Environmental Science and Pollution Research (2020) 27:10790–10801
https://doi.org/10.1007/s11356-020-07694-8

RESEARCH ARTICLE

Cost-effective treatment of sludge conditioning using supernatant fluid polyelectrolyte

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Received: 23 October 2019 / Accepted: 9 January 2020 / Published online: 16 January 2020

Abstract

Treatment of activated sludge using pure polyelectrolyte and its supernatant fluids for sludge dewatering was examined. The supernatant was used for treatment of fresh sludge for reducing the total cost of sludge conditioning by almost 50% and had great impact on wastewater treatment especially on that with large flow rate. The utilization of supernatant can be considered as a sustainable and economical method for pollution reduction especially in the developing countries. This would overcome the problem of imperfect mixing, difficulties in operated sludge conditioning, and utilized wasted polyelectrolyte. A slightly high positively charged polyelectrolyte was selected during this study. The results showed this polymer and the supernatant had significant influence on the sludge volume index (SVI) and sludge settling. The SVI and settling were improved by 50% and 60%, respectively. We found the sludge treated with supernatant showed a highest sludge settling properties compared with using pure polyelectrolyte especially for sludge samples with low total suspended solid (TSS) and SVI. Using mixed supernatant with pure polyelectrolyte showed higher settling compared to second treatment. Zeta potentials were measured, and increases in zeta potentials were observed for use of both pure polymer and supernatant fluids. The experiments of using supernatants for sludge treatment were found to reflect the use of waste for waste and principle of circulation cleaning; thus it can be a valuable reference for the researchers working in the field of sludge treatment.

Keywords Activated sludge · Supernatant · Sludge volume index · Settling · Zeta potentials

Introduction

The discharges of industrial and domestic wastewater had increased significantly nowadays due to the fast industrialization and over growth of human population. Due to this reason, huge quantities of sludge may be produced from wastewater treatment plants in many countries. For example, the total amount of sludge is expected to reach 13 million tons in European countries by 2020 (Samolada and Zabniotou 2014).

The water content of the activated sludge was reported more than 95% (Thomas and Rolf 1997). The pollutants in wastewater pose dangerous threat to human and aquatic environment (Devi and Saroha 2016). Thus, the purification of wastewater is very important to avoid critical global scarcity and shortages of water. The biological wastewater treatment is one of the most commonly any economically used methods for the degradation of organic contaminants by utilization of bacterial metabolism (Al-Dawery 2016 2017; Nielsen et al. 2010). As a result of the microorganism growth, formation of the activated sludge takes place (Ahmed and Wahid 2014). The amount and bioactivity of the activated sludge are the core factors for a successful operation of the wastewater treatment plant (Han et al. 2012; Ahmed 2018). However, excessive amount of solid sludge would have serious problems in sludge disposing management and a negative impact on the environment and economic concerns (Appels et al. 2008; Abe, et al. 2011; Hait and Tare 2011).

Sludge dewatering is an important and at the same time a very difficult task; thus, the optimization of sludge treatment is a great challenge. In addition, the presence of the

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Table 1 Wastewater volumetric flow rate treated in some countries

Country	Treatment rate m^3/day	Reference
Chicago in USA	1.26×10^6	Environmental Protection Agency (EPA, 2003
Gig Harbor City in Washington USA	1.23×10^6	City of Gig Harbor 2019
England	2.6×10^6	Murphy et al. 2016
Finland	2.7×10^6	Talvitie et al. 2016
Tehran	675,000	Mesdaghinia et al., 2015
Sumedang district in Singapore (small city)	18	Mamat et al. 2017

bacterial extracellular polymeric substance in the activated sludge causing water-biomass bonding and leading to a negative influence on the water-solid separation (Poxon and Darby 1997; Mikkelson and Kieding 2002; Liu and Fang 2003). Related to this study, large efforts have been done by many researchers to develop and improve the purification of wastewater especially that which contains organic pollutants and application of biological treatment such as inorganic ions and organic polyelectrolyte (Al-Dawery 2015); Li, et al. 2016; Kozminykh et al. 2016), membrane bioreactor (Lin et al. 2012; Skouteris et al. 2012; Smith, et al. 2012), collagen dispersions (Davis and Maffia 1995), enzymatic treatment (Nelson et al. 1988), ultrasonic pretreatment (Yin, et al. 2004), ozonation pretreatment (Ahmed 2019), activated sludge treatment (Ahmed and Wahid 2014), freezing/thaw treatment (Wu, et al. 2001; Zheng, et al. 1998), etc. Most of the sludge treatment methods are used for sludge dewatering and the widely used mechanisms that are proposed for the sludge particles flocculation. For example, there are three major theories for flocculation and sludge dewatering based on using cationic ions; these are alginatation sludge; double layer, and cation bridging (Sobeck and Higgins 2002).

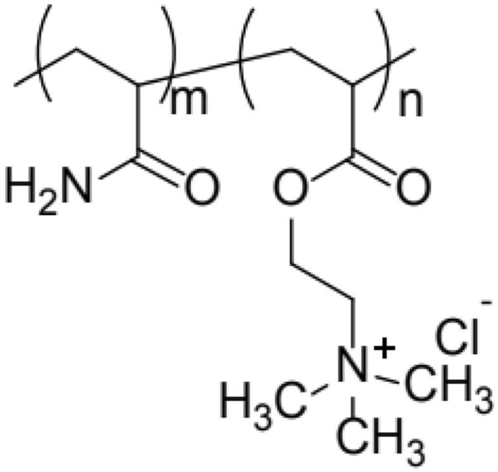


Fig. 1 Chemical structure of SNF polyelectrolyte

In addition to the importance of sludge dewatering for many countries that are suffering from water scarcity, the wastewater treatment plants produce biosolid. Application of biosolids is useful if treated sufficiently, can be applied for soil improvement, and supplies plant with the necessary nutrients. The biosolids were in rich of organic materials and fertilizers. Also, the handling and management of sludge cost can reach up to 50% of the total operating cost of wastewater treatment plant.

