CHARACTERISTICS OF SEWAGE SLUDGE AFFECTING DEWATERING BY BELT PRESS FILTER

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ABSTRACT

Dewatering characteristics of sewage sludge were determined by conditioning the sludge with the most effective cationic polyelectrolyte studied, and dewatering using a belt press filter. The characteristics of sludges (16 mixed, and 8 anaerobically digested) were measured for 33 factors affecting dewaterability. The correlations of sludge factors with sludge dewaterability were investigated.

The results revealed the following. A factor affecting the gravitational filterability of conditioned sludge is the suspended solids concentration of raw sludge. A factor affecting the moisture content of dewatered sludge cake is viscosity of the sludge adjusted to 4.0% of suspended solids concentration. Factors affecting the viscosity are the intrinsic viscosity of alkaline extracts, the ratio of (VSS-Fiber)/SS : Ash/SS : Fiber/SS, and the charge density of sludge particles. A factor affecting the extension degree of dewatered sludge cake is the charge density of sludge particles. Factors affecting the amount of residual solids on the filter cloths are the charge density of sludge particles and the fibrous substances content of sludge. As for polyelectrolytes, a highly cationized polyelectrolyte is effective to lower the moisture content, the extension degree and the amount of residual solids on filter cloths. And a factor affecting the required dosage of a polyelectrolyte is anionic substances content in the liquid of raw sludge.

KEYWORDS

Characteristics of sewage sludge; dewatering characteristics; moisture content of dewatered sludge cake; conditioning; belt press filter; viscosity; cationic polyelectrolyte.

INTRODUCTION

In many wastewater treatment facilities, the production of biological sludges has given rise to increasing problems in dewatering. Under many operating conditions, various types of dewatering equipment such as vacuum filter, belt press filter, centrifuge, filter press and screw press, have been utilized for the sludge dewatering. The performance of such dewatering equipment is critically dependent on the characteristics of the sludge and on the foregoing sludge conditioning, which is normally carried out by adding a polyelectrolyte.

Many sludge factors affecting the dewatering characteristics of sludge have been reported in the literature. These are pH (Tenney et al., 1970), suspended solids concentration (Tenney et al., 1970), organic content (Randall et al.,

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1971), cellulose content (Gale and Baskerville, 1970), particle size and its distribution (Bargman et al., 1958; Lapple, 1968; Karr and Keinath, 1978), extracellular polymers (Gulas et al., 1979), bound waters (Katsiris and Kouzelli-Katsiri., 1987), etc.

And many sludge factors determining the suitable polyelectrolyte and the dosage of it have been reported in the literature. These are colloidal and low supra - colloidal particles (Roberts and Olsson, 1975; Eriksson, 1987), anionic biopolymers (McGregor and Finn, 1969; Tenney and Stumm, 1965; Wu, 1978), biopolymers in the supernatant (Novak and More, 1982), lipid, protein and carbohydrate (Bowen, 1982), particle size distribution (Karr and Keinath, 1978), etc.

In spite of considerable experience, it is still to a considerable extent a matter of trial and error to choose the suitable polyelectrolyte and the dosage of it for each sludge, and to predict the dewatering characteristics of the sludge and preserve good dewatering operations. In the literature, the dewatering characteristics of the sludge were determined mostly in bench-scale dewatering tests, not in the dewatering tests using actual dewatering equipment.

One of the objectives of this study was to define the sludge factors affecting the dewatering characteristics of sewage sludge, when the sludge was dewatered using a belt press filter. The other objective of this study was to define the sludge factors determining the suitable polyelectrolyte and the dosage of it for each sewage sludge.

