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# Assessment of using synthetic polymers in dewatering of sewage sludge

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ABSTRACT

This study was carried out to identify the optimum dosage of different types of polymer for sewage sludge conditioning to achieve high dewaterability. The sludge conditioners used in this study were synthetic polymers; cationic polymer (Magnafloc LT 22S), anionic polymers (Magnafloc LT 25 and Magnafloc LT27), and nonionic polymer (Magnafloc LT 20). Sewage sludge samples were collected from the holding tank of the treatment plant located at Taman Tun Dr Ismail, state of Selangor, Malaysia. Different laboratory tests were carried out to determine the effectiveness of each polymer in conditioning the sewage sludge and to obtain the best conditioner. In this study, the optimum conditions for sludge dewatering were determined from the results of laboratory experiments conducted on polymers with different dosages, mixing speeds, and mixing durations. Laboratory experiments conducted for this purpose include capillary suction time (CST), specific resistance to filtration (SRF), and zeta potential. Measurement of CST and SRF on the cationic polymer showed that the optimum condition was obtained when mixing duration was 4.5 min, polymer dosage at 5.3 mg/L and mixing speed of 83 rpm. The zeta potential values indicated cationic polymer managed to reduce the charge; however, the anionic polymers were not effective in causing any neutralization. At optimum condition, the zeta potential values are expected to be near to zero.

*Keywords:* Synthetic polymers; Optimum dosage; Dewatering; Sewage sludge

## 1. Introduction

Wastewater from communities contains both liquid and solid. The source of liquid portion is water supplied to the community after it has been fouled by variety of uses and finally disposed as wastewater. Sewage is a liquid waste that includes substances such as human waste, food scraps, oils, soaps, and chemicals. In homes, sewage comes from toilets, baths, showers, kitchens, etc. that is disposed via sewers.

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Sewage sludge is the solid waste extracted in the process of sewage treatment. Since the sludge has to be disposed, the liquid sludge has first to be dewatered in order to convert it to dry and porous form. This shows the importance of sludge dewatering process before disposal. The term sludge dewatering process means any process which reduces the water content of the sludge from its usual value of 93–99% by weight to about 90% by weight or less [1]. For a good dewatering, size and firmness of the sludge agglomerates are important, so that these remain porous during the compression. Dewatering can be done naturally (dry beds, solar drying), however, this is only possible during a long period of time. Machine processes such as pressing (filter press) and centrifugation (centrifuge) are faster and smaller but they are costly. Sludge dewatering systems normally involve feeding a machine with the liquid sludge that has been dosed with polymer. The polymer binds the sludge in order to make the process more effective. However, regardless of the mechanical process used for dewatering, it has become a standard practice to condition the sludge prior to dewatering [2]. So, normally sludge dewatering is preceded by chemical conditioning in order to enhance sludge dewaterability. Chemicals conditioning will result in coagulation of the solids and release of the absorbed water. The process usually consists of the addition of destabilizing chemicals, followed by flocculation and filtration. More serious technical and economical problems are related to the choice of the polyelectrolyte and the control of its optimum dose under different operating conditions. In most cases, conditioning chemicals are the largest single-cost component of the sludge management process [3]. This being the case, any attempt to reduce wastewater treatment cost should focus on economizing the sludge management aspects in general and reducing the amount spent on conditioning chemicals in particular. Considering the high conditioner costs, it makes sense to continually monitor and evaluate the performance of conditioning chemicals used. Polymer has been used to produce large flocs of sludge particles and higher porosity for easy draining by the bridging effect of long-chain polyelectrolytes in coagulation [4]. Also, an experimental study was conducted on municipal sludge dewatering capacity using quicklime and slag [5]. Polyelectrolytes are classified into anionic (negatively charged), cationic (positively charged), and nonionic (no charge). Polyelectrolyte is available in a wide range of molecular weights and charge densities. So, the type of conditioner selection and the optimal dosage used are very important in predicting the performance of the dewatering mechanical process. Different dosages of inorganic flocculant ($AlCl_3$) were investigated but inorganic coagulants and polyelectrolytes were used for conditioning of sonicated and nonsonicated sewage sludges. The impact of conditioning process on the sludges rheological parameters and dewatering process were studied too [6,7].