Organic polyelectrolytes are the most effective sludge conditioning and dewatering that form a long-chain network and adsorb sludge particles leading to flocculation and rapid settling (Al-Dawery 2017). The huge amount of produced activated sludge requires large quantities and high concentrated polyelectrolytes. Reduction of application of chemicals and sustainable cost-effective method is a challenge for the operation of sewage treatment. Manufacturing cost of polyelectrolyte is approximately 3000–5000 USD per ton. The effective dosages of polyelectrolyte concentration for sufficient sludge conditioning and dewatering are 50–100 ml depending on solid content of the sludge. The generation per capita per day of wastewater characteristics would be estimated from measured collected wastewater flow, the population, and concentration data. The results indicate that there is a huge amount of wastewater produced daily.

Pollution from wastewater in terms of capita values, the conception of pollution would be understandable for many citizens. However, the changes in living standards and technologies application for wastewater treatment would suggest re-examination of the pollution per capita loadings. On the other hand, considerable problems in environment are caused

Table 2 The characteristics of the collected samples sludge

Sample No.	pH	TSS (g/L)	VSS (g/L)	FSS (g/L)	Conductivity mS/cm	SVI mL/g solid
1	7.17	1.265	1.163	0.0102	2.527	553,359.7
2	7.58	2.71	2.25	0.46	2.2	296,296.5
3	7.76	6.7	4.69	2.01	2.33	146,884.3

by discharge and sludge produced from wastewater. The increase in population would increase pollution of water, and imposing of restrictive limits by local authorities would lead to the need for new treatment technologies. Thus, it is very important that the discharged wastewater be assessed and current treatment technologies be improved. Accordingly, additional cost would be needed for covering new technologies, handling and sludge management, transportation, plant operation, etc. Worldwide, the capacity of wastewater treatment plants is varying from country to country as shown in Table 1.

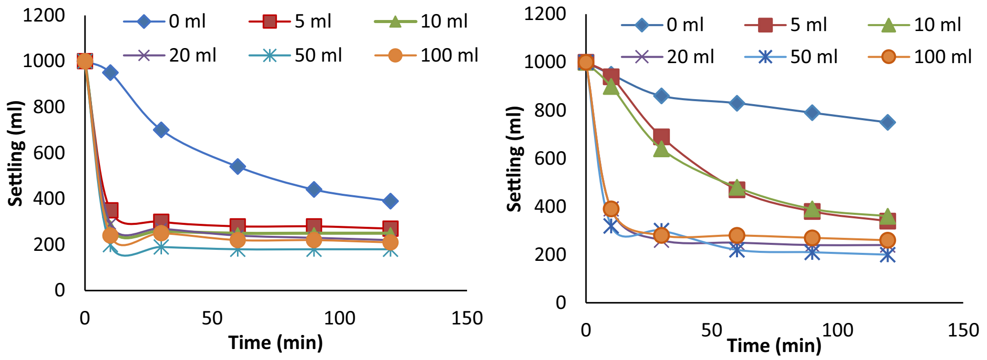
The aim of this research was to evaluate the effectiveness of using supernatant fluid that produced from previously conditioned sludge for treatment of a fresh municipal wastewater and also to study the impact of this method on reducing dosage of polyelectrolyte and decreasing cost of conditioning sludge and its operation.

Materials and methods

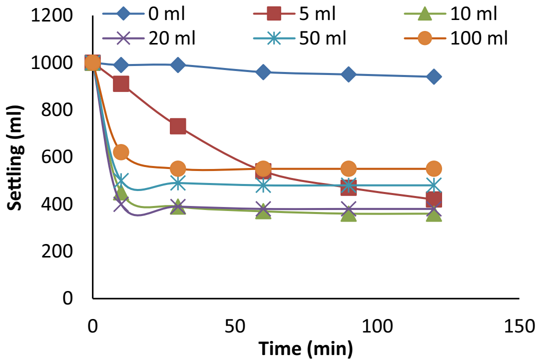
Materials

The SNF slightly high cationic polyelectrolyte used for sludge conditioning was provided by manufacturer SNF FLOERGER, France. SNF is organic coagulants and flocculants for water treatment. SNF molecular structure is shown in Fig. 1. The conditioning solution was prepared by mixing 1 g of polyelectrolyte with 1 liter of deionized water and then stirred using the

Fig. 2 Sludge settling using fresh polyelectrolyte with different TSS

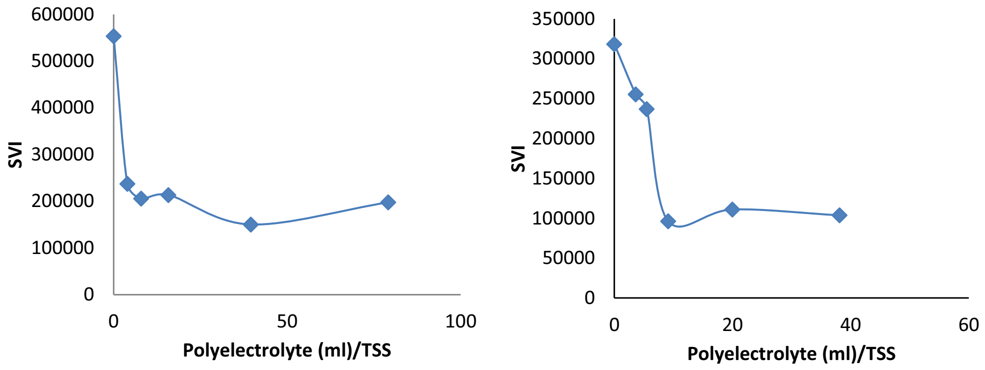


a) Settling using SNF with TSS=1.265 g L^{-1} b) Settling using SNF with TSS=2.71 g L^{-1}

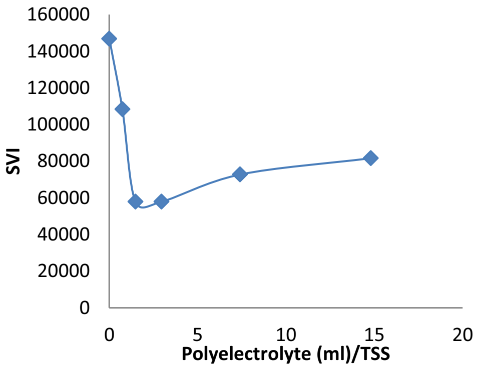


c) Settling using SNF with TSS=6.7 g L^{-1}

Fig. 3 SVI using fresh polyelectrolyte with different TSS



a) SVI using SNF with TSS=1.265 g L^{-1} b) SVI using SNF with TSS=2.71 g L^{-1}



c) SVI using SNF with TSS=6.7 g L^{-1}

orbital shaker for at least 24 h. Different concentrations of polymer solution were used during operating the jar test.