MATERIALS AND METHODS

Polyelectrolytes

Chemical flocculants used as sludge conditioners were homopolymers of methacryloyloxyethyltrimethylammonium chloride (DAM(CH₃Cl)) and copolymers of DAM(CH₃Cl) with acrylamide (AAm). The characteristics of cationic polyelectrolytes studied are presented in Table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Composition</th>
<th>Intrinsic vis.(dl/g)</th>
<th>Colloid eq. (meq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>DAM(CH₃Cl)</td>
<td>3.2</td>
<td>4.8</td>
</tr>
<tr>
<td>B1</td>
<td>DAM(CH₃Cl)</td>
<td>4.6</td>
<td>4.8</td>
</tr>
<tr>
<td>B1.5</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>5.3</td>
<td>4.0</td>
</tr>
<tr>
<td>B2</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>5.1</td>
<td>3.7</td>
</tr>
<tr>
<td>B3</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>4.9</td>
<td>2.8</td>
</tr>
<tr>
<td>B5</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>5.3</td>
<td>1.8</td>
</tr>
<tr>
<td>C1</td>
<td>DAM(CH₃Cl)</td>
<td>7.6</td>
<td>4.8</td>
</tr>
<tr>
<td>C1.5</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>7.2</td>
<td>4.2</td>
</tr>
<tr>
<td>C2</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>7.5</td>
<td>3.5</td>
</tr>
<tr>
<td>C3</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>7.6</td>
<td>2.8</td>
</tr>
<tr>
<td>C5</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>7.8</td>
<td>1.8</td>
</tr>
<tr>
<td>D3</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>10.6</td>
<td>2.8</td>
</tr>
<tr>
<td>D5</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>10.4</td>
<td>1.8</td>
</tr>
<tr>
<td>E5</td>
<td>DAM(CH₃Cl)/AAm</td>
<td>13.1</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Measurements of Sludge Characteristics

Two different types of sewage sludges were studied: 16 mixed sewage sludges of primary settled sludge and excess activated sludge, and 8 anaerobically digested sludges. The characteristics of supernatant (1) and (2), raw sludge and alkaline extracts were measured, where the supernatant (1) and (2) were obtained by centrifuging the sludge respectively at 2,000 rpm (relative centrifugal force = 720 x g) and 10,000 rpm (r.c.f. = 11,700 x g). The alkaline extracts solution was obtained by extracting the sludge with a 0.4 % NaOH solution, centrifuging, and purifying in a cellulose film tube. The alkaline extracted substances content, expressed as Mc, was determined as the evaporated residue
The characteristics of the sludge in Table 2 were measured, and those marked by * were measured according to JIS K0102-1971, -1986 or Standard Method of Analysis for Sewage (Japan Sewage Works Association, 1985).

<table>
<thead>
<tr>
<th>TABLE 2 Characteristics of Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supernatant(1)</td>
</tr>
<tr>
<td>*pH</td>
</tr>
<tr>
<td>*Conductivity</td>
</tr>
<tr>
<td>*M-alkalinity</td>
</tr>
<tr>
<td>*P-acidity</td>
</tr>
<tr>
<td>Capillary suction time</td>
</tr>
<tr>
<td>Supernatant(2)</td>
</tr>
<tr>
<td>Colloid equivalent</td>
</tr>
<tr>
<td>Protein</td>
</tr>
<tr>
<td>Neutral polysaccharide</td>
</tr>
<tr>
<td>Acid polysaccharide</td>
</tr>
<tr>
<td>Nucleic acids</td>
</tr>
<tr>
<td>Relative viscosity</td>
</tr>
<tr>
<td>Capillary suction time</td>
</tr>
<tr>
<td>Raw sludge</td>
</tr>
<tr>
<td>*Total solids</td>
</tr>
<tr>
<td>*Volatile TS</td>
</tr>
<tr>
<td>*Suspended solids</td>
</tr>
<tr>
<td>*Volatile SS</td>
</tr>
<tr>
<td>Fiber A</td>
</tr>
<tr>
<td>Fiber B</td>
</tr>
<tr>
<td>Protein</td>
</tr>
<tr>
<td>Al</td>
</tr>
<tr>
<td>Fe</td>
</tr>
<tr>
<td>Colloid equivalent</td>
</tr>
<tr>
<td>Viscosity</td>
</tr>
<tr>
<td>Capillary suction time</td>
</tr>
<tr>
<td>Sludge expansion index</td>
</tr>
<tr>
<td>Moisture content</td>
</tr>
<tr>
<td>Alkaline extracts</td>
</tr>
<tr>
<td>Extracted substances</td>
</tr>
<tr>
<td>Protein</td>
</tr>
<tr>
<td>Neutral polysaccharide</td>
</tr>
<tr>
<td>Acid polysaccharide</td>
</tr>
<tr>
<td>Nucleic acids</td>
</tr>
<tr>
<td>Colloid equivalent</td>
</tr>
<tr>
<td>intrinsic viscosity</td>
</tr>
</tbody>
</table>

Colloid equivalent was measured by the colloid titration method (Terayama, 1952; Senju, 1969). Protein, neutral and acid polysaccharides, and nucleic acids concentration in supernatant (2) and alkaline extracts were determined respectively by the Lowry - folin method, the anthrone - sulfuric acid method and the carbazole - sulfuric acid method, and a spectrophotometric method using 257 to 258 nm ultraviolet rays. Protein content in raw sludge was determined by the Kjeldahl method.

