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Dual polyelectrolytes incorporating *Moringa oleifera* in the dewatering of sewage sludge

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ABSTRACT

One of the main costly problems at wastewater treatment plants is the treatment of sludge, which is responsible for about 50% of the total operating cost of the whole treatment system. Chemical conditioning of sludge before dewatering is often necessary to increase the process efficiency of dewatering devices. *Moringa oleifera* seeds were evaluated as an alternative natural conditioning material during dewatering; as a single conditioner and as a base conditioner in dual polyelectrolytes conditioning (using Zetag 8140) for sewage sludge dewatering. The sewage sludge used in the experiments was collected from a sludge holding tank of the treatment plant located in Taman Shamelin Perkasa, Kuala Lumpur, while the *M. oleifera* seeds were collected from Serdang, Selangor, and stored in a room temperature for not more than 3 d, and then the quality seeds were identified and used. The preparation of the stock solution will start with placing the seeds in the oven for 24 h at 50˚C. After drying, the seeds were shelled and blended before use. The stock solution was prepared by using 50 g of *M. oleifera* powder with 1 L of distilled water to get a stock solution of 5,000 mg/L. Capillary suction time (CST), specific resistance to filtration, zeta potential, settled sludge volume, and sludge volume index (SVI) were used to evaluate the performance as a single conditioner and dual or co-conditioner in sludge dewatering. The lowest CST achieved using *M. oleifera* as a single conditioner was 7.1 s corresponding to a 5,000 mg/L dosage compared to 5.5 s achieved by using Zetag 8140 alone with a dosage of 13 mg/L. In dual polyelectrolytes conditioning, the minimum CST achieved was 4.6 s with a dosage of 2,000 mg/L *M. oleifera* and 9 mg/L of Zetag 8140. It can be concluded that at low dosages, dual polyelectrolytes show better conditioning compared with the use of *M. oleifera* as a single conditioner.

Keywords: Dual polyelectrolytes; *Moringa oleifera*; Dewatering; Sewage sludge; Conditioning

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1. Introduction

Sewage sludge is a liquid or semisolid product resulting from the physical separation, and biological and chemical treatment of wastewater [1]. It typically contains from 0.25 to 12% solids by weight, depending on the wastewater treatment operations and process used [2]. However, sludge can also contain substantial nutrients and organics.

In the recent past, treatment and disposal of sewage sludge have become an expensive and environmentally sensitive problem in western countries. Also, it is becoming a growing problem worldwide with its focus on the megacities in the newly developed countries, since sludge production will continue to increase as new sewage treatment plants are built and environmental quality standards become more stringent.

Large amount of sludge is produced in Malyasia as a result of the increasing development. As stated by the Indah Water Consortium (IWK), the sludge is projected to increase from 3.4 million m^3 in the year 1998 to 4.71 million m^3 in year 2007 as shown in Table 1. Therefore, land and time are urgently needed to treat and dispose the produced sludge. It is projected that by the year 2020, the increment in sludge production is 41.5% [3].

Sludge consists of mixture of wastes from homes, commercial establishments, and local industries. Although mostly water form 94 to 99%, sludge may also contain a wide variety of materials that could be harmful in concentration and that often must be substantially removed prior to discharge. The sludge has to be treated for safe disposal.

The sludge contains from 0.25 to 12% solid, and the remaining percentage is water. Therefore, dewatering process is an urgent necessity in sludge treatment. Usually, dewatering is followed the conditioning and thickening of sewage sludge process.

Table 1
Total sludge production in Malaysia [3]

Year	Total population	Total volume (m^3)
1994	13,226,865	3,018,281
1995	13,491,402	3,078,647
1996	13,761,230	3,140,220
1997	14,036,455	3,235,197
1998	14,317,184	3,400,765
1999	14,603,528	3,531,173
2000	14,895,589	3,665,437
2001	15,193,510	3,803,659
2002	15,497,380	3,957,376
2003	15,807,328	4,037,385
2004	16,123,475	4,156,448
2005	16,445,944	4,330,237
2006	16,774,863	4,462,807
2007	17,110,360	4,712,468

Sludge treatment is a costly operation, often responsible for approximately 50% of the total operating cost of the whole wastewater treatment plant [4,5].