On the other hand, *Moringa oleifera* seeds as an alternative natural conditioning material during dewatering were evaluated [8]. Also, studies on the synthesis and characterization of a dewatering reagent: cationic polyacrylamide (P(AM–DMC–DAC)) for activated sludge dewatering treatment beside others on the potential of residue biochar derived from copyrolysis of dewatered sewage sludge (80% of moisture content (MC)) and pine sawdust for the adsorption of methylene blue from aqueous solution were conducted too [9,10].

This is study focuses on studying the effectiveness and determination of optimal dosage of cationic, anionic, and nonionic polymers used in conditioning of sewage sludge including determination of optimum mixing speed and optimum duration for each polymer used in conditioning operation.

## 2. Materials and methods

In this study, the sludge samples were collected from the sludge holding tank located at the treatment plant of Taman Tun Datuk Ismail area, Kuala Lumpur, Malaysia. Flow to the concrete sludge tank is continuous and sludge is kept in the tank for a period between 30 and 60 d. The samples were collected in a 10-L plastic container from locations slightly below the surface of the sludge holding tank (Fig. 1). To avoid aging that will affect the dewaterability of the sludge, the samples were then refrigerated to 4°C within 1 h before conducting the experiments. This

Fig. 1. Sewage sludge collection point.

made all samples to have the same temperature before starting laboratory analysis.

The methodology can be divided into three phases which are phase 1: sludge characterization, phase 2: optimizing the dosage of polymer, and phase 3: sludge conditioning optimization test. An overall experimental design and the components of each phase are shown in Fig. 2.

## 2.1. Sludge characterization (Phase 1)

### 2.1.1. pH measurement

The pH of the sludge should be measured because it will affect the surface charge of the sludge particles. Hence, pH will influence the type of polymer to be used for conditioning of sludge. The test procedure given by Standard Methods for the Examination of Water and Wastewater is used for pH measurements. The pH of the sludge samples were determined by using pH meter, (pH 500 bench Cyberscan USA). Before the sludge samples were tested, calibration test was first carried out to ensure the accuracy of measurement.

### 2.1.2. Solids measurement

Solids is the most important physical characteristic in wastewater which is composed of floating matter, matter in suspension, colloidal matter, and matter in solution. It is important to analyze solids in wastewater because of the control of biological and physical wastewater treatment processes and for assessing compliance with regulatory agency wastewater effluent limitation. The test procedure of solids measurement is according to Standard Methods for the Examination of Water and Wastewater.

### 2.1.3. Total solids (TS)

Total solids (TS) content in wastewater is defined as all matter that remains as residue upon evaporation at 103–105˚C. TS or residue upon evaporation can be classified as either suspended solids or filterable solids by passing a known volume of liquid through a filter. A well-mixed sludge sample was poured into the clean glass dish using the measuring cylinder. The dish was then put in the oven and heated to up to 105˚C until it is fully dried. The dish was taken out from the oven and cooled in the desiccator. The dish with the sludge residue was weighed using the analytical balance and following equation was used to determine the TS in the sample.

$$\mathrm{CS} = \frac{W_1 - W_2}{V_s} \tag{1}$$

where CS is the concentration of solids in mg/l (it is either TS, dissolved solids, or suspended solids), $W_1$ is the weight of dried residue at the required temperature plus the weight of the dish in mg, $W_2$ is the weight of dish in mg, and $V_s$ is the volume of the sample in liter.

### 2.1.4. Total dissolved solids (TDS)

The total dissolved solids (TDS) consist of colloidal and dissolved solids. The colloidal fraction consists of