The Fiber A in this study is identical to the VSS captured on a stainless fabric mesh having 0.149 mm openings. The Fiber B in this study is identical to the VSS measured by the improved method of the Hennenberg - Stohmann method. Al and Fe were measured by the following procedures. A sludge was mixed with a HCl solution to make the pH of the mixture less than 0.3, and centrifuged at 3,000 rpm. The obtained supernatant was filtered through a No. 5C filter paper, and Al and Fe ion concentrations of the filtrate were determined by the atomic absorption analysis method.

The relative viscosity of supernatant (2) and the intrinsic viscosity of alkaline extracts were measured on a Cannon - Fenske type viscosimeter in 1N - NaCl at 30 °C. Capillary suction time value was measured by the CST instrument (Baskerville
The viscosity of the sludge adjusted to 4.0 % of suspended solids concentration, was measured on a Brookfield viscosimeter at 30 rpm, 20 °C. The moisture content of the sludge centrifuged at 3,500 rpm (r.c.f. = 2,190 x g) was measured and expressed as WSI. The sludge extension index in this study is identical to the SVI measured at a suspended solids concentration of 0.5 % and settled for 30 minutes in a graduated cylinder.

**Measurements of Sludge Dewatering Characteristics**

**Bench-scale dewatering test.** Two hundred ml samples of raw sludge were conditioned with the cationic polyelectrolytes in Table 1, and filtered through a Buchner funnel with the same polyester filter cloth as used in the belt press filter below. The volume of the filtrate in a graduated cylinder was observed after 10, 20, 30, 45, 60 and 120 seconds, and the colloid equivalent of the filtrate was measured by the colloid titration method. Then, the sludge on the Buchner funnel was placed between two pieces of the polyester filter cloths, and pressed at 0.5 kg/cm² for 2 minutes. The area and the moisture content of the dewatered sludge cake were measured. And the amount of the residual solids on the filter cloths were obtained by measuring the suspended solids concentration of the water used for the filter cloth washing.

**Dewatering test using a belt press filter.** The sludge was conditioned and dewatered by a belt press filter having the filter cloth of 50 cm wide. The dewatering rate was adjusted to 70, 100 and 130 kgSS/m²h, and the maximum pressure at a portion of the press rolls was adjusted to 0.3, 0.5 and 0.75 kg/cm². In these experiments, the area and the moisture content of the dewatered sludge cake were measured, and the amount of the residual solids on the belt filter cloths was obtained by measuring the suspended solids concentration of the water used for the belt filter cloths washing.

**DETERMINING THE DEWATERING CHARACTERISTICS OF SLUDGE**

The data obtained by the dewatering tests using a belt press filter and the bench-scale dewatering tests were stocked in a computer. The dewatering characteristics of the sludges used in this study were determined by the following procedures.

**Gravitational Filterability of Conditioned Sludge: R30**

The gravitational filterability was determined in the bench-scale dewatering test as the water/solids ratio of the sludge after the gravitational filtration for 30 seconds, and expressed as R30. The minimum R30 for each sludge was obtained by computer calculation from the filtrate volume after 30 seconds and the suspended solids concentration of the raw sludge under the following conditions: dewatering pressure, 0.50 kg/cm²; mixing rate, 250 rpm.

**Moisture Content of Sludge Cake: WF70, WF100, WF130, WT**

The bench-scale dewatering tests revealed that the polyelectrolyte B1 was the most effective to lower the moisture content of all dewatered sludge cake in this study. Hence, the minimum moisture content for each sludge in the dewatering test using a belt press filter was obtained using a computer under the following conditions: polyelectrolyte, B1; the maximum dewatering pressure, 0.50 kg/cm²; dewatering rate, 70, 100 and 130 kgSS/m²h. Thus obtained moisture contents are expressed as WF70, WF100 and WF130 respectively for each dewatering rate.

The minimum moisture content of dewatered sludge cake in the bench-scale dewatering test, expressed as WT, was obtained using a computer under the following conditions: polyelectrolyte, B1; dewatering pressure, 0.50 kg/cm²; mixing rate, 250 rpm.