The sludge was typically gravitationally thickened and stabilized in anaerobic or aerobic digesters and then mechanically dewatered at a dewatering device, such as centrifuge, belt press, and filter press. Among the different press types, filter press has received widespread application due to its reliability and in-depth dewatering ability. The sludge cake from a filter press holds a solid concentration higher than that from any other mechanical dewatering equipment, thereby favoring the following transportation and disposal of sludge [6].

The chemical conditioning of sludge before dewatering is often necessary to increase the processing efficiency of dewatering device. Conditioning aims to enlarge the floc size and to compress the floc interior to facilitate solid–liquid separation.

In recent years, polyelectrolytes have become a primary choice as a conditioner for sludge dewatering operations. Conventionally, a single polyelectrolyte is used in sludge conditioning in which two main mechanisms are involved: charge neutralization and interparticle bridging. However, recently there have been several studies on dual polyelectrolyte systems to improve flocculation of particles in water and wastewater treatment [7].

The *Moringa oleifera* seed extract was used for coagulation in water treatment [8–12]; also used for sludge conditioning [13–15].

Common conditioners include ferric chloride, lime, aluminum sulfate, polyelectrolytes, fly ash, magnesium carbonate, etc. The production of these chemicals is often associated with high cost due to nonavailability of the raw materials. Therefore, it is necessary to search for local raw materials that have conditioning potential. It would be an added advantage if local materials could be used without processing [13].

The aim of this study is to evaluate the usage of *M. oleifera* seeds as a natural conditioner for sludge dewatering as a single conditioner and as a base conditioner in dual polyelectrolytes.

In this study, sludge dewatering was conducted using *M. oleifera* as a natural conditioner and the polymer Zetag 8140 as a synthetic conditioner.

The evaluation was done by measuring and comparing capillary suction time (CST), specific resistance to filtration (SRF), zeta potential (ZP), settle sludge volume (SSV), and sludge volume index (SVI).

2. Materials and methods

In this study, the methods include collecting, characterizing of raw sludge samples, conditioning using single conditioner (natural and synthetic), and conditioning using dual polyelectrolytes.

The sludge was collected from sludge holding tank of the sewage treatment plant located at Taman Shamelin Perkasa, Kuala Lumpur. Samples were taken from several well-mixed points within the tank. Secondly, the sludge was collected into a 9 L container and delivered to the laboratory within 1 h and stored at 4˚C for less than 10 d to minimize the changes in sludge characteristics due to microbial activity.

In this study, *M. oleifera* was chosen as a natural conditioner, and Zetag 8140 was chosen as a synthetic polymer for sludge conditioning.

M. oleifera was collected from a housing area in Serdang. Good quality seeds were identified from those, which were not rotten, old, and infected with diseases, but brownish and dried seeds were opened. Only the matured *M. oleifera* was plucked from the tree. The seeds were removed from the pods and oven-dried for 24 h at 50˚C. After drying it, the seeds were shelled and blended. The stock solution would be prepared fresh for use to avoid deterioration.

Stock solution was prepared by using 50 g of *M. oleifera* seed powder added to 1 L of distilled water. This gave a stock solution of 50,000 mg/L of *M. oleifera*. The powder did not dissolve fully by stirring. Hence, it was blended again for a minute. For the synthetic polymer, 1 g of Zetag 8140 powder was added to 1 L of distilled water. This gave a stock solution of 1,000 mg/L of Zetag 8140. After a mixing period of approx 1 h, the solution became ready for use.

A raw sludge of 400 ml was used for to conduct characteristic tests. Parameters for sludge characteristics include pH, temperature, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), CST, SRF, ZP, moisture content, SSV, and SVI.