Sludge sample

Sludge samples were collected from the aeration tank of Nizwa wastewater treatment plant in Nizwa, Sultanate of Oman. Samples were conditioned with SNF polyelectrolytes and supernatant of previously conditioned sludge. The average values of the total suspended solids (TSS), volatile suspended solid (VSS), and fixed suspended solid (FSS) of the collected samples, conductivity, and pH are presented in Table 2 and were analyzed according to APHA 1998. The calculation of TSS in the wastewaters was as follows: 20 ml of sludge sample was firstly filtered using a pre-weighed filter paper on a porcelain crucible and then placed in drying oven for 1 h at 105 °C. After drying, the sample was weighed for TSS. The sample was then dried in a muffle furnace for 1 h at 550 °C. The dried sample was weighed for FSS.

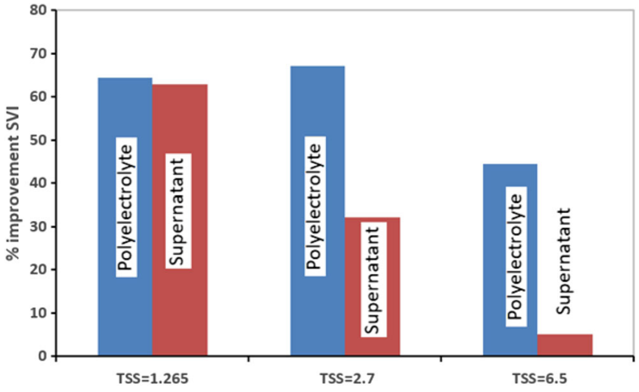
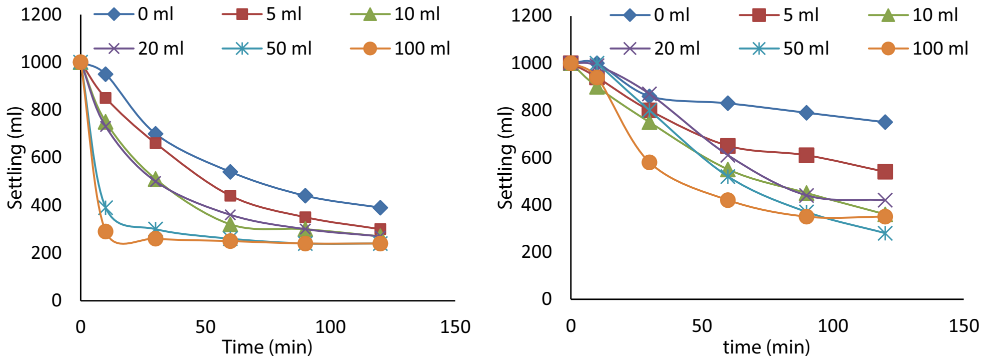


Fig. 4 SVI improvement of conditioned sludge samples using fresh polyelectrolyte and supernatant with different TSS

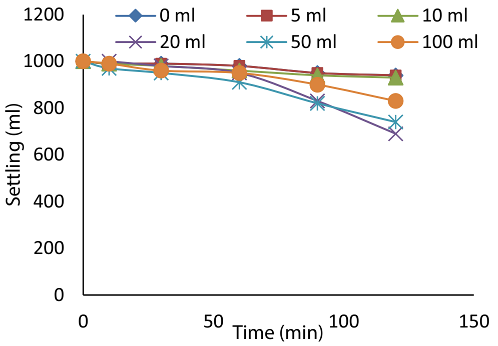
Flocculation test

The coagulation and flocculation of the activated sludge were evaluated using jar test to determine the optimum dosage of conditioning chemicals. Six cylindrical glass jars were used, and each contained 1 liter of sludge suspension. Different dosages of polyelectrolyte were added to each jar simultaneously. The solutions in the six jars were stirred using Armfield (USA) variable speed mixer. Two mixing rates were performed, rapid mixing at rate 200 rpm for 2 min to simulate proper and fast mixing followed by slow rate mixing at 90 rpm for 30 min to

Fig. 5 Settling using supernatant from first conditioned sludge with different TSS



a) conditioned sludge with TSS=1.265 g L^{-1} b) conditioned sludge with TSS=2.71 g L^{-1}



c) conditioned sludge with TSS=6.7 g L^{-1}

promote flocculation process. Floc formation was observed during the slow mixing.

Sludge volume index

Settling properties of the collected sludge samples were characterized using the total suspended solid (TSS) and the sludge volume index (SVI) as described by 2540D and 2710D methods according to APHA standard methods (APHA 1998). The SVI test requires pouring a 1000 mL of sludge fluid into graduated cylinder. Collect a gallon of sludge, mix gently, and after 30 min, record the volume to which the sludge is settled. The SVI formula is given in Eq. 1.

$$SVI\left(\frac{mL}{gTSS}\right)=\frac{Settled\ sludge\ volume\left(\frac{mL}{L}\right)}{Suspended\ solids\ concentration\left(\frac{mg}{L}\right)}x1000\ (mg/g) \quad (1)$$

The treated sludge samples using jar test were poured into a 1 liter graduated cylindrical glass vessel and allowed to settle; the interface position between the sludge and the supernatant was measured during settling.

Sludge volume index is the measured volume that is occupied by 1 g of sludge after 30 min of settling. The data of SVI were used to calculate the improvement of settling of the conditioned sludge samples with pure polyelectrolyte and supernatant separately using the following Eq. 2.