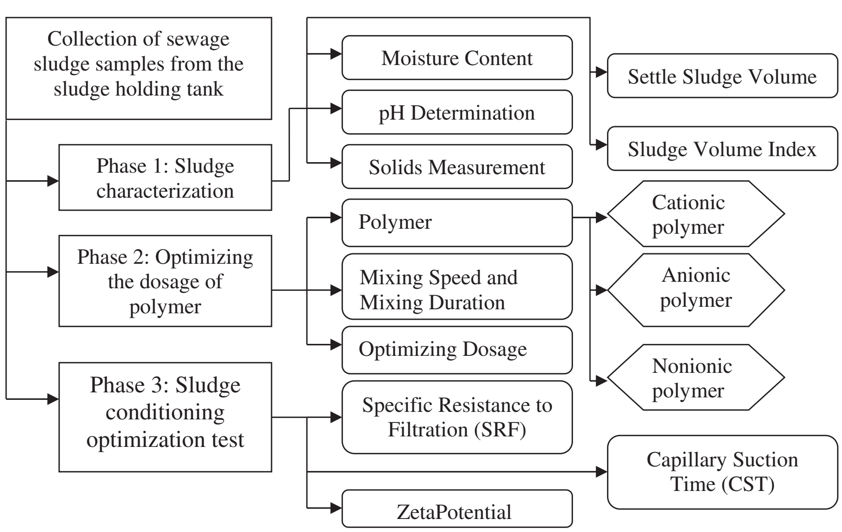


Fig. 2. The experimental design.

the particulate matter with an approximate diameter range of from 1 millimicron (mμ). It cannot be removed by settling but it can be removed by biological oxidation or coagulation followed by sedimentation. TDS is the portion of solids that passes through a filter of 2.0 μm (or smaller) nominal pore size under specified conditionals. A wellmixed sample was filtered through a standard glass fiber filter, transferred into evaporating dish (ceramic dish) and dried for about an hour in the oven at 180˚C. The dish was taken out from the oven and cooled in the desiccator and the TDS of the sample were determined using Eq. (1).

#### 2.1.5. Total suspended solids (TSS)

The total suspended solids (TSS) include solids that will be settled in the bottom of a cone-shaped container which is called Imoff cone in a 60-min period. The minimum diameter of the suspended solids is about 1 micron (μ). Settleable solids are an approximate measure of the quantity of sludge that will be removed by sedimentation. A total suspended solid is the portion of TS retained by a filter. A well-mixed sample was filtered through a standard glass fiber filter, transferred into evaporating dish (ceramic dish) and dried it in the oven at 105˚C for 1 h. The dish was taken out from the oven and cooled in the desiccator and the TSS of the sample was determined using Eq. (1).

#### 2.1.6. Moisture content (MC)

Five grams of sludge in a previously weighed glass dish were put in the oven and heated up to 105˚C for 24 h. The sludge was weighed again after it was dried in the oven. The glass dish and its residue were cooled and weighted. The weights were used to determine MC of the sample.

#### 2.1.7. Settle sludge volume

The settle sludge volume is useful in routine monitoring of biological process. A 1.0 L of sludge sample was placed in settling column and the cylinder was covered and then inverted for three times to distribute the solids evenly. The sludge suspension was allowed to settle and the height of sludge–liquid interface at measured time interval was monitored.

#### 2.1.8. Sludge volume index

The sludge volume index was used to monitor settling characteristics of the sludge sample. Sludge volume index was calculated using the following equation:

$$\mathrm{SVI} = \frac{\mathrm{SSV\ (mL/L)} \times 1000}{\mathrm{SS\ (mg/L)}} \tag{2}$$

where SSV is the settled sludge volume and SS is the suspended solids.

### 2.2. Optimization of polymers dosage (Phase 2)

#### 2.2.1. Preparation of polymer solution

The cationic polymer (MAGNAFLOC LT 22S), anionic polymer (MAGNAFLOC LT 27 and MAGNAFLOC LT 25), and also nonionic polymer (MAGNAFLOC LT 20) were used in this study. All polymers are in powder form. Polymer properties were listed in Table 1. About 0.5 g of powder and 100 ml of water was poured rapidly into the beaker and the contents were mixed well to complete the solution preparation. So, 0.5% solution of the product was produced. Further dilution was obtained by applying Eq. (3) to get the desire concentration of the conditioner:

$$C_1 \times V_1 = C_0 \times V_0 \tag{3}$$

where $C_1$ is the required concentration, $V_1$ is the required volume, $C_0$ is the stock solution concentration, and $V_0$ is the stock solution volume.