Conditioning process was done by using jar test apparatus. In the case of single conditioning process, the precalculated dosage was added and mixed at 100 rpm for 1 min. However, in the case of dual conditioning, the precalculated dosage of Zetag 8140 was added to the sludge volume and stirred for 30 s at 100 rpm, and then *M. oleifera* dosage was added and mixed for 1 min at 100 rpm.

3. Results and discussion

Tests were carried out in the public health laboratory, Department of Civil Engineering and in the environmental laboratory, Faculty of Engineering, Universiti Putra Malaysia.

3.1. Optimization of polymer dosages

To optimize sludge conditioning, sludge dewatering characteristics such as CST, SRF, and ZP must be carefully monitored. CST represents the filterability, while SRF represents the permeability.

In operation, CST result was affected by overdosing of sludge conditioning [16].

On the other hand, the process of SRF is similar to the operation of a filter press. Large errors are generally encountered when dealing with the sludge of low solid content.

To truly reflect the efficiency of sludge conditioning, the monitored dewatering index must have a good correlation with the final water content of the sludge cakes. In this section, activated sludge samples were conditioned with various amounts of synthetic and natural polymers.

In general, the dewaterability through centrifuge can be represented by the CST values, because in both operations, no pressure is exerted on flocs. CST is not a reliable index for filter press or the belt press because pressure is exerted on flocs when a belt press and filter press are used for dewatering. Since no pressure is given in the process of CST measurement, the CST value cannot reflect the strength of the floc and therefore the filterability of the sludge.

On the other hand, SRF is a better option for filter press dewatering because of the similar filtration behavior. Very inconsistent results are associated with belt press dewatering. No conclusion can be made for the belt press, mostly due to the great experimental error involved in the scrapping of sludge cake from the belt.

Therefore, choosing suitable optimization dosage test either CST test or SRF test is more dependent on the dewatering equipment.

3.2. Capillary suction time

Results of CST are shown in Figs. 1 and 2. The optimal dosage achieved using natural polyelectrolyte *M. oleifera* is 5,000 mg/L corresponding to 7.1 s CST value as shown in Fig. 1. Any further increase beyond the optimal dosage does not enhance the dewaterability. This overdosing caused destabilization of the particles due to insufficient number of particles to form more interparticle bridging [17].

The optimal dosage for synthetic polyelectrolyte Zetag 8140 was 13 mg/L as shown in Fig. 1, and the

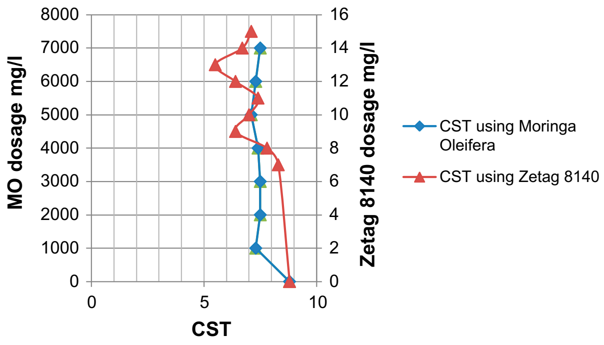

Fig. 1. Capillary suction time (CST) using single polymer.

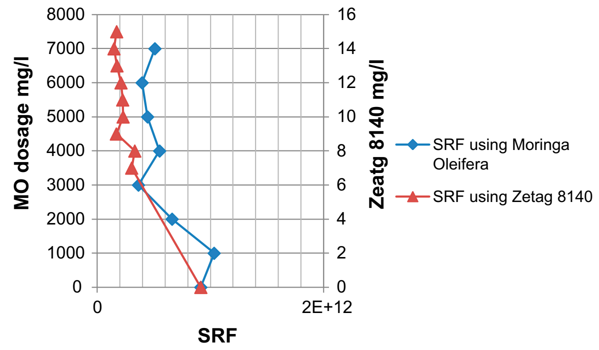

Fig. 3. SRF using single polymer.