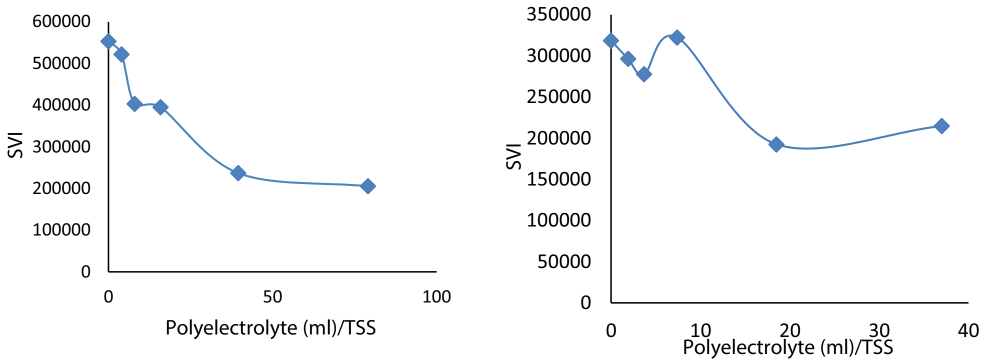
$$\%\ of\ improved\ SVI=\frac{SVI\ of\ fresh\ sample{-}SVI\ of\ conditioned\ sample}{SVI\ of\ fresh\ sample}x100 \quad (2)$$

Zeta potential

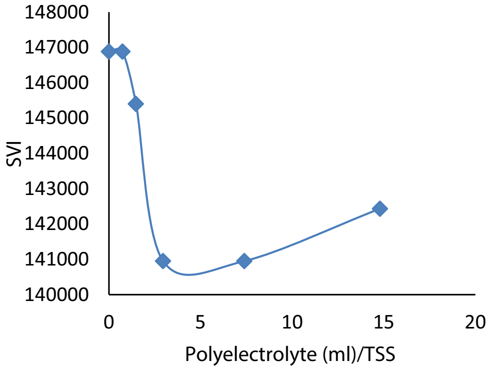
Zeta potential is the measure of the electrostatic magnitude or charge attraction/repulsion between sludge particles and is considered as fundamental parameters measuring the effect of stability (Shaikh et al. 2017). A high value of zeta potential indicates highly stable system with either a positive or negative surface charge, for which strong electrostatic between the particles is incorporated.

Electrical charges of the supernatant of the conditioned activated sludge samples were measured using Malvern Instruments Zetasizer (UK). This device performs three times zeta analysis for each sample as loaded into its capillary cell; the average values were used.

Fig. 6 SVI using supernatant from first conditioned sludge with different TSS



a) conditioned sludge with TSS=1.265 g L^{-1} b) conditioned sludge with TSS=2.71 g L^{-1}



c) conditioned sludge with TSS=6.7 g L^{-1}

Results and discussion

The samples collected from wastewater treatment plant at the city of Nizwa, Oman, showed high SVI as shown in Table 1. Due to the bulking sludge phenomenon as a result of high organic content and presence of the extracellular polymer increase SVI and lead to low settling rate (Pere, et al. 1993; Sanin and Vesilind 1996). Cationic polyelectrolyte showed a considerable impact on dispersed negatively charge sludge particles, hence on settling and dewatering. Due to this reason, SNF polyelectrolyte with slightly positive charge density was used for conditioning for the selected sludge with different total suspended solids.

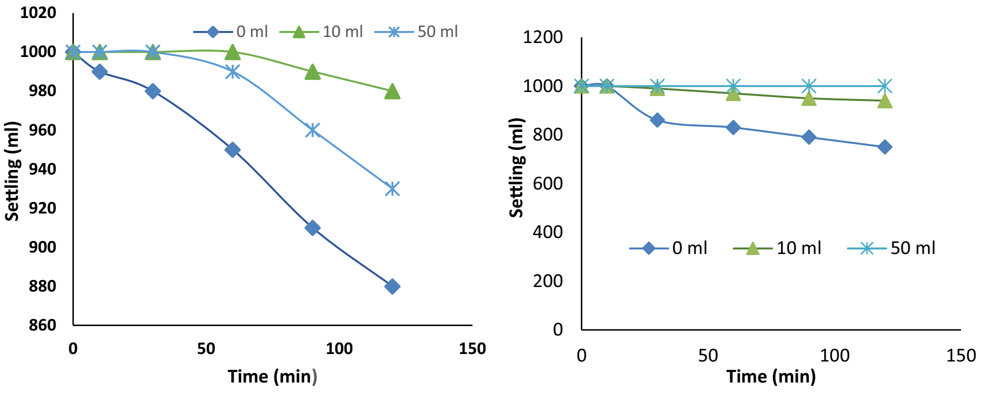
Fresh SNF polyelectrolyte for sludge conditioning

Fresh SNF polyelectrolyte for sludge conditioning was selected, and several experiments were carried out in order to examine the effects of addition of the pure SNF polyelectrolyte on the sludge settling and characteristics of sludge volumes.

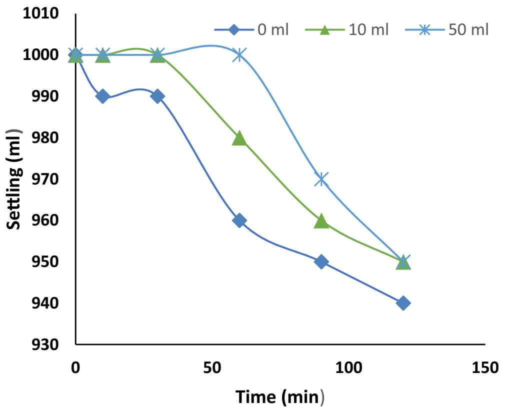
The position of the interface between supernatant liquid and sediment after jar test was measured during settling as a function of time after being poured into the cylindrical flasks with various dosages of the polymer. The results of settling and SVI of the conditioned sludge samples with different TSS were shown in Figs. 2 and 3, respectively. It can be seen from Fig. 2 that the SNF polymer had a larger effect on the reduction of the sediment thickness, showing 50% reduction in the sediment thickness. Thus, it can be indicated that a significant settling with the greatest effect being achieved for the least amount of TSS, settling was improved by 50% for sample with TSS 1.265 g L^{-1}. Similarly, the results showed improvement by almost 45–65% in SVI for the conditioned sludge sample as shown in Fig. 3 and Fig. 4. The highest improvement in SVI was for lower TSS. However, TSS content was largely affecting SVI; the results indicated a higher SVI 550,000 for lower TSS 1.265 g L^{-1} and a lower SVI 150,000 for higher TSS 6.7 g L^{-1}. The high suspended solid is considered electrically stable according to Greenwood and Kendall 1999, leading to aggregation of sludge particles. Other researcher Al-Dawery 2015, found sludge SVI improvement due to effects of suspended solid and polyelectrolyte on settling and rheological properties of municipal activated sludge.

