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Impact of Temperature and Coagulants on Sludge Dewaterability

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Abstract. Temperature and coagulant types have an important impact on the quantity and quality of the residue (sludge) in water and wastewater treatment processes. Temperature influences water viscosity and the distribution of the coagulant in water. Coagulants can promote the agglomeration of fine particles into larger flocs so that they can be more easily separated from the water. Experiments have been conducted to explore the relationship between temperature (16-26°C), the type of coagulant, and sludge dewaterability (estimated using the capillary suction time (CST)). Alum, Ferric, and *Moringa oleifera* Lam were used as coagulants. The influences of different mixer shapes, turbidity values, and flocs sizes on sludge dewaterability have been assessed. The results show that ferric chloride was unaffected by temperature, whereas alum and *M. oleifera* performances were influenced by temperature. CST results using the coagulant ferric chloride, regardless of mixer shape, turbidity, and floc size, were insensitive to temperature differences.

Keywords: Capillary suction time; Coagulants; Floc sizes; Sludge dewaterability; Temperature

1. Introduction

A large volume of sludge is produced by water and wastewater treatment plants every day, and; unfortunately, this is unavoidable in water and wastewater treatment processes. Hernando et al. (2010) estimated that around 40% of the treatment costs of a typical treatment plant are linked to dewatering and the disposal of sludge. In modern societies where populations are globally increasing, and access to sewage and water treatment has become easier, the amount of sludge increases steadily. The type of treatment process in the wastewater plant defines the quality and quantity of sludge (Sanin et al., 2011). Considered one of the mostimportant issues related to sludge management, dewatering sludge is also the most expensive process in water and wastewater treatment plants (Jin

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et al., 2004). Basically, the chemical composition and physical configuration of the flocs or solid particles that form the sludge determine the dewaterability characteristics of sludge (Verrelli et al., 2009). When treating water in water and wastewater treatment plants, a number of process phases are performed to remove contaminants. According to Zhan et al. (2011), coagulation is identified as one of the significant elements within the treatment process, whilst Diaz et al. (2011) and Verrelli et al. (2009) stressed the importance of the coagulation's influence on both production and the dewaterability of sludge.

Temperature and type of coagulant are equally effective on the coagulation efficiency (Duan & Gregory, 2003; Rodrigues et al., 2008). Temperature can affect the metal ion hydrolysis reaction rate (Inam et al., 2021). A higher temperature causes an enhanced reaction rate and vice versa. Furthermore, Duan and Gregory (2003) emphasize that temperature is a significant parameter in determining the distribution of the coagulant and the formation of the hydrolysis products. In turn, it will also affect the coagulation and flocculation efficiency (Gao et al., 2005).

Low reaction rates produce an inhomogeneous distribution of coagulation species caused by ineffective coagulation that results from low water temperature. In fact, water temperature not only affects the performance of coagulation in general, but also differentiates the efficiency of different types of coagulants (Duan & Gregory, 2003), and the removal of turbidity (Xiao et al., 2009).

Literature highlights research work conducted on the effect of temperature on coagulant efficiency (Xiao et al., 2008; Xiao et al., 2009). However, contradictory results have been reported. Some of the findings indicated that temperature does have an impact on coagulation efficiency (Xiao et al., 2008; Xiao et al., 2009). Comparing alum with ferric performances, Duan and Gregory (2003) found that ferric has a better performance than alum under low-temperature conditions.

Many coagulants have been commonly used in conventional water resources recovery facilities (Duan & Gregory, 2003). Coagulants can be inorganics (e.g., aluminium sulphate and ferric sulphate), synthetic organics (e.g., polyacrylamic derivatives), or natural flocculants (microbial flocculants). These have different impacts on the coagulation process (Karamany, 2010). Alum and ferric chloride-based salts such as alum, aluminium chloride, ferric chloride, and ferric sulphate are frequently used as traditional coagulants (Bektas, 2004). Alum and ferric can have good coagulant properties (Lubis et al, 2019).