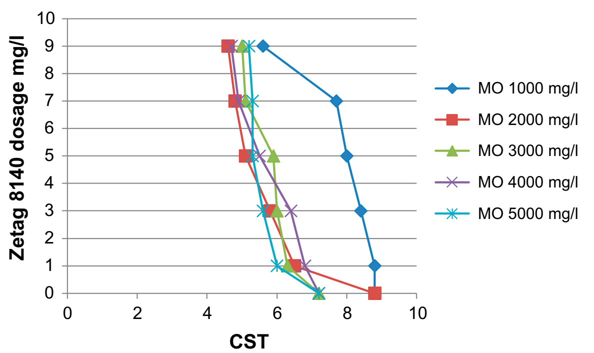

Fig. 2. CST using dual polyelectrolytes.

corresponding CST was 5.5 s. Any further increase in dosage of Zetag 8140 result in decreasing the sludge dewaterability. However, in Fig. 2., in the case of dual polyelectrolytes, the sludge preconditioned with Zetag 8140 and followed by *M. oleifera* showed a better dewaterability at 9 mg/L of Zetag 8140 dosage and 2,000 mg/L of *M. oleifera* dosage to achieve CST value of 4.5 s. Any further increment in *M. oleifera* concentration did not improve the dewaterability of sludge. In addition, the overdose was found to occur when the *M. oleifera* seeds dosage exceeded 2,000 mg/L. From the CST result, the combination of *M. oleifera* seeds and Zetag 8140 gave a better result than single polyelectrolyte (either *M. oleifera* seeds only or Zetag 8140 only).

3.3. Specific resistance to filtration

From Fig. 3 the optimal dosage achieved using *M. oleifera* was 3,000 mg/L, while the corresponding SRF was 3.648×10^{11} m/kg. The overdose was found when the dosage of *M. oleifera* increased beyond the optimal value. This is because if the dosage increases, the specific resistance also increases, which means that the polymer would not be efficient in increasing the dewaterability process of sludge sample. The optimum dosage of *M. oleifera* seeds was found in agreement with that of previously used [18]. The optimal dosage for Zetag 8140 was 14 mg/L, and the corresponding SRF was 1.487×10^{11} m/kg. There was no significant change of SRF with any further increase in 8140 dosage. On the other hand, for sludge preconditioned with dual polyelectrolytes (Zetag 8140 followed by *M. oleifera*), the SRF decreased up to a dosage combination of 4,000 mg/L of *M. oleifera* seeds and 9 mg/L of Zetag 8140, while the SRF was 8.55×10^{10} m/kg. The SRF did not change much for further increment in *M. oleifera* seeds concentration as shown in Fig. 4.

From the SRF results, it could be proved that the best dewaterability was obtained when the sludge was conditioned with the dual polymer. In fact, the difference in SRF values between the sludge conditioned with the dual polymer was found with great significance compared with the value of raw sludge.

3.4. Zeta potential

Fig. 5 shows ZP of sludge as a function of *M. oleifera* seeds dosage. The ZP of raw sludge was found to be

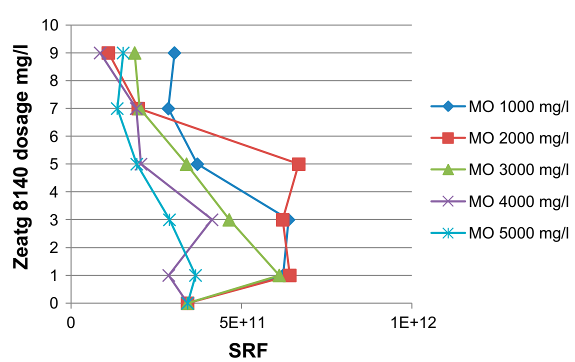

Fig. 4. SRF using dual polyelectrolytes.