**Extension Index of Sludge Cake: EXT70, EXT100, EXT130**

The sludge extension index in this study is the ratio of area(2)/area(1), where area(1) is the area of the sludge after the gravitational filtration on the filter cloth, and area(2) is the area of the dewatered sludge cake in the
dewatering test using a belt press filter. The sludge extension index for each sludge was obtained using a computer under the same condition used for determining the WF, and expressed as EXT70, EXT100 and EXT130 respectively for each dewatering rate.

Residual Solids on Filter Cloth: SSD70, SSD100, SSD130

The amount of the residual solids on the belt filter cloths is a factor related to the suspended solids recovery in the belt press filter dewatering. The amount of the residual solids was obtained using a computer under the same condition used for determining the WF, and expressed as SSD70, SSD100 and SSD130 respectively for each dewatering rate.

CHARACTERISTICS OF SLUDGE AFFECTING DEWATERING

Factors affecting the dewatering characteristics were investigated using a computer, where the factors in Table 1 were transformed into 77 different forms for the convenience of computer analysis.

Factors Affecting Gravitational Filterability

In bench-scale dewatering tests, a highly cationized polyelectrolyte was effective to lower the water/solids ratio expressed as R30 of all mixed sludges and some anaerobically digested sludges, and a moderately cationized polyelectrolyte was effective to lower that of the other digested sludges. Consequently, when restricting the polyelectrolyte to B1, the above correlation coefficients between the 77 factors and the R30 for all sludges studied were lower than 0.75 as absolute value. However, as for all mixed sludges studied, the correlation coefficient between the suspended solids concentration of the raw sludge and the R30 was 0.89. Then, when not restricting the polyelectrolyte to B1, the correlation coefficient obtained for all sludges was 0.81.

If SS (g/dl) is transformed into (100-SS)/SS, the ratio indicates the water/solids ratio of a raw sludge. Consequently, the result mentioned above can be described as follows: the gravitational filterability of the sludge conditioned with a suitable polyelectrolyte is affected by the water/solids ratio, i.e. suspended solids concentration of a raw sludge.

Factors Affecting Moisture Content of Sludge Cake

The correlation coefficients between the 77 sludge factors and the moisture content of dewatered sludge cake determined as WF70, WF100, WF130 and WT were calculated. The results revealed that only log(Vis) and WSl were correlated with WFs and WT as shown in Figs.1 and 2, where R is a correlation coefficient. The correlation coefficients of the other factors were lower than 0.75 as absolute value.

Fig. 1. Factors affecting the moisture content of dewatered sludge cake.

Fig. 2. Correlation between log(Vis) and WF100.

The correlation coefficient between the log(Vis) and the WSl was calculated for many other sewage sludges. The correlation coefficients calculated was 0.90
(n=118) for mixed sludges shown in Fig. 3; 0.90 (n=66) for anaerobically digested sludges shown in Fig. 4; 0.87 (n=10) for excess activated sludges; 0.97 (n=7) for primary settled sludges, where n is the number of sludge samples. The additional result was that all obtained regression lines were nearly in the same line.

Fig. 3. Correlation between log(Vis) and WSI for mixed sewage sludges

Fig. 4. Correlation between log(Vis) and WSI for anaerobically digested sludges.

If the moisture content WSI is transformed into (100-WSI)/100, the form indicates the solids content of the sludge centrifuged at 3,500 rpm. Therefore, WSI is the factor of sludge compressibility by centrifugation, but not elemental characteristics influencing the sludge dewaterability.

Viscosity of Suspension

The log(Vis) means viscosity of a suspension. In 1906, Einstein presented his famous equation:

$$\eta_r = 1 + k \phi$$  \hspace{1cm} (1)

where $\eta_r$ is relative viscosity of a suspension of discrete spherical particles, $\phi$ is fractional solids volume concentration, and parameter $k$ is commonly referred to as the "Einstein coefficient". As equation (1) is restricted to infinite dilute suspensions, some attempts have been made to extend this equation to higher concentration, and the following equation was obtained:

$$\eta_r = (1 + 0.5 \phi)/(1 - \phi)^2$$  \hspace{1cm} (2)

Using equation (2) as a starting point, Einstein's theory has been extended by many researchers. Gillespie (1963) presented the following equations:

$$\eta_r = 1/(1 - s \phi)$$  \hspace{1cm} (3)

$$k = 5a/2s$$  \hspace{1cm} (4)

where $a$ is the hydrodynamic volume of a typical particle divided by its volume in the dry state, and $s$ is equal to the increase in volume of the suspension when one particle is added, divided by the volume of the particle in the dry state.

