rheogram for physical conditioning of inorganic water sludge

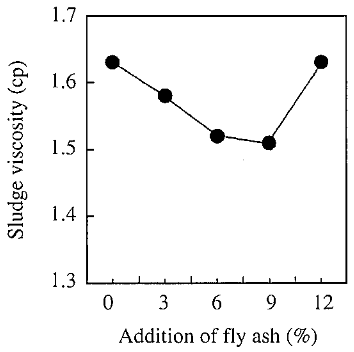

Fig. 3 Sludge viscosity versus fly ash addition in physical conditioning of inorganic water sludge

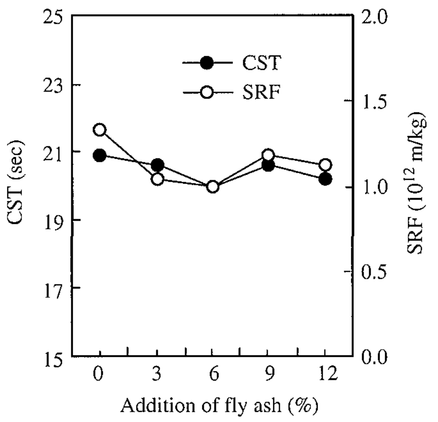

Fig. 4 Response of SRF and CST to various fly ash dosages in physical conditioning of organic activated sludge

or the shear rate.

This study examines rheology of sludge by establishing the relationship between its shear rate and shear stress using a rotational viscometer with a UL spindle (Brookfield model DV-III). The speed of rotation was increased from zero to 100 rpm for 2 minutes, and the shear stress was determined from the measured torque. The sludge viscosity used in this study was obtained from the shear stress versus shear rate curves.

III. RESULTS AND DISCUSSION

1. Relationship between Minimum Sludge Viscosity and the Dewaterability Properties of Fly Ash-conditioned Sludge

Physical conditioning improves the dewatering characteristics of sludge by providing a skeleton builder for the floc structure (Zall *et al.*, 1987; Hwa and Jeysaaelem, 1997). Fig. 1 shows measurements of SRF and CST for the inorganic water sludge conditioned with various amounts of fly ash. The SRF declined from 2.11×10^{12} to a minimum value of 1.15×10^{12} m/kg as fly ash grew from 0% to 9%. Adding more fly ash did not further decrease the specific resistance. The optimal dosage of 9% fly ash was obtained from the minimum SRT. Fig. 1 also shows that the CST dropped from 55.7 sec to a minimum value of 48.0 sec when 9% fly ash had been added. Therefore, physical conditioning with fly ash enhanced the dewaterability of the inorganic water sludge.

Figure 2 displays the sludge rheogram for the inorganic water sludge conditioned with fly ash. The conditioned inorganic water sludge behaved like a Bingham fluid, and its shear rate was linearly proportional to the shear stress with an initial yield stress. Fig. 3 shows a dramatic change in sludge viscosity. The sludge viscosity dropped to a minimum value of 1.51 cp when 9% fly ash had been added. Further addition of fly ash caused the sludge viscosity to rise. This minimum sludge viscosity at 9% fly ash coincided with the minimum SRF and CST, as indicated in Fig. 1. This finding implies that fly ash could build a skeleton for inorganic water sludge to form a permeable and rigid lattice structure. This series of tests suggests that the minimum sludge viscosity can be used as a dewatering index to determine the optimal

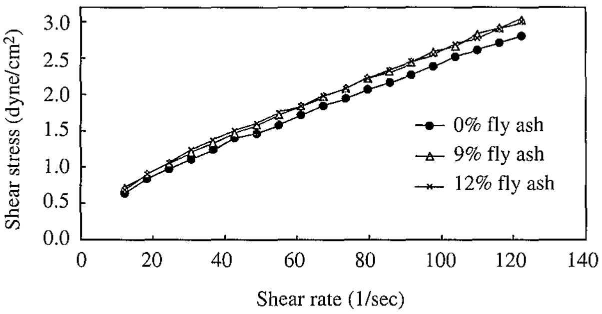

Fig. 5 Rheogram for physical conditioning of organic activated sludge

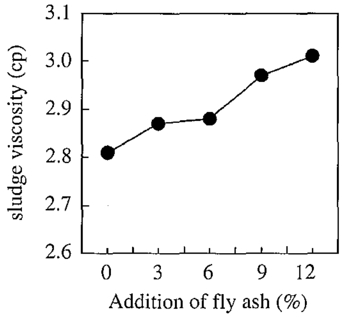

Fig. 6 Sludge viscosity versus fly ash addition in physical conditioning of organic activated sludge

dosage in conditioning inorganic water sludge.