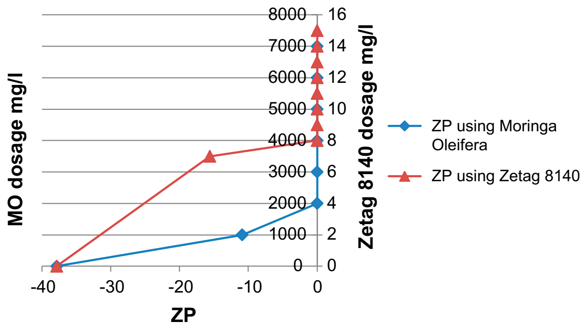

Fig. 5. ZP using single polymer.

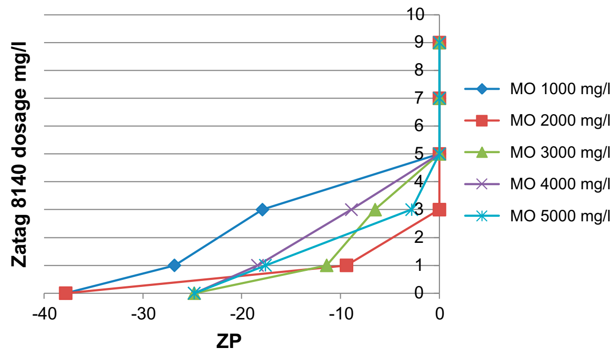

Fig. 6. ZP using dual polyelectrolytes.

−13.4 mV. Upon the addition of 2,000 mg/L of *M. oleifera*, the ZP increased to zero and did not change with further increase in the concentration of *M. oleifera*. The ZP of the solution of shelled *M. oleifera* was found to be in the range of +9 to +14 mV. It is reported that a value of +6 mV of ZP with a 5% solution of *M. oleifera* seeds was found [19]. Preliminary studies on the active ingredients of *M. oleifera* as coagulant have suggested that the active components are cationic peptides [20]. Therefore, the increase of *M. oleifera* concentration will also increase the positive charges in the solutions.

The variation of these values can be attributed to the changing in the characteristics of the sludge, but the results are still in agreement with the previous studies which stated that practically all aqueous colloids are electronegative, with the general range of the ZP between −50 mV and 100 mV. As mentioned earlier, the mechanisms involved in the coagulation activity with *M. oleifera* are adsorption and the neutralization of charges or adsorption and bridging of particles [21]. Therefore, coagulation efficiency is affected by positive charges in the stock solution of *M. oleifera*. Fig. 5 shows the ZP of sludge as a function of Zetag 8140 dosages. The ZP of raw sludge was −15.6 mV. Upon dosage increment of Zetag 8140 to 8 mg/L, the ZP increased to zero and did not change when the dosage of polyelectrolyte was increased beyond 8 mg/L.

However, in the case of dual polyelectrolytes conditioning with Zetag 8140 followed by *M. oleifera* seeds, ZPs showed a similar trend as shown in Fig. 6. ZP was increased with the dosage increment of Zetag 8140, and a charge reversal was observed at 3 mg/L when followed by 2,000 mg/L of *M. oleifera* seeds. The dosage of 2,000 mg/L of *M. oleifera* seeds was obtained from the optimization, and the charge neutralization had been achieved with a dosage of 8 mg/L for Zetag 8140.

The adsorption of the cationic polyelectrolyte could mainly be attributed to the electrostatic force, resulting in the charge neutralization. The van der Waals force could also be important in the adsorption reaction owing to the high molecular weight of polyelectrolyte and less negative value of ZP (−7.1 mV) on sludge surfaces. The adsorbed polyelectrolyte formed loops, trains, and tails on sludge surfaces [22,23]. Due to hindrance and electrostatic repulsion, it was difficult for the polyelectrolyte to adsorb on the loops, tails, or the surface of the particles at higher concentration. Hence, the ZPs did not change much when sludge was conditioned with the cationic polyelectrolyte. Hydrogen bonding and van der Waals force were the probable driving forces for the polyelectrolyte adsorption on particles [23,24].