Natural coagulants like *M. oleifera* can also be used as a substitute for metal-based coagulant in selected water and wastewater treatment processes such as coagulation and flocculation (Tat et al., 2010). *Moringa oleifera* is a pan-tropical, multi-purpose tree, the seed from which contains high-quality edible oil (up to 40% by weight) and water-soluble proteins that act as an active agent for water and wastewater treatment. The further advantage of using *M. oleifera* include safe, natural, and environmentally friendly coagulant handling processes (Bhatia et al., 2007).

Capillary suction time (CST) is a measurement of sludge dewaterability properties. It can be used for the rapid determination of filterability after the addition of coagulant aids (Scholz, 2005). Sawalha and Scholz (2012) observed that the results of CST tests were sensitive to variations in temperature. The results tend to reduce with higher temperatures, probably due to the increase in filtrate viscosity with increasing temperature.

Despite differences in coagulant performance responding to temperature variation, further research is needed to investigate the correlation between temperature and coagulants on sludge dewaterability. This paper aims to assess the impact of (a) different temperatures on sludge dewaterability indicated by CST values using alum, ferric chloride, and *M. oleifera* as coagulants, and (b) different temperatures on sludge dewaterability indicated by turbidity and median floc size using ferric chloride or alum as a coagulant.

2. Methods

The key measurement of the efficiency with respect to the sludge dewatering process is traditionally the CST value. The CST apparatus and associated equipment have been described with the support of photos by Scholz (2005). Coagulation experiments (three replicates each, variability of around 7%) were undertaken to explore the influence of each variable on CST. Mean values were subsequently presented on graphs. The materials and methods section covers an overview of the coagulants and mixers (Fitria et al., 2013) used as an indication of how samples were prepared and an outline of the coagulation and temperature experiments.

2.1. Coagulants

The coagulants alum, ferric chloride, and *M. Oleifera* have been investigated. Alum and ferric stock solutions were prepared by diluting alum sulphate and ferric chloride with distilled water each to produce alum and ferric solutions. Moreover, defatted and shell-free *M. oleifera* powder (flocculating agent) was mixed with distilled water by using a magnetic stirrer for five minutes to obtain an *M. oleifera* solution. Optimum coagulant concentrations were used where alum, ferric chloride, and *M. Oleifera* were 21 mg Al/l, 17 mg iron/l, and 80 mg *M. oleifera*/l, respectively. The optimum coagulant concentration was determined by experimenting with different coagulant concentrations, plotting them against CST producing graphs demonstrating the optimum coagulant concentrations.

2.2. Mixers

In this research, five shapes of mixers have been used (radial, axial, wheel, magnetic and 3-blades) to disperse the coagulant into the water to be ‘treated’. Different mixer shapes have different power numbers, producing different mixing energy (Tchobanoglous et.al, 2003). To analyse the temperature’s effect on coagulant performance, an examination of the influence of all mixers on the sludge dewaterability process is needed.

2.3. Kaolin Solution Preparations

A kaolin solution was used in this study. Sample preparation was undertaken by adding 10 mg kaolin to 1000 mL distilled water, resulting in a solution comprising about 1% total suspended solids.

2.4. Temperature Experiments

Room temperature (20°C±1°C) was chosen as a general temperature applied for all investigations unless stated otherwise. The reason is that it reflects well the laboratory temperatures present in a lot of temperate and oceanic regions. To eliminate temperature effects on the CST measurements, this value was constantly maintained. Additionally, to simulate field (i.e., outside) measurements, temperatures of 16°C±1°C and 26°C±1°C have been applied during spring and autumn, and summer, respectively. In the case of laboratories located in warmer countries, the operating temperatures may also be reflected by selecting higher temperatures. However, temperature adjustment can be executed in most laboratories to acquire all target temperatures.