Smoluchowski presented the following equation for charged particles suspended in water:

$$\eta_r = 1 + 2.5 \phi \{1 + \{1/\kappa \eta_o r^2 \} (\zeta \epsilon/2\pi)^2 \}$$  \hspace{1cm} (5)

where $\kappa$ is specific conductivity, $\eta_o$ is viscosity of liquid, $r$ is radius of particle, $\zeta$ is $\zeta$ - potential of particle surface, and $\epsilon$ is dielectric constant.

Factors Affecting log(Vis)

Einstein's equation (2) was modified here to the following equations:

$$\log(Vis) = (1 + 0.5 \phi_*)/(1 - \phi_*)^2$$  \hspace{1cm} (6)

$$\log(Vis) = (1 + P_1 \phi_*)/(1 - \phi_*)^2$$  \hspace{1cm} (7)

$$\log(Vis) = (1 + P_2 \phi_*)/(1 - P_2 \phi_*)^2$$  \hspace{1cm} (8)
where \( n_r \) was substituted for \( \log(\text{Vis}) \), and \( \phi \) for \( \phi_r = \Sigma s_i \phi_i \), and \( P_1 \) and \( P_2 \) are constants. In these equations, the elemental sludge factors were put into \( \phi_s \), and \( P_1 \) and \( P_2 \) were determined by the simplex method using a computer. By these calculations, no good correlations between the calculated \( \log(\text{Vis}) \) and the observed \( \log(\text{Vis}) \) were obtained. The elemental sludge factors used in these calculations are FiberA, FiberB, ProtSl, Al, Fe and Mc shown in Table 1. Although many factors were measured and used, the elemental sludge factors were not thoroughly measured. Furthermore, the equation (6) to (8) does not contain the factors indicating surface characteristics of sludge particles.

Then, Gillespie's equation (3) and (4) were modified to the following equation:

\[
\log(\text{Vis}) = 1 / (1 - f_\phi) \cdot P_1
\]

where \( n_r \) was substituted for \( \log(\text{Vis}) \), \( \phi \) for \( \phi_r = \Sigma s_i \phi_i \), and \( k \) for a constant \( P_1 \). In equation (9), the elemental sludge factors were put into \( \phi_s \), and \( P_1 \) was determined by the simplex method using a computer. These calculations did not give a higher correlation between the calculated \( \log(\text{Vis}) \) and the observed \( \log(\text{Vis}) \).

In Smoluchowski's equation (5), \( n_r \) was substituted for \( \log(\text{Vis}) \), \( \phi \) for \( \phi_r = \Sigma s_i \phi_i \), and \( (1/\kappa n_r r^2) (\zeta e/2\pi)^2 \) was assumed to be proportional to CESF as mentioned below. As suspended solids concentration of the sludge was 4.0 % when \( \log(\text{Vis}) \) was measured, hence \( n_r = (4/3)\pi r^2 \rho \), \( \rho_1 = n_r / (4/3)\pi r^2 \rho_2 \), then \( n_r = \rho_2 / \rho_1 (r_2 / r_1)^3 \) is derived, where \( n_r \), \( r_1 \), and \( \rho_1 \) are respectively number, radius and density of particles. If the charge density of particle surfaces is expressed as \( \rho_1 \), then \( (\sigma_1 / \sigma_2) = (\text{CES}1 / \text{CES}2) (n_2 / n_1) (r_2 / r_1)^2 = (\text{CES}1 / \text{CES}2) (\sigma_1 / \sigma_2) (r_1 / r_2) \).