3.5. Settle sludge volume

Settleability has also been used to investigate the floc structure and the sludge water separation behaviors [25–27]. The settling rate of sludge, expressed in terms of height of the sludge–water interface as a function of time. Fig. 7 shows the SSV against optimum dosage of *M. oleifera* seeds used in sludge conditioning. It could be seen that the volume of settled sludge measured initially increased with increasing *M. oleifera* dosage to 5,000 mg/L and then decreased again, indicating an overdose of polymer. The greatest SSV was 18 mL/L, and the concentration of *M. oleifera* seeds was 5,000 mg/L. Overall, the value of settling rate obtained here was noticed to be quite constant.

Fig. 7 shows the SSV against the optimum dosage of Zetag 8140 used in sludge conditioning. The settling rate of the sludge after the treatment with Zetag 8140 was also quite constant. It can be seen that the volume of settled sludge measured initially was increased up to the dosage of 9 mg/L, and then the value decreased up to the dosage of 15 mg/L. The greatest SSV was 20 mL/L, and the concentration of Zetag 8140 was 9.3 mg/L.

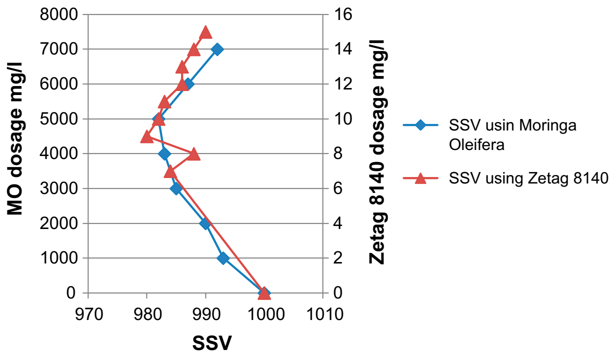

Fig. 7. SSV using single polymer.

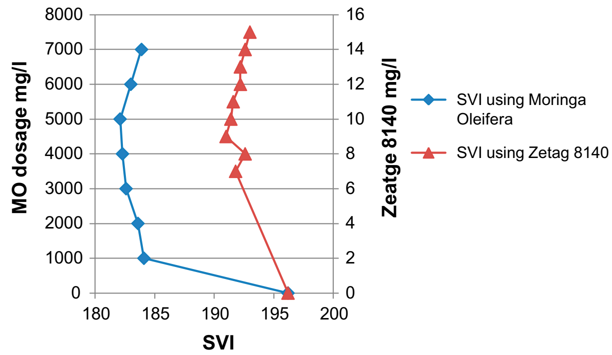

Fig. 9. SVI single polymer.

However, for dual sludge conditioning with Zetag 8140 followed by *M. oleifera*, the ultimate SSV is 320 mg/L when the dosage of *M. oleifera* seeds is 5,000 mg/L and the dosage of Zetag 8140 is 9 mg/L as shown Fig. 8. The floc density and floc diameter are known to affect the settling behaviors [27]. However, the floc size is relatively more significant in determining SSV.

When sludge is conditioned with the *M. oleifera* seeds or Zetag 8140, relatively more compact flocs were formed due to the electrostatic attraction between cationic polyelectrolyte and the sludge surfaces. In addition, relatively smaller flocs were formed owing to the lower molecular weight of the cationic polyelectrolyte. Concerning the effect of the sequence of dual polyelectrolytes conditioning, sludge preconditioned with the cationic polyelectrolyte followed by the natural polyelectrolyte seemed to have larger flocs than sludge preconditioned with the natural polyelectrolyte followed by the cationic polyelectrolyte, as evidenced by the faster settling rate [6].

3.6. Sludge volume index

The SVI obtained here as the volume in milliliter occupied by 1 g of sludge after it has settled for 1/2 h. For economical sludge conditioning using *M. oleifera* seeds dosage from 1,000 to 7,000 mg/L, the value of SVI was found to be from 182.1 to 184.5 as shown in Fig. 9. This showed that the *M. oleifera* seeds extract has proven to be inefficient in the settleability process of the sludge. This is because low SVI is an indication of good sludge settleability.