#### 2.2.2. Mixing speed and mixing duration

Jar test was used to mix the sludge where sludge samples of 300 mL in a 500-mL beaker were placed on the stirring machine which was operated at the required constant of mixing. For optimization of mixing speed, the duration of mixing, and polymer dosage were determined using response surface method (Software: DESIGN EXPERT, Version 6). A total of 17 runs were required to be conducted on cationic polymer. However, the similar runs were not conducted on anionic and nonionic polymer. The mixing speeds used were from 30 to 100 rpm, whereas the durations of mixing were fixed between 1 and 15 min. The dosages of the cationic polymer were fixed between 4 and 10 mg/L. Jar tests, which rely on visual observation, were used for an initial screening of conditioning chemicals. However, to evaluate conditioner performance or dewaterability in detail, parameters such as SRF and capillary suction time (CST) provide a much reliable option.

Table 1
Polymer properties used in this study

| Name of polymer | Ionic charge | Effective pH range | Molecular weight |
|---|---|---|---|
| MAGNAFLOC LT 22S | Medium cationic (30%) | 4–9 | Ultra-high |
| MAGNAFLOC LT 27 | Medium anionic (30%) | 5–10 | Ultra-high |
| MAGNAFLOC LT 25 | Medium to low anionic (25%) | 5–10 | High |
| MAGNAFLOC LT 20 | Nonionic | 0–5 | High |

#### *2.2.3. Optimum dosage*

In order to get the optimum dosage of the polymer used, jar test followed by the CST test was carried out. The range of 0–100 mg/L with interval dosages of 10 mg/L is chosen to get a minimized range of the optimal dosage of polymer used. Then, a 5 mg/L interval dosage was used. Lastly, the interval was minimized to 1 mg/L in order to get the exact optimal dosage of the polymer. This test was carried out for cationic polymer, anionic polymer, and nonionic polymer, respectively.

### *2.3. Sludge conditioning optimization test (phase 3)*

#### *2.3.1. Zeta potential*

Zeta potential is used to measure the electrical charge at the surface of solid sludge particles in order to evaluate particle stability and effective flocculation. The zeta potential of sludge was measured using Zeta-Meter 3.0+ before and after the sludge conditioning. Resulted supernatant was collected for zeta potential measured. The zeta meter was switched on and the “function” switch was turned to “standby.” After the cell was cleaned with distill water, the sample was poured into the cell and the electrode leads was attached to electrodes. The specific conductance, average of zeta potential, and standard deviation of the sludge samples were read on the display screen on the meter. The procedure was according to the Operation Manual for Zeta-Meter 3.0+.

#### *2.3.2. Capillary suction time (CST)*

The CST test was performed by placing a sludge sample in an upright metallic cylinder, or sludge reservoir, resting on a chromatography grade paper. The capillary suction of the paper extracted the liquid from the sludge, wetting the paper. The time required for the filtrate to flow 1 cm readily was recorded as the CST [11]. The CST test is to determine the rate of water release from sludge. It provides a quantitative measure, reported in seconds, of how readily sludge releases its water. The results were used to assist in sludge dewatering process and to evaluate sludge conditioning aids and dosages. The CST value was measured using CST apparatus (Model Type 319 with Multi-Radii Test Head including funnel) with specific diameter cylinder (from 2.0 cm) and a unique CST filter paper (7 × 9 cm) [12]. The filter paper was placed between the upper and lower plastic test blocks. The stainless steel cylinder was placed inside the cavity in the test head. The timer case was turned on and 7–8 mL of the sludge sample was withdrawn using a large bore pipette and slowly dispensed inside the metal cylinder. The filtrate from the sludge was absorbed outward on the filter paper. The CST, in seconds, was read directly from the timer display.

#### *2.3.3. Specific resistance to filtration (SRF)*

Specific resistance is numerically equal to the pressure required to produce unit rate of flow through a cake having unit weight of dried solids per unit area, when the viscosity of the liquid is unity [13]. SRF is a method widely used to monitor the effects of chemical conditioning. The SRF test was performed using a standard Buchner funnel apparatus with a Whatman No. 1 filter paper [12]. A Whatman No. 1 filter paper was moistened and placed inside the Buchner funnel. The vacuum pump was turned on, and 100 mL of sludge was gently poured into the Buchner funnel and filtered with a constant vacuum pressure of 51 kPa. A stopwatch was started simultaneously. Time to filtrate was noted as the time taken for 40 mL of filtrate to accumulate in the cylinder. A minimum of three replicates are to be determined. By gathering bench data on Buchner filtration time and filtrate volume, and combining these with actual filter pressure, filter area, sludge solids concentration, and filtrate viscosity, the resistivity of the sludge was calculated using the following equation:

$$r = \frac{2bPA^2}{wc} \tag{4}$$

where $b$ is the slope of filtrate time vs. filtrate volume (sec/m$^2$), $P$ is the filtration pressure (N/m$^2$), $A$ is the area (m$^2$), $w$ is the viscosity (Ns/m$^2$), $c$ is the weight of solids/unit volume of sludge prior to filtration (kg/m$^3$), and $r$ is the specific resistance (m/kg).