The mechanism of bonding particles may be referred to Van der Waals force attraction (Al-Dawery 2017). The use of low concentration of polyelectrolyte leads to better settling especially

Fig. 7 Settling using supernatant from second conditioned sludge with different TSS



a) conditioned sludge with TSS=1.265 g L^{-1} b) conditioned sludge with TSS=2.71 g L^{-1}



c) conditioned sludge with TSS=6.7 g L^{-1}

in samples with low TSS 1.265 g L^{-1}, compared to samples with higher TSS 6.7 g L^{-1}; bridging was governed by the mechanism of attraction of particles. The successive addition of polyelectrolyte caused small repulsion between particles resulting higher level of settling, and thus the optimum conditioning necessarily happened with high concentration of polyelectrolyte.

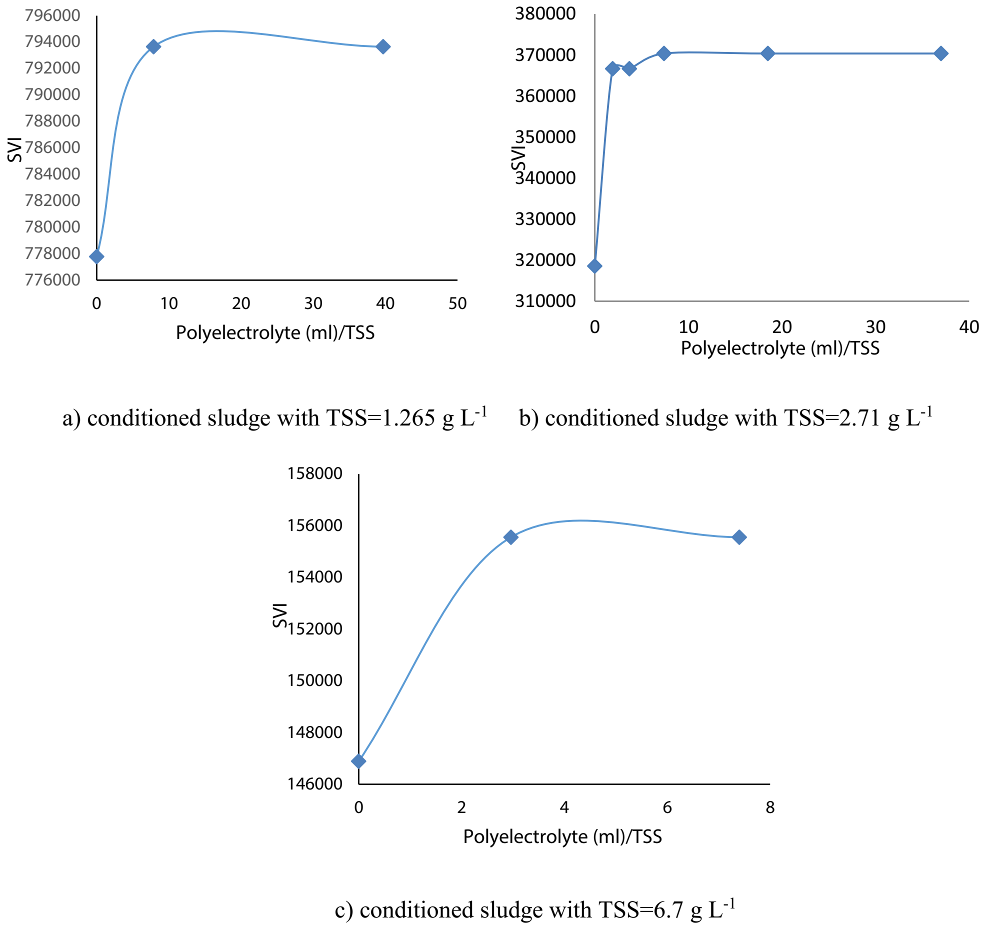
Sludge conditioning with supernatant from first conditioning

For economical and cost-effective treatment operations and for reducing amount of used polyelectrolyte, supernatant from the previous conditioning process was used for the sludge conditioning instead of using pure polyelectrolyte. The results were presented in Figs. 5 and 6 for different TSS. It can be observed that the use of supernatant showed a significant impact on sludge settling as good as fresh polyelectrolyte, especially for treatment of sample with low solid content. The obtained settling referred to the partial availability of non-consumed polyelectrolyte in the supernatant that extracted from treated sludge sample with low TSS 1.265 g L^{-1}. Regarding the results of settling zone and final sediment thickness value, as can be seen from Fig. 5, the supernatant has a larger effect on the reduction of the sediment thickness, which resulted in almost a 65% reduction in the sediment thickness for sample with low TSS 1.265 g L^{-1}. The results showed a reduction by almost 60% in SVI for sample with low TSS as shown in Figs. 4 and 6a, while improvements of 30% were obtained for samples with higher TSS, from Fig. 4 and 6b,c. The improved settling using supernatant over that of pure polymer may be due to less repulsion between sludge particles caused by excessive addition of pure polymer.

Sludge conditioning with supernatant from second conditioning

In a similar procedure, supernatant from the second conditioning sludge was used for treatment of fresh sludge samples. The results showed no improvement on sludge settling and SVI at all cases as shown in Figs. 7 and 8. These results indicated that the whole polyelectrolyte had been consumed during first and second sludge treatment. The negative effect would be explained due to the repulsion between non-treated fine particles in the supernatant and those in the fresh sludge samples which had same negative particle charges.