Fig. 9 also shows the decreasing value of SVI with increasing dosage. This means that as the dosage increases, the sludge settles more efficiently. The lowest value of SVI was 182.1, and it was obtained at dosage of 5,000 mg/L of *M. oleifera* seeds extract. The SVI of the conditioned sludge with Zetag 8140 was decreased as the dosage increased to 9 mg/L, and it was increased when the dosage increased to 15 mg/L. This indicates that a lower dosage of Zetag 8140 is recommended for efficient sludge settleability. The best value of settleability was found o be 144.4 which was obtained by using a dosage of 9 mg/L of Zetag 8140. However, for dual sludge conditioning with Zetag 8140 (dosage from 1 to 9 mg/L) followed by *M. oleifera* (dosage from 1,000 to 5,000 mg/L), the values of SVI was found to be from 132 to 194.1 as shown in Fig. 10. In dual conditioning, the lowest SVI was found to be 132 when the sludge was conditioned using *M. oleifera*

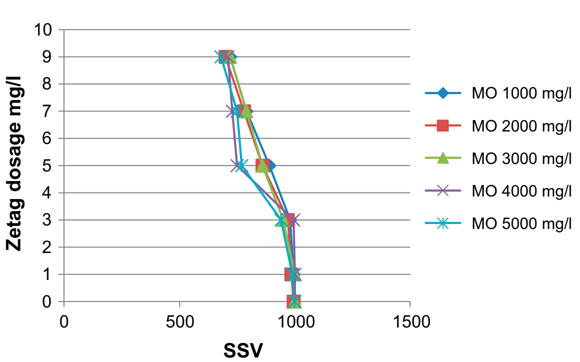

Fig. 8. SSV using dual polyelectrolytes.

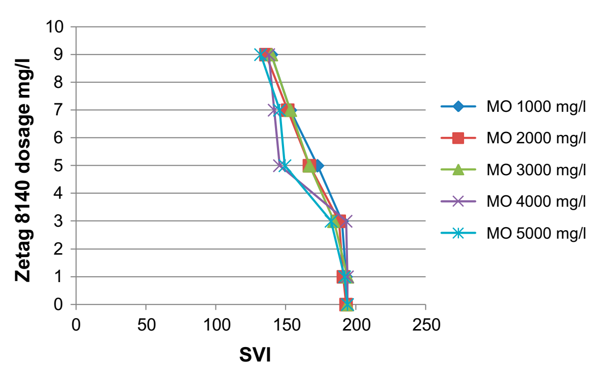

Fig. 10. SVI dual polyelectrolytes.

seeds with a dosage of 5,000 mg/L and Zetag 8140 with a dosage of 9 mg/L of. This is because higher floc strength was observed in dual polymer conditioning than in single polymer conditioning. This may attributed to the formation of super-flocs [28].

4. Conclusions

The study focuses on comparing the dewaterability and settleability of the activated sludge after conditioning with natural and synthetic polymers. The laboratory tests were carried out to evaluate sludge characteristic such as CST, SRF, ZP, SSV, and SVI. Performance of each polymer varies in each laboratory testing. From the conducted laboratory tests, the following conclusions can be drawn:

(1) By using *M. oleifera* seeds powder with Zetag 8140 as a dual polyelectrolyte in sludge conditioning and dewatering, the value of CST was lowered by 30–37% compared to sludge conditioning using single polymer.
(2) By using dual polyelectrolyte for sludge conditioning, the value of SRF was decreased by 43–76% compared to the values of SRF when a single polymer is used in sludge conditioning.
(3) By using dual polyelectrolyte for sludge conditioning, the value of SSV was decreased by 30%, and the value of SVI was decreased by an average of 20% compared with using single polymer (natural or synthetic alone) for sludge conditioning.
(4) The value of ZP charge was increased to zero by using dual polyelectrolyte for sludge conditioning by using optimal dosage of *M. oleifera* (2000 mg/L) combined with a dosage of Zetag 8140 (3 mg/L).

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