2.5. Coagulation Experiments

The coagulation experiment was started by pouring 100-ml synthetic water into a glass beaker, followed by the coagulant. The pH value was adjusted using sulphuric acid (H_2SO_4) or sodium hydroxide (NaOH) to reach a pH value of approximately 6.5, followed by a rapid mix at a high variable rate (60, 65, 70, 75, 80, 85, 90, 95 and 100 rpm) for 1 minute and then at a moderate rate of 50 rpm for 15 minutes. Sedimentation was allowed for 15 minutes. The supernatant was removed carefully by decanting, and the sludge was characterised in terms of dewaterability, turbidity, and floc size.

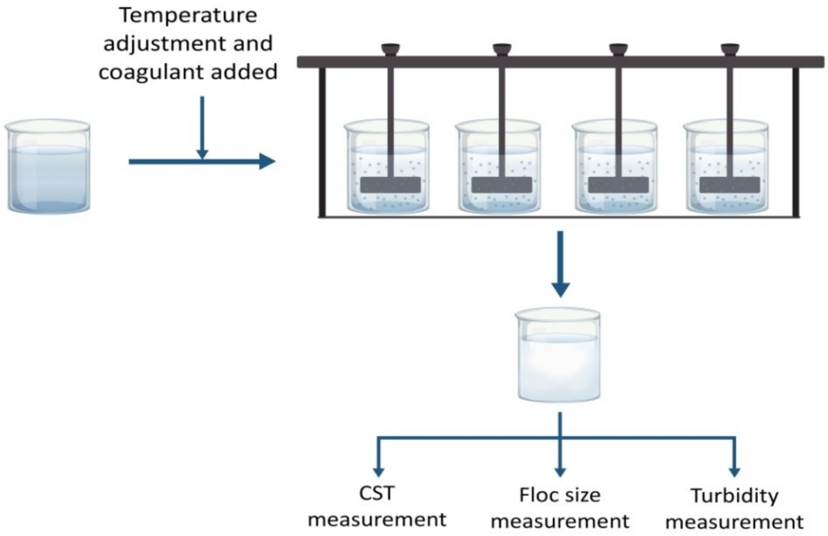

Figure 1 Coagulation Experimental Process

2.6. *Sludge Dewaterability Measurement*

The dewaterability of the settled sludge (residue) was measured by the CST apparatus using CST paper (Whatman 17 chromatographic paper) provided by Triton Electronics.

2.7. *Turbidity Measurement*

The turbidity of the supernatant was determined by a Lovibond turbidity meter.

2.8. *Floc Size Measurement*

The synthetic sludge was also characterized by analyzing the distribution of particle sizes with a particle size analyzer (Horiba Laser Scattering Particle Size Analyzer LA-950)

3. Results and Discussion

3.1. *Alum as a Coagulant*

The research assessed the influence of different temperatures on sludge dewaterability using three different coagulants. For the first stage, alum sulphate ($Al_2(SO_4)_3$) was used as a traditional coagulant to assess the effect of temperature on the CST value. The impact of room temperature (20°C) was compared with an elevated temperature of 26°C.

Figure 2 indicates the influence of different temperatures. All of the results, in general, showed that a temperature of 26°C has lower CST values compared to a temperature of 20°C. This indicates that alum performance is affected by temperature. Duan and Gregory (2003) pointed out that a more effective coagulant distribution is easier and faster to achieve at high compared to low temperatures. Both the temperature and floc properties are important factors in sludge dewatering (Lee & Liu, 2001). Water was released from the experimental alum sludge more readily at elevated temperatures, which resulted in CST values being higher at 20°C compared to 26°C.