If \( (\rho_1 / \rho_2) (r_1 / r_2) = 1 \), hence \( (\sigma_1 / \sigma_2) = (\text{CES}1 / \text{CES}2) \), and \( (1/\kappa n_r r^2) (\zeta e/2\pi)^2 \) is a constant, \( (1/\kappa n_r r^2) (\zeta e/2\pi)^2 \) can be modified to the following forms:

\[
\log(\text{Vis}) = 1 + 2.5 \phi_s (1 + P_1 X_1^2)
\]

where \( \phi_s \) is the fractional solids volume concentration of uncharged particles, and \( \phi_2 \) is that of charged particles. In equations (10) to (14), the elemental sludge factors were put into \( \phi_s \) or \( \phi_2 \), the factors indicating the charge density of sludge particles into \( X_1 \), and the Rel2 in Table 1 into \( X_2 \). By these calculations, the higher correlation coefficients between the calculated \( \log(\text{Vis}) \) and the observed \( \log(\text{Vis}) \) were obtained when the equation (11) and (12) were used, where FiberA/SS, AshOn/SS, AshPass/SS and (VSS-FiberA)/SS were put into \( \phi_s \), and CES1/SS, CES1/Pass or CES1/(VSS-FiberA) were put to \( X_1 \). The obtained correlation coefficients were 0.79 to 0.81. The results obtained above can be described as follows: Factors affecting \( \log(\text{Vis}) \) were the ratio of (VSS-FiberA)/SS : Ash/SS : FiberA/SS, and the charge density of sludge particles.

More attempts were made to extend Smoluchowski's equation, where \( \log(\text{Vis}) \) was regarded as the viscosity of a colloid solution. And the equation (5) was modified to the following forms:

\[
\log(\text{Vis}) = P_4 \{ 1 + 2.5 \phi_s (1 + P_1 X_1 + P_2 X_2^3) \}
\]

In equations (15) to (18), the elemental sludge factors were put into \( \phi_s \), the intrinsic viscosity of alkaline extracts into \( X_1 \), and the factors indicating the charge density of sludge particles into \( X_2 \).

In conclusion, the results obtained can be described as follows: factors affecting \( \log(\text{Vis}) \) are the intrinsic viscosity of alkaline extracts, the ratio of (VSS-FiberA)/SS : Ash/SS : FiberA/SS, and the charge density of sludge particles. Hence, \( \log(\text{Vis}) \) is likened to the viscosity of a colloid solution such as polyelectrolyte solutions, because the intrinsic viscosity, the ratio
and the charge density correspond respectively to the molecular weight, the concentration and the charge density of a polyelectrolyte.

The obtained equation was applied to many other sewage sludges. A good correlation between the calculated log(Vis) and the observed log(Vis) was confirmed with a correlation coefficient of 0.88 for 53 sludges as shown in Fig. 5.

\[
\text{log}(\text{Vis})_{\text{calc}} = P_4 \{1 + P_1 \phi_s X_1, P_2 X_2, P_3 X_3\} \\
\phi_s = P_5 X_3 + P_6 X_4 + P_7 X_5
\]

\[
X_1 = \frac{\text{Vis} \cdot \text{Mc}}{	ext{la}}
\]

\[
X_2 = \frac{\text{CES1}/(\text{VSS} - \text{FiberA})}{100}
\]

\[
X_3 = \frac{\text{100(VSS - FiberA)/SS}}{100}\text{Ash}/\text{SS}
\]

\[
X_5 = \frac{\text{100FiberA}/\text{SS}}{100}
\]

\[
P_1 = 1.77 \times 10^3
\]

\[
P_2 = 2.73 \times 10^{-1}
\]

\[
P_3 = 1.29 \times 10^{-1}
\]

\[
P_4 = 3.24 \times 10^{-1}
\]

\[
P_5 = 2.07 \times 10^{-3}
\]

\[
P_6 = 7.12 \times 10^{-4}
\]

\[
P_7 = 1.03 \times 10^{-3}
\]

Fig. 5. Correlation between the calculated log(Vis) and the observed log(Vis).

**Factors Affecting Extension of Dewatered Sludge Cakes**

The polyelectrolyte B1 was one of the most effective polyelectrolytes to lower the sludge extension index in this study, and the EXT for each sludge was obtained when the sludge was conditioned with the polyelectrolyte B1. The correlation coefficients between the 77 sludge factors and the EXT were calculated using a computer. By these calculations, a good correlation between the EXT and the CES1/VSS was obtained, and the correlation coefficient was 0.83.

**Factors Affecting the Residual Solids on Filter Cloth**

As for solids recovery, the polyelectrolyte B1 was one of the most effective polyelectrolytes to lower the amount of residual solids on the filter cloths in these experiments, and the SSD for each sludge was obtained when the sludge was conditioned with the polyelectrolyte B1. The correlation coefficients between the 77 sludge factors and the SSD100 were calculated using a computer. By these calculations, a good correlation of the SSD100 with the CES1/VSS and the FiberA/SS were obtained, and the correlation coefficients were 0.83 and -0.82 respectively.