## 3. Results and discussion

Jar tests, which rely on visual observation, can be used for an initial screening of conditioning chemicals. However, when there is a need to evaluate conditioner performance or dewaterability in detail, parameters such as SRF or CST provide a much more reliable option. In this study, the determination of mixing speed, mixing duration, and optimum dosages in conditioning of domestic sewage sludge were based on the evaluation of the sample dewaterability potential and was conducted based on dewaterability parameters. Hence, it was necessary to define the criteria applied in interpreting these parameter values.

### 3.1. Characteristics of the sewage sludge

The characteristics of the raw sludge from the sludge holding tank within a period of 4 months were studied. After the samples were analyzed in the Public Health Laboratory, Department of Civil Engineering, Universiti Putra Malaysia the summary of the sludge characteristics are shown in Table 2.

### 3.2. Determination of polymers dosage

The optimization of the dosage of polymers was conducted using Jar test and by measuring the CST value of the conditioned sludge. The primary purpose of this CST test is to indicate the sewage sludge filterability. The water in sludge structure was drained out during the CST test, which resulted in different CST values. Basically, the CST values are depending on the filterability of the sample. Higher CST value means that ease to filtrate the sample is lower. On the other hand, lower CST value indicates that ease to filtrate the sample is higher. So, if the sample is too thick, it will give higher CST value compare to the sample with better conditioned dosage. The synthetic polymer used in this study may condition the sludge by charge neutralization due to its high charge density or by bridging due to its high molecular weight [14].

### 3.3. Cationic polymer

The mixing speed and mixing duration were first fixed at 30 rpm and 2 min, respectively [14]. The first trial of finding the optimum dosage of cationic polymer (Magnafloc LT 22 S) was fixed using the range between 10 and 50 mg/L [15]. From Fig. 2, the dosage of the cationic polymer is increasing after 10 mg/L which means the optimum dosage of the cationic polymer was fell within the range between 1 and 10 mg/L. The increase in CST value with the increase in polymer dosages showed that there was an overdosing situation. Overdosing will attribute to an increase in filtrate viscosity caused by excess polyelectrolyte [16]. As a result, the range to find the optimum dosage of the cationic polymer is narrow down from 1 to 10 mg/L as shown in Fig. 2. Based on the result shown in Fig. 3, the optimum dosage for cationic polymer was between 6 and 7 mg/L which produced CST of 4.3 s. As a result of optimizing cationic polymer dosages, the experiments were carried out from the dosages within the range of 4–10 mg/L. So, 17 experiments for cationic polymer were carried out for the dosage between 4 and 10 mg/L.

Table 2
Range of the overall raw sludge samples characteristics from sludge holding tank

| Characteristics | Range |
|---|---|
| pH | 6.23–6.89 |
| Temperature (°C) | 27.7–29.4 |
| SSV (mL/L) | 990–1,000 |
| SVI | 110.09–300.30 |
| MC (%) | 98.99–99.66 |
| TS (mg/L) | 3,600–10,020 |
| TSS (mg/L) | 3,310–9,080 |
| TDS (mg/L) | 70–260 |
| Corrected ZP (mV) | −12.8 to −19.1 |
| CST (s) | 5.4–9.3 |
| SRF (× $10^{11}$ m/kg) | 2.00–6.94 |

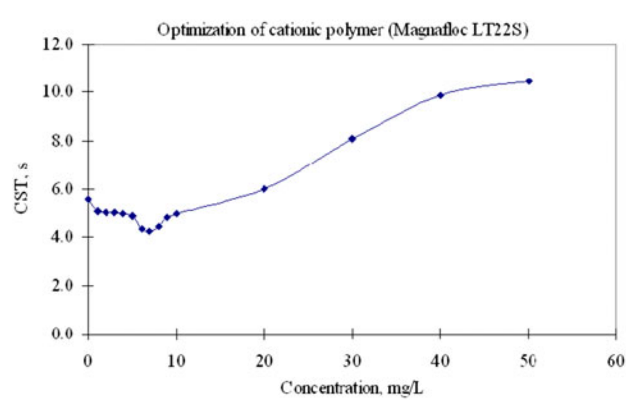


Fig. 3. Optimization of cationic polymer (Magnafloc LT 22S) (10–50 mg/L).