Fig. 8 SVI using supernatant from second conditioned sludge with different TSS



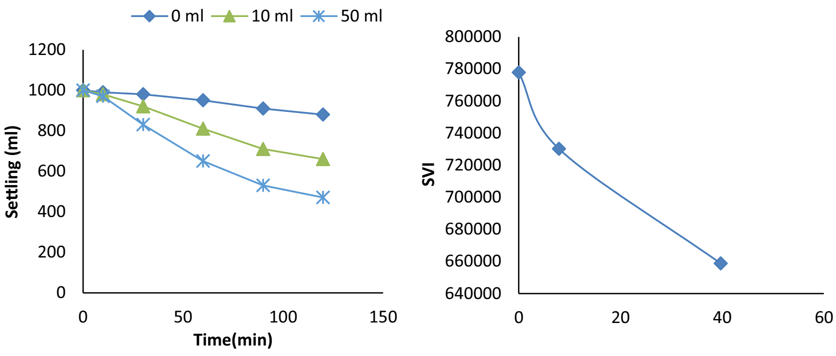
a) conditioned sludge with TSS=1.265 g L^{-1} b) conditioned sludge with TSS=2.71 g L^{-1}

c) conditioned sludge with TSS=6.7 g L^{-1}

Sludge conditioning using mixed pure polyelectrolyte with exhausted supernatant

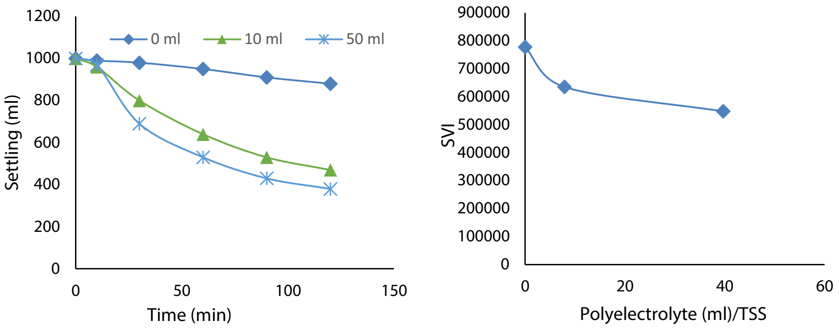
Sludge conditioning using mixed fresh polyelectrolyte with exhausted supernatant from second treatment was examined for sludge sample with different TSS. Results of using 25% fresh polyelectrolyte and 75% of supernatant for conditioning sludge sample with TSS 1.265 g L^{-1} were plotted in Fig. 9. Better settling and lower SVI can be observed compared to results of using only exhausted supernatant shown in Figs. 6-a and 7-a. Results showed almost a 47% reduction in the sediment thickness and improvement by almost 16% in SVI. Sludge conditioning with cationic polyelectrolytes improves sludge settling, and SVI was achieved but slightly less than the findings of Nguyen (Nguyen et al. 2008). The results of similar test using 50% pure polyelectrolyte and 50% of supernatant for conditioning of two separate sludge samples with

Fig. 9 Test using 25% fresh polyelectrolyte and 75% supernatant with TSS = 1.265 g L^{-1}



a) Sludge settling **b)** Sludge volume index

Fig. 10 Test using 50% fresh polyelectrolyte and 50% supernatant with TSS = 1.265 gL^{-1}



a) Sludge settling **b)** Sludge volume index

1.265 g L^{-1} and TSS 6.7 g L^{-1} were plotted in Figs. 10 and 11, respectively. Both settling and SVI were improved in both cases compared to results presented in Figs. 7 and 8. For sample with TSS = 1.265 g L^{-1}, the results showed improvement of 57% in sediment settling and 30% in SVI, while for sample with TSS = 6.7 g L^{-1}, the results showed improvement of 49% in sediment settling and 46% in SVI.

Results of using 25% fresh polyelectrolyte and 75% of supernatant were mentioned in Fig. 9. A better settling and improvement in SVI were obtained compared to results of using only exhausted supernatant. Increasing concentration of fresh polyelectrolyte improved the conditioning process as shown in Fig. 10 for samples with TSS 1.625 g L^{-1} compared with Fig. 11 for samples with TSS 6.7 g L^{-1}.

Effect of zeta potential

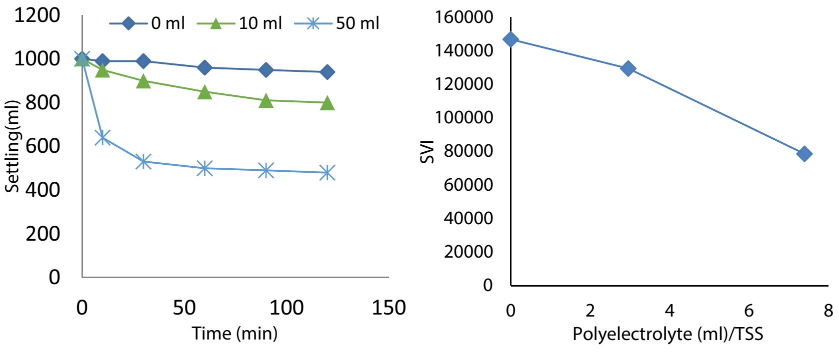
The results of zeta potential of the supernatant of the settled sludge using various concentrations of the polyelectrolyte are presented in Fig. 12. In this regard, the results showed that the fresh sludge sample had slightly negative initial zeta values −3.6 mV for sample with low TSS 1.265 g L^{-1} but under conditioning process by both pure polyelectrolyte and supernatant. The negative zeta values of sample were largely reduced and reached to an average value of +4 mV using pure polymer and + 5.9 mV using supernatant from first conditioning process. These results indicated the significant effect of polymer and supernatant on the surface charges of sludge samples especially those with low TSS. As shown, the results revealed that setting properties were improved respecting the positive measurement of zeta. This behavior explained that the dominant mechanism of flocculation into larger flocs was governed by the interparticle bridging rather than by the charge neutralization.

Therefore, the addition of a pure cationic polyelectrolyte and first supernatant lowered the zeta potential as shown in Fig. 12-a and b, while the opposite, an increase in the zeta potential was seen with the use of second supernatant (Fig. 12-c). The mechanism of this behavior may be referred to van der Waals force attraction as explained in the above results.