When the conditioned and gravitationally filtered sludge was pressed by filter cloths in a belt press filter, the sludge was compacted and then dewatered. The EXT value is almost determined at a portion of the gravitational filtration and the first press roll of a belt press filter. And the SSD value is determined at a portion of the press rolls. Therefore, both the EXT and the SSD are factors related to the rigidity of the conditioned sludge. Hence, it is understandable that the CES1 affects both the EXT and the SSD. And as the filter cloths are lead to respectively in different speed at a portion of press rolls, greater rigidity of the conditioned sludge is required to obtain a good solids recovery. Hence, the Fiber A can be assumed to be a factor increasing the rigidity of the conditioned sludge.

**Factors Affecting the Dosage of Polyelectrolyte**

The optimum dosage of a polyelectrolyte for each sludge in the bench scale dewatering test was obtained using a computer under the same condition used for determining the minimum R30, and expressed as OD250. The solids captured on a stainless steel fabric mesh having 0.149 mm openings require no addition of a cationic polyelectrolyte, and the solids passed through the mesh, expressed as Pass, require addition of that. Hence, the OD250 was transformed into OD250/Pass, and the correlation coefficients between the OD250/Pass and the 77 sludge
Dewatering by belt press filter factors were calculated using a computer. By these calculations, a good correlation between the CE2/Pass and the OD250/Pass was obtained, and the coefficient was 0.86 as shown in Fig. 6.

If the polyelectrolyte is added to the sludge, the polyelectrolyte reacts simultaneously with anionic substances in the liquid of sludge and those of sludge particles. When the anionic substances in the liquid are coagulated and the surfaces of sludge particles are covered with the polyelectrolyte, the minimum R30 of the conditioned and filtered sludge is obtained. If the dosage becomes larger than the optimum dosage, the R30 becomes larger. The results obtained above can be described as follows; the OD250/Pass is affected mainly by anionic substances in the liquid of raw sludge, not by anionic substances of sludge particles.

Moreover, CE2 affected the floc size of a conditioned sludge. If the amount of anionic substances was small, then the CE2/Pass value was nearly zero, and the floc size was small. But, it was confirmed that if an anionic polyelectrolyte was added to the sludge, the floc size became larger. Thus, it can be described that the CE2/Pass is the factor affecting both the dosage of a polyelectrolyte and the floc size of the conditioned sludge.

The CE2 value is the amount of anionic charge of substances in the supernatant (2). Hence, The CE2 is nearly identical to the content of anionic substances in the supernatant (2). Consequently, the results in this study are in agreement with the results presented in the literature (Roberts and Olsson, 1975; Eriksson, 1987; Novak and More, 1980).

CONCLUSIONS

When sewage sludge is conditioned with a cationic polyelectrolyte and dewatered by a belt press filter, the dewatering characteristics of the sludge are affected by the following sludge factors.

1. A factor affecting the gravitational filterability of conditioned sludge is the suspended solids concentration of raw sludge.
2. A factor affecting the moisture content of dewatered sludge cake is viscosity of the sludge adjusted to 4.0% of suspended solids concentration.
3. Factors affecting the viscosity above are the intrinsic viscosity of alkaline extracts, the ratio of (VSS-Fiber A)/SS : Ash/SS : FiberA/SS, and the charge density of sludge particles.
4. A factor affecting the extension degree of dewatered sludge cake is the charge density of sludge particles.
5. Factors affecting the amount of residual solids on the belt filter cloths are the charge density of sludge particles and the fibrous substances content of raw sludge.

As for polyelectrolyte, the following are confirmed.

\[ Y = ax + b \]
\[ a = 4.15 \times 10^{-1} \]
\[ b = 0.398 \]
\[ CORR = +0.855 \]
1. A highly cationized polyelectrolyte is effective to lower the moisture content, the extension degree, and the amount of residual solids on the filter cloths.

2. A highly cationized polyelectrolyte is effective to increase the gravitational filterability of all mixed sewage sludges and some anaerobically digested sewage sludges, and a moderately cationized polyelectrolyte is effective to lower the gravitational filterability of the other digested sludges.

3. A factor affecting the dosage of the polyelectrolyte is anionic substances in the liquid of raw sludge.

REFERENCES