Figure 4 presents SRF and CST measurements for the organic activated sludge conditioned with fly ash. Only a slight change occurred. The SRF slightly fell from 1.33×10^{12} to 1.00×10^{12} m/kg and the CST slightly decreased from 20.9 to 20.0 sec when the fly ash was increased from 0% to 12%. Physical conditioning with fly ash does not significantly improve the dewaterability of organic activated sludge.

Figure 5 presents the rheogram for the organic activated sludge to which fly ash has been added; the conditioned sludge remained as a Bingham fluid. Adding fly ash led to a gradual increase in the sludge viscosity, as shown in Fig. 6. The sludge viscosity increased from 2.81 to 3.01 cp as the dosage of fly ash varied from 0% to 12%. Figs. 2 and 6 show that no minimum sludge viscosity existed if sludge dewaterability was not improved. Restated, the nature of the sludge dictated the existence of a minimum sludge viscosity. Sludge viscosity is not an effective dewatering index for organic activated sludge conditioned with fly ash.

2. Rheogram as a Measure of Sludge Dewaterability in Polymer Conditioning

Figure 7 shows that the SRF decreases from 2.11×10^{12} to a minimum value of 0.24×10^{12} m/kg at a dosage of 20 mg/L polymer, for chemically conditioned inorganic water sludge. The increase in the SRF was observed in the overdosing region. Fig. 8 reveals that the CST declines from 55.7 sec to a minimum value of 20.3 sec at 20mg/L polymer. The optimal dosage of 20 mg/L polymer was obtained from the minimum SRT and CST.

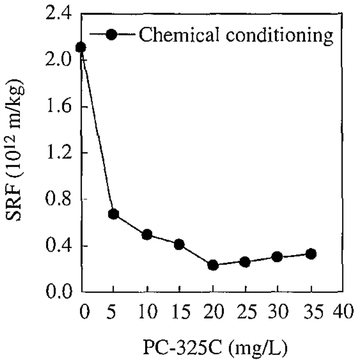

Fig. 7 Response of SRF to various polymer dosages in chemical conditioning of inorganic water sludge

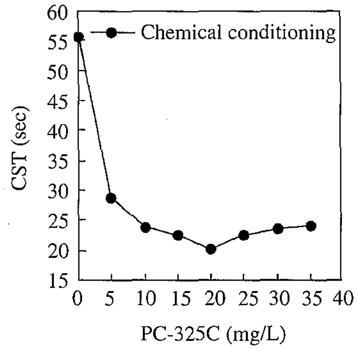

Fig. 8 Response of CST to various polymer dosages in chemical conditioning of inorganic water sludge

Polymer conditioning of the inorganic water sludge improves its dewatering characteristics by flocculating the gel-like sludge particles into larger and stronger aggregates, strongly affecting the rheological behavior of the sludge. Fig. 9 presents typical rheogram curves, illustrating the relationship between the shear rate and the shear stress for inorganic water sludge conditioned with various polymer dosages. The initial yield stress for the sludge increased and the characteristic shape of the rheogram curve changed with polymer dosage. An initial peak was evident in the rheogram curve, and the optimal dosage corresponded to a specific height of this peak. Rheological literature has designated this peak as the strength of the gel or the entanglement network (Schurz, 1991). Referring to Figs. 7, 8 and 9, a peak