Cost-effective utilization of supernatant for sludge treatment

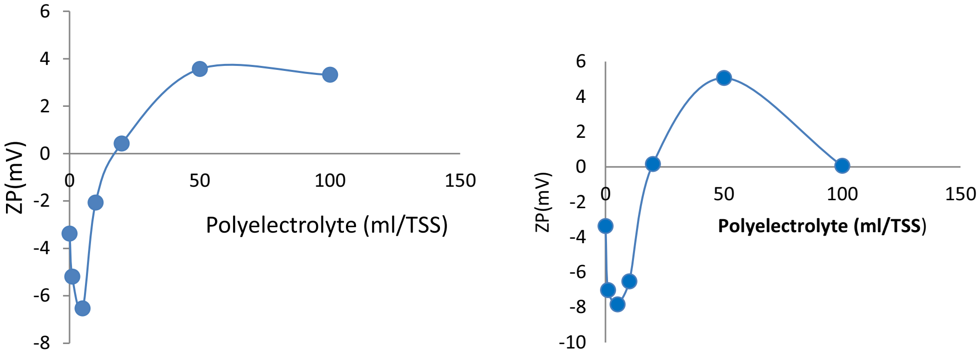
The use of supernatant for sludge treatment could reduce the cost of using pure polyelectrolyte for such treatment. The cost of which ranges between 2000 and 3000 USD per ton.

Fig. 11 Test using 50% fresh polyelectrolyte and 50% supernatant with TSS = 6.7 g L^{-1}



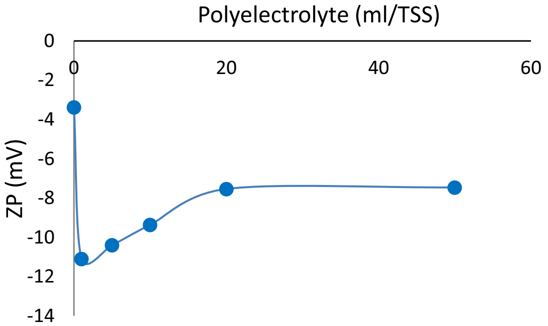
a) Sludge settling **b)** Sludge volume index

Fig. 12 Zeta potential using sludge sample with TSS = 1.265 g L^{-1}



a) Zeta of sample using pure polyelectrolyte

b) Zeta of sample conditioned using supernatant from first treatment



c) Zeta of sample conditioned with supernatant from second treatment

As per the experimental study, using the maximum dosage 100 mg polyelectrolyte per one liter of wastewater would require 100 g polymer/m^3 of wastewater. Accordingly, the total amount of polyelectrolyte for treatment of one million m^3/day is 100 tons d^{-1} which cost around 300,000 USD d^{-1}. However, considering the use of supernatant, the cost would be reduced by more than 50%. This can be considered as a sustainable economic method for pollution reduction especially in the developing countries.

It was found that the application of maximum dosage 100 mg polyelectrolyte per liter of wastewater for treatment, this would require 100 g polymer/m^3 of wastewater. Accordingly, the total amount of polyelectrolyte required for the treatment of 100 liter per day needs only 30 USD. However, we considered that the use of supernatant would reduce the cost of treatment more than 65%. In terms of fresh polyelectrolyte, it requires huge money and management of sludge solids so that sustainable economic method for pollution reduction could be achieved especially in the developing countries.

Conclusions

The application of supernatant polyelectrolyte can be considered as sustainable and cost-effective techniques for sludge conditioning and solid reduction especially in the developing countries. A high positively charged SNF polyelectrolyte was used for sustainable treatment selected for wastewater treatment. The findings of this study compared to polymer and the supernatant indicated significant effluence on the sludge volume index (SVI) and sludge settling. Both settling and SVI were improved by 50% and 60%, respectively.

- The utilization of supernatant for sludge treatment would reduce the cost of sludge conditioning by almost 50%.
- The results of using supernatant improved sludge settling by 50%, and SVI improved by 60% especially for sludge samples with low TSS.
- Using mixed pure polyelectrolyte and supernatant gave better settling results compared to that of using only supernatant.
- Increases in zeta potentials were observed for the case of using pure polymer and supernatant.

- The obtained results showed that using supernatant could be attributed to utilize the excess polyelectrolyte particles remaining in the supernatants or that unattached particles, hence, reducing cost of operation.

Acknowledgments The authors wish to thank R&D panels of University of Nizwa for valuable discussions on industrial wastewater treatments and as source of energy. They fully supported the research discussion and helped the experimental sample analysis through Research Cluster Group Energy, Environment and Sustainable technology.

References

Abe N, Tang YQ, Iwamura M, Otha H, Morimura S, Kida K (2011) Development of an efficient process for the treatment of residual sludge discharged from an anaerobic digester in a sewage treatment plant. Bioresour Technol 102:7641–7644

Ahmed A (2018) Process evaluation of co-digestion petroleum wastewater with rye grass for the performance of methane production. Wastes and Biomass VolarizationSpringer:1–11. https://doi.org/10.1007/s12649-018-0473-9

Ahmed A (2019) Effect of ozonation on biodegradation and methanogenesis of palm oil mill effluent treatment for the production of biogas. Ozone Sci Eng 5(41):427–436

Ahmed A, Wahid ZA (2014) Immobilized cement kiln dust enhances biomass and neutralizing of palm oil mill effluent for biogas production. Environ Prog Sustain Energy 34:736–743

Al-Dawery SK (2015) Conditioning process and characterization of fresh activated sludge. J Eng Sci Tech 10(5):692–711

Al-Dawery SK (2016) Effects of suspended solid and polyelectrolyte on settling and rheological properties of municipal activated sludge. J Envir Chem Eng 4:4731–4743

Al-Dawery SK (2017) Degree of flocculation and Interparticles charges of conditioned Municipal Activated Sludge using Mixed Polymers. J Macromolecular Sci part b: Phys 56(8):578–594

APHA, (1998), Standard methods for examination of water and wastewater, Washington D.C: American Public Health Association, American water works association, water Pollution Control Federations