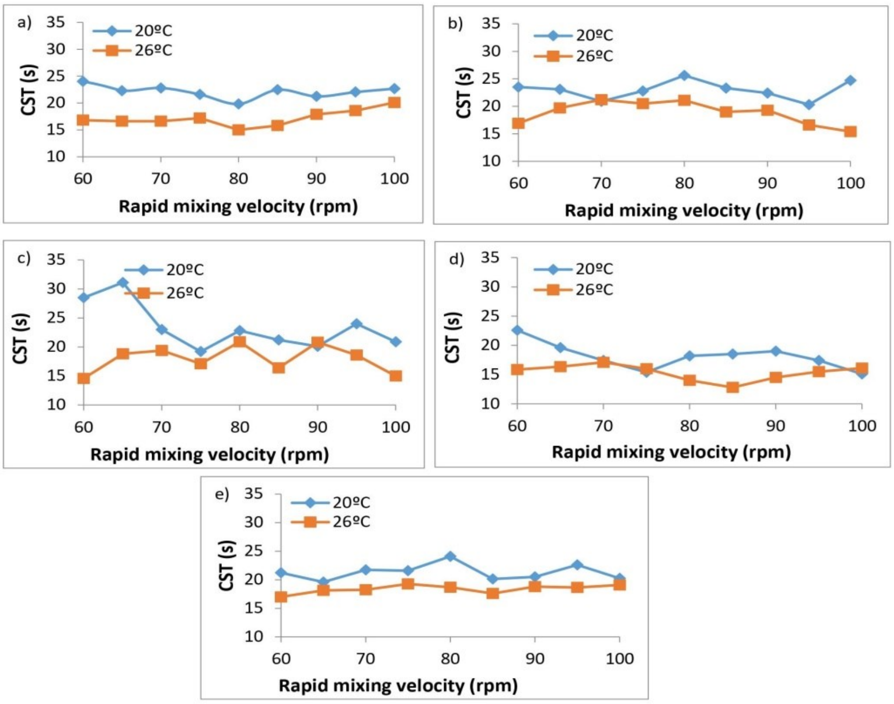

Figure 2 Impact of different mixer types ((a) radial, (b) axial, (c) wheel, (d) magnetic, and (e) 3-blades), temperatures and mixing velocities on sludge dewaterability indicated by capillary suction time (CST) using alum as a coagulant

3.2. Ferric Chloride as a Coagulant

Figure 3 shows in relation to temperature measurements that there is no significant (p<0.05) impact on the CST value when ferric chloride($FeCl_3$) is used as a coagulant.

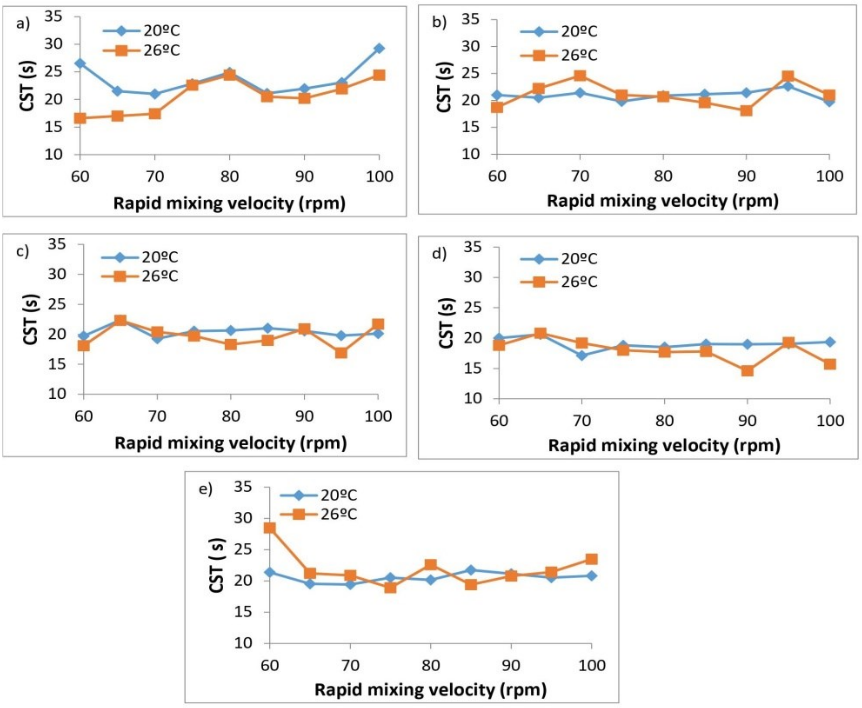

Figure 3 Impact of different mixer types ((a) radial, (b) axial, (c) wheel, (d) magnetic, and (e) 3-blades), temperatures and mixing velocities on sludge dewaterability indicated by capillary suction time (CST) using ferric chloride as a coagulant