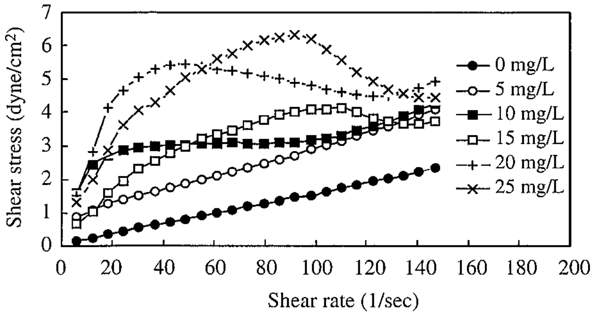

Fig. 9 Rheogram for chemical conditioning of inorganic water sludge

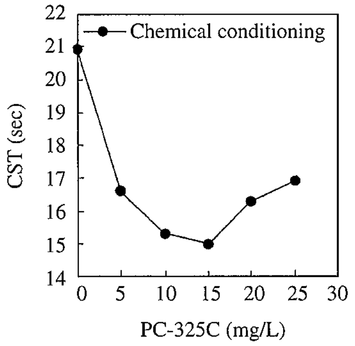

Fig. 11 Response of CST to various polymer dosages in chemical conditioning of organic activated sludge

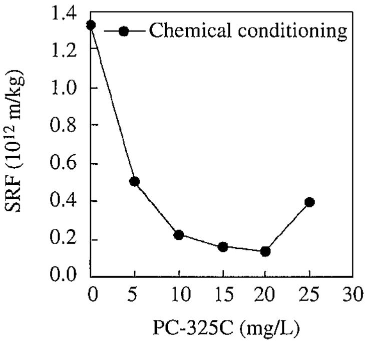

Fig. 10 Response of SRF to various polymer dosages in chemical conditioning of organic activated sludge

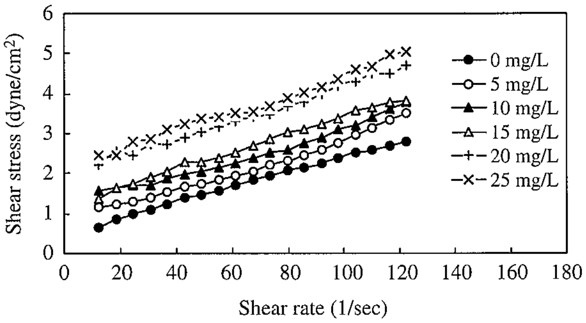

Fig. 12 Rheogram for chemical conditioning of organic activated sludge

at a shear stress of 5.5 dyne/cm^2 was observed when the inorganic water sludge was conditioned with the optimal dosage of 20 mg/L. Accordingly, continuously monitoring the rheogram peaks can provide an alternative means of characterizing polymer conditioning and dewatering.

Figures 10 and 11 show the measurements of the SRF and CST for the chemical conditioning of the organic activated sludge. Polymer markedly affects the sludge dewaterability. The SRF declined from 1.33×10^{12} to 0.13×10^{12} m/kg, as shown in Fig. 10, and the CST decreased from 20.9 to 15.0 seconds, as shown in Fig. 11. The above findings suggest that the optimal dosage for the organic activated sludge is around 15 mg/L.

The shear rate was linearly proportional to the shear stress with an initial yield stress at polymer dosages from 0 to 25 mg/L as shown in Fig. 12. The rheogram curves of polymer-conditioned organic activated sludge exhibited no obvious peaks. Consequently, the conditioned organic activated sludge behaved like a Bingham fluid, no specific height of rheogram peak is available to determine the best point of coagulation.

The aftermentioned results clarify that sludge types and conditioning methods greatly affect the feasibility of using rheological properties of conditioned sludge as dewatering indices.

IV. CONCLUSIONS

Rheological characteristics can be used to assess the dewaterability of sludge. Sludge viscosity and rheogram peaks are potential measurements for the dewaterability of sludge. The choice to use rheological parameters as a dewatering index to determine the optimal dosage in sludge conditioning depends upon the type of sludge and the means of conditioning. For inorganic water sludge conditioned with fly ash, but not for organic activated sludge, the minimum sludge viscosity is a promising method for controlling the optimal dosage. For inorganic water sludge conditioned with polymer, but not for organic activated sludge, the specific height of the rheogram peak can be used to obtain the best condition for coagulation. Type of sludge and the method of conditioning must be specified to relate rheological characteristics to the dewaterability of sludge. Rheological parameters can be used as operational tools to optimize sludge conditioning and dewatering.

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