### 3.4. Anionic polymer

The range of the first trial to find the optimum dosages of the anionic polymer of Magnafloc LT 27 (30% ionic charge and ultra-high molecular weight) and Magnafloc LT 25 (25% of ionic charge and high molecular weight) was fixed between 10 and 50 mg/L with the interval of 10 mg/L as shown in Fig. 3 using the same mixing speed of 30 rpm and mixing duration of 2 min which was used with cationic polymer. The optimum dosage was found not within the above range. So, the range was further narrowed down to an interval between 1 and 10 mg/L. However, Fig. 4 shows rising in CST values with the rising concentration. It is found that the anionic polymers of Magnafloc LT 27 and Magnafloc LT 25 had no effect in conditioning the sewage sludge. The rising of CST value shows that the anionic polymer is further thickened the sewage sludge sample due to the increment in concentration of the anionic polymer and decrease of the filterability of the sample as supported by published literature [16]. On the other hand, the sludge sample was found with negative charge, meaning that the anionic polymer had no effect on neutralizing the negative charge of the sludge polymer. Also, the anionic polymer dosages will not reduce the CST value, so it is not necessary to carry out further test on the anionic polymer. The increase in CST values during the conditioning process indicates that the anionic polymer causes the excess polyelectrolytes in sludge sample. In this study, it can be concluded that the anionic polymer do not have any effect on sludge conditioning.

### 3.5. Nonionic polymer

Fig. 5 shows the optimum dosage of nonionic polymer for conditioned sludge sample. It also shows that

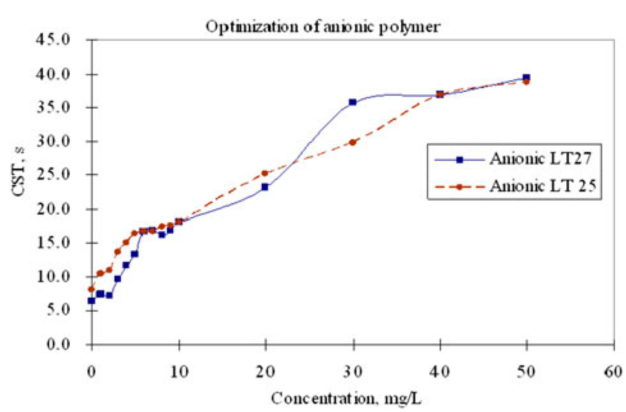


Fig. 4. Optimization of anionic polymer (Magnafloc LT 27 and LT 25).

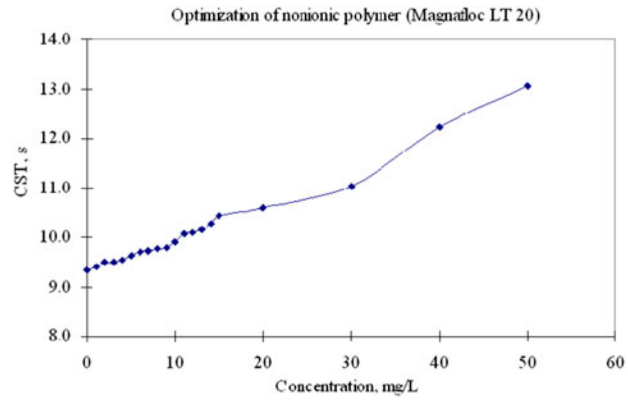


Fig. 5. Optimization of nonionic polymer (Magnafloc LT 20).