All results show that CST values are nearly the same when responding to different temperatures. Past observations can explain this: reduced amounts of soluble oxygen and the formation of iron salts were inhibited by protons resulting from an increase in temperature (Vilcaez et al., 2009).

A slight but insignificant increase of CST with increasing rapid mixing was noted for the radial mixer. This increase might be due to the mixer shape used. Although the comparison was made repeatedly using different types and shapes of mixers, findings still indicate that the performance of ferric chloride is not impacted by temperature. In contrast, other investigations have shown that ferric chloride as a coagulant was influenced by temperature (Duan & Gregory, 2003; Inam et al., 2021).

3.3. *Moringa oleifera as a Coagulant*

As an alternative and more sustainable coagulant with high popularity in developing countries (Ahmed et al., 2010), *M. oleifera* was also assessed in this study. The flocculating protein from the seeds of *M. oleifera* is comparable to that of a cationic polymer on a polyacrylamide basis. The effects of different types and shapes of mixers and different temperatures on the CST value were evaluated (Figure 4).

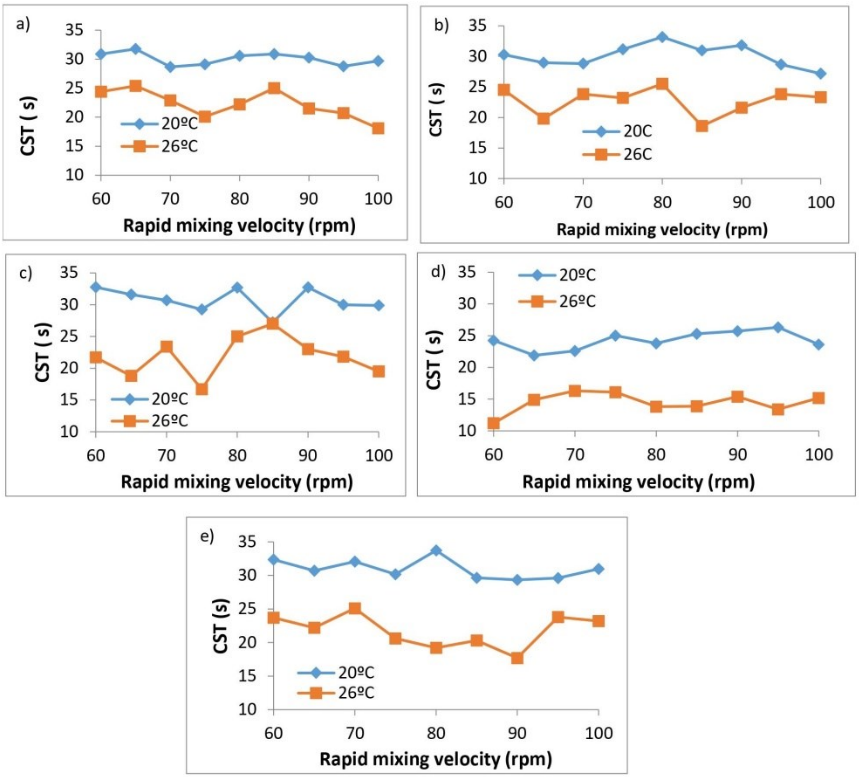

Figure 4 Impact of different mixer types ((a) radial, (b) axial, (c) wheel, (d) magnetic and (e) 3-blades), temperatures and mixing velocities on sludge dewaterability indicated by capillary suction time (CST) using *Moringa oleifera* Lam. as a coagulant