Appels L, Baeyens J, Degreve J, Dewil R (2008) Principles and potential of the anaerobic digestion of waste-activated sludge, Prog. Energy combust. Sci. 34:755–781

City of Gig Harbor (2019) Wastewater Comprehensive Plan Update Wastewater Flow Projections https://www.cityofgigharbor.net/DocumentCenter/View/570/Chapter-3%2D%2D-Wastewater-Flow-Projects-PDF

Davis JF, Maffia GJ (1995) Collagen dispersions for liquid-solid separations in water treatment and sludge dewatering. Sep Technol 5:147–152

Devi P, Saroha AK (2016) Improvement in performance of sludge-based adsorbents by controlling key parameters by activation/modification: critical review. Crit Rev Environ Sci Technol 46:1704–1743

EPA Environmental Protection Agency, (2003), Wastewater technology fact sheet — screening and grit removal, Office of Water, EPA 832-F-03-011, US

Greenwood R, Kendall K (1999) Selection of suitable dispersants for aqueous suspensions of zirconia and titania powders using acoustophoresis. J Eur Ceram Soc 19:479–488

Hait S, Tare V (2011) Vermistabilization of primary sewage sludge, Bioresour. Technol 102:2812–2820

Han Y, Liu J, Guo X, Li L (2012) Micro-environment characteristics and microbial communities in activated sludge flocs of different particle size. Bioresour Technol 124:252–258

Kozminykh P, Heistad A, Ratnaweera HC, Todt D (2016) Impact of organic polyelectrolytes on coagulation of source-separated black water. Environ Technol 37(14):1723–1732

Li J, Liu L, Liu J, Ma T, Yan A, Ni Y (2016) Effect of adding alum sludge from water treatment plant on sewage sludge dewatering. J Environ Chem Eng 4:746–752

Lin H, Gao W, Meng F, Liao BQ, Leung KT, Zhao L, Chen J, Hang H (2012) Membrane bioreactors for industrial wastewater treatment: a critical review, Crit. Rev. environ. Sci Technol 42:677–740

Liu Y, Fang HHP (2003) Influence of extracellular polymeric substance (EPS) on flocculation, settling and dewatering of activated sludge. Crit Rev Environ Sci Technol 33:237–273

Mesdaghinia A, Nasseri S, Mahvi AH, Tashauoei HR, Hadi M (2015) The estimation of per capita loadings of domestic wastewater in Tehran. J Environ Health Sci Eng 13(25):1–9

Mikkelson LH, Kieding K (2002) Physico-chemical characteristics of full scale sewage with implications to dewatering. Water Res 36:2451–2462

Murphy F, Ewins C, Carbonnier F, Quinn B (2016) Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. Environ Sci Technol 50(11):5800–5808

Nelson TC, Huang JYC, Ramaswami D (1988) Decomposition of exopolysaccharide slime by a bacteriophage enzyme. Water Res 35(11):2615–2620

Nguyen TP, Hilal N, Hankins NP, Novak JT (2008) Characterization of synthetic and activated sludge and conditioning with cationic polyelectrolytes. Desalination 227:103–110

Nielsen PH, Mielczarek AT, Kragelund C, Nielsen JL, Soundres AM, Kong Y, Hansen AA, Vollertsen J (2010) A conceptual ecosystem model of microbial communities in enhanced biological phosphorous removal plants. Water Res 44:5070–5088

Pere J, Aley R, Viikari L, Eriksson L (1993) Characterization and dewatering of activated sludge from pulp and paper industry. Water Sci Technol 28(1):193–201

Poxon TL, Darby JL (1997) Extracellular polyanionic in digested sludge measurement and relationship to sludge dewaterability. Water Res 31(4):749–758

Samolada MC, Zabniotou AA (2014) Comparative assessment of municipal sewage sludge incineration, gasification and pyrolysis for a sustainable sludge-to-energy management in Greece. Waste Manag 34:411–420

Sanin FD, Vesilind PA (1996) Synthetic sludge: a physical/chemical model in understanding bioflocculation. Water Environ Res 68(5): 927–933

Shaikh SMR, Nasser MS, Hussein I, Benamor A, Onaizi SA, Qiblawey H (2017) Influence of polyelectrolytes and other polymer complexes on the flocculation and rheological behaviors of clay minerals: a comprehensive review. Sep Purif Technol 187:137–161

Mamat, N Sintawardani, J T Astuti, D Nilawati, D R Wulan, Muchlis, L Sriwuryandari, T Sembiring and N W Jern (2017) Flow rate analysis of wastewater inside reactor tanks on tofu wastewater treatment plant, IOP. Conf Series: Earth and Environmental Science 60

Skouteris G, Hermosilla D, Lopez P, Negro C, Blanco A (2012) Anaerobic membrane bioreactor for wastewater treatment: a review. Chem Eng J 198:138–148

Smith AL, Stadle LB, Love NG, Skerlos SJ, Raskin L (2012) Perspectives on anaerobic membrane bioreactor treatment of domestic wastewater: a critical review, Bioresour. Technol 122:149–159

Sobeck DC, Higgins MJ (2002) Examination of three theories for mechanisms of cation-induced bio-flocculuation. Water Res 36:527–538

Talvitie J, Mikola A, Setälä O, Koistinen AP (2016) How well is microlitter purified from wastewater? – a detailed study on the stepwise removal of microlitter in a tertiary level wastewater treatment plant. Water Res 1(109):164–172

Thomas N, Rolf K (1997) Change of particle structure of sewage sludge during mechanical and biological processes with regard to the dewatering result. Water Sci Technol 36(4):293–306

Wu RM, Lee DJ, Wang CH, Chen JP, Tan RBH (2001) Novel cake characteristics of waste-activated sludge. Water Res 35(5):1358–1362

Yin X, Han P, Lu X, Wang Y (2004) A review on the dewaterability of bio-sludge and ultrasound pretreatment. Ultrason Sonochem 11:337–348

Zheng J, Graff RA, Fillos J, Rinard J (1998) Incorporation of rapid thermal conditioning into wastewater treatment plant. Fuel Process Technol 56:183–200