the nonionic polymer had no conclusive results in determining the optimum dosage in conditioning of sewage sludge. The range to find the optimum dosages of the nonionic polymer of Magnafloc LT 20 was first fixed between 10 and 50 mg/L with an interval of 10 mg/L [15]. The mixing speed and mixing duration used were same as that used in the optimization of cationic and anionic polymers tests where mixing speed of 30 rpm and mixing duration of 2 min were used. Fig. 4 shows an increasing in CST values indicate that optimum dosage was not found within the entire tested range. So, the range was narrowed down with an interval of 1 mg/L range of 1–15 mg/L. Results show that an increase in CST values indicate that the optimum dosage was not fall within the entire range. The CST value was rising as of the concentration of nonionic polymer increase from 10 to 50 mg/L. It was found any further increment in the nonionic polymer dosages would increase CST value. This is because the nonionic polymer possesses no charge; it cannot neutralize the negative charge on the sludge samples [17]. It is found that further increment in nonionic polymer dosages will not reduce the CST values. So, it is not necessary to carry out further tests on the nonionic polymer. Also, increment in the CST values show that nonionic polymer is further thickened the sewage sludge sample due to the increase in the concentration of the nonionic polymer and decrease in the filterability of the sample.

### 3.6. Comparison of optimization results

The overall results obtained with the synthetic polymer of cationic, anionic, and nonionic polymer as shown in Fig. 6. It can be seen that cationic polymer is the most effective used in sewage sludge conditioning.

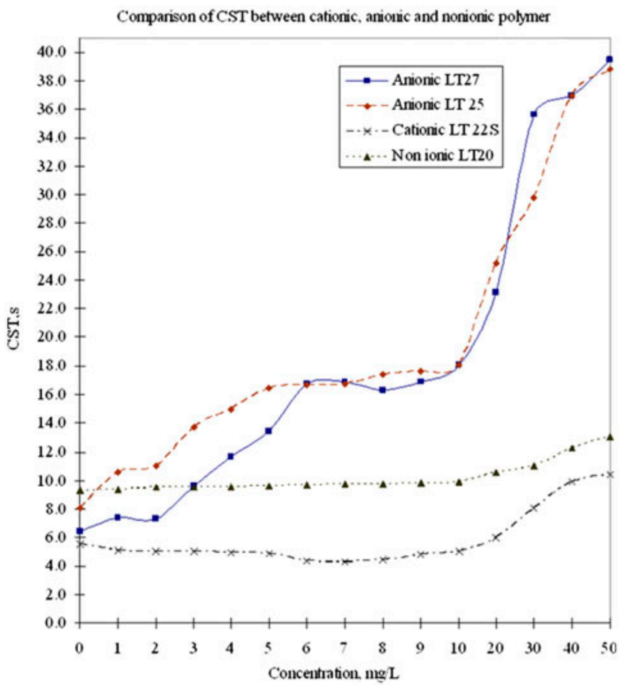


Fig. 6. Comparison of optimization between cationic, anionic, and nonionic polymer.

Fig. 6 had shown an optimum CST value (4.3 s) using the cationic polymer at polymer concentration of 7 mg/L compared with the raw sludge CST value which is 5.6 s. In the meanwhile, the anionic and nonionic polymer did not give optimum dosages where the CST values were increased when the dosage of both polymers were increased too.

### 3.7. Determination of optimum cationic polymer dosage, CST, SRF, and ZP

The optimum condition of optimization of mixing speed, duration mixing, and polymer dosage was determined using response surface method (Software: DESIGN EXPERT, Version 6). The total of 17 runs was required to be conducted on the conditioning using cationic polymer. The 17 experiments were conducted using cationic polymer after conditioning with the dosages range between 4 and 10 mg/L, mixing speed range between 30 and 100 rpm, and the mixing duration range between 1 and 15 min. The low and high levels for each factor were randomly distributed with the experimental conditions. The performances of dewaterability of the samples were indicated by the measurement of CST and SRF. The reduction on CST and SRF values shows that the samples have an improvement on the dewaterability after the conditioning of the sample with cationic polymer. The main purpose of measuring the zeta potential parameter is to observe the charge transitions and not to affect the dewaterability performance of the samples. The solution to find the optimum mixing speed, optimum mixing duration, and also optimum dosages of cationic polymer in terms of minimum of CST and SRF value was shown in Table 3. From the economical point of view, the solution number 8 is the best choice because the dosage used is only 5.3 mg/L if compared to the solution number 9, which is using 5.5 mg/L but getting the same CST value. Besides, from the academic point of view, solution number 8 consists of a moderate mixing duration and speed which are 4.5 min and 83 rpm, respectively which means that the time used by this combination is not too long as solution number 1, 2, 3, 4, 5, 6, and 7, but it is longer compared to number 9. Consequently, the best-selected combination of optimum mixing speed, optimum mixing duration, and optimum dosages of cationic polymer in terms of minimum of CST and SRF value was solution number 8 with dosage of 5.3 mg/L, mixing speed of 83 rpm, and mixing duration of 4.5 min. The optimum values were found within the recommended values.

Table 3
The combination of optimum mixing speed, optimum mixing duration, and optimum dosages of cationic polymer

| Number | Dosage (mg/L) | Duration (min) | Speed (rpm) | SRF (m/kg) | CST (s) | Zeta potential ($\times 10^{-5}$ mV) |
|---|---|---|---|---|---|---|
| 1 | 5.6 | 15.0 | 100 | $9.07 \times 10^{10}$ | 5.7 | −1.49 |
| 2 | 5.6 | 15.0 | 95 | $8.07 \times 10^{10}$ | 5.7 | −1.94 |
| 3 | 4.8 | 15.0 | 55 | $3.56 \times 10^{10}$ | 5.8 | −1.58 |
| 4 | 4.9 | 15.0 | 59 | $4.12 \times 10^{10}$ | 5.8 | 1.79 |
| 5 | 4.3 | 13.2 | 45 | $5.99 \times 10^{9}$ | 5.8 | −2.06 |
| 6 | 5.2 | 14.1 | 71 | $4.09 \times 10^{10}$ | 5.8 | 2.42 |
| 7 | 4.9 | 7.1 | 69 | $1.07 \times 10^{9}$ | 5.9 | 2.03 |
| 8 | 5.3 | 4.5 | 83 | $1.16 \times 10^{8}$ | 6.0 | 4.38 |
| 9 | 5.5 | 2.1 | 94 | $2.94 \times 10^{9}$ | 6.0 | −2.76 |

Table 4
The effectiveness of cationic polymer used in sludge conditioning

| Types of sludge | Performances | | |
|---|---|---|---|
| | CST (s) | SRF (m/kg) | Zeta potential (mV) |
| Raw sludge | 7.9 | $5.28 \times 10^{11}$ | −13.4 |
| Conditioned sludge | 6.0 | $1.16 \times 10^{8}$ | $4.38 \times 10^{-5}$ |
| Effectiveness (%) | 24.1 | 99.8 | 99.9 |

### *3.8. Testing the effectiveness of cationic polymer in sludge conditioning*

The optimum condition when mixing speed, mixing duration, and cationic polymer dosage was 83 rpm, 4.5 min, and 5.3 mg/L, respectively, was found to reduce the raw sludge CST value by 24.1%, the SRF value by 99.8%, and also to increase the raw sludge zeta potential value by 99.9% as shown in Table 4. This optimum condition is applicable within the sludge temperature ranged from 27.7 to 29.4˚C, the settled sludge volume ranged from 990 to 1,000 mL/L, and also the pH ranged from 6.23 to 6.89.

## 4. Conclusions

Basically, there are three main factors affecting the conditioning of the sewage sludge using synthetic polymer. The three factors are mixing speed, mixing duration, and dosages of the synthetic polymer. Three different types of synthetic polymers were tested and these are cationic, anionic, and nonionic which show different dewaterability efficiencies. From the conducted work, the followings conclusions can be drawn:

(1) The optimum dosage cationic polymer for conditioning of domestic sewage sludge using cationic polymer (Magnafloc LT 22S) was found to be 5.3 mg/L, while the values of associated mixing speed and mixing duration were 83 rpm and 4.5 min, respectively. Also, the optimum values of CST and SRF were found to be 6.0 s and $1.16 \times 10^{8}$ m/kg, respectively.

(2) The effectiveness of cationic polymer used in conditioning of sewage sludge at optimal dosage (5.3 mg/L) for dewatering was evaluated by CST and SRF. Reduction of 24.1 and 99.8% were obtained in the values of CST and the SRF of the raw sludge, while the zeta potential indicated charge neutralization compared with the anionic and nonionic polymers which have no effect in conditioning of sewage sludge.

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