The impact of different mixer types and shapes (i.e. radial, axial, wheel, magnetic and 3-blade) had virtually no impact on CST. However, different temperatures had different impacts on the CST value. Experiments undertaken at 20°C produced higher CST values compared to those at 26°C. This can be attributed to the effect of viscosity, which increases as the temperature decreases (Sawalha & Scholz, 2012). Moreover, *M. oleifera* proteins seem to be more active at a higher temperature, increasing sludge dewaterability. At relatively high temperatures, the coagulation process is more effective, because the coagulant is distributed better in the wastewater. This improves the contact between the coagulant and the colloid particles (Gao et al., 2005).

3.4. Impact of Different Temperatures on Capillary Suction Time

Temperature affects water and synthetic sludge viscosities. In theory, the synthetic sludge viscosity reduces at a relatively high temperature, and subsequently, water within the synthetic sludge is released more readily. This suggests that the time required for sludge dewatering reduces as the temperature increases (Scholz and Sawalha, 2012).

Temperature fluctuations impact on the CST values and the coagulation process. The higher CST means, the harder is the dewaterability of the sludge. Lower CST values indicate easy dewaterability of sludge. Table 1 indicates the influence of temperature on the performance of the coagulants alum, ferric chloride, and *M. oleifera* at optimum concentrations. CST value reductions (%) due to different treatment processes are compared to the initial CST value at 0 rpm.

Table 1 Comparison of different temperature effects on capillary suction time(CST) value reduction

Coagulant	Temperature (°C)	CST value reduction for different mixer shapes (%)					Average (%)
		Radial	Axial	Wheel	Magnetic	3-Blades	
Alum	20	40.26	37.96	36.70	50.99	42.41	41.66
	26	31.29	24.58	28.19	38.58	26.44	29.82
Ferric	20	40.85	47.43	48.70	52.18	48.34	47.50
	26	48.42	46.91	50.56	54.86	45.02	49.15
M. oleifera	20	-2.63	-2.76	-4.98	17.12	-5.64	0.22
	26	3.66	1.78	5.97	34.63	3.04	9.81

Using alum and *M.oleifera* shows that as temperature increases, CST values decrease. Ferric applications may result in different results where the use of ferric chloride seems to be largely unaffected by temperature. Using ferric, the percentages of CST value reductions at 20°C and 26°C are almost similar for all mixer shapes. However, this is not the case when a radial mixer is used. These findings will support treatment facility operators in using the right mixer and most appropriate coagulant for different temperature scenarios. For example, if temperature fluctuations between 20°C and 26°C are common, an axial mixer and ferric chloride should be used to obtain stable results.

The negative CST value of *M. Oleifera* means the dewaterability of sludge after coagulation process is lower compared to the sludge before the coagulation at 0 rpm. The *M. oleifera* CST value is lower than those for alum and ferric. This means that the sludge produced by this natural coagulant is easier to be dewatered than those sludges where alum and ferric were used. Alum and ferric produce coagulant hydrolysis products (Sharfan et al., 2018). On the other hand, *Moringa oleifera* does not yield coagulant hydrolysis products. The agglomeration happens as a result of adsorption and charge neutralization processes of the contaminant by *Moringa oleifera*'s active protein (Bhatia et al., 2007; Kristianto et al., 2018). It seems that the agglomeration due to adsorption and charge neutralization is more effective in terms of dewaterability compared to the agglomeration produced by hydrolysis products.

3.5. Impact of Different Temperatures on Floc Size

In order to obtain a more realistic result concerning the influence of temperature on the CST value using ferric chloride as a coagulant, additional experiments were conducted at a lower than normal laboratory temperature (16°C) and floc size. An axial paddle was used as the only mixer in this floc size study. The axial paddle was chosen at random, considering that all five types of mixers produced similar results, indicating that any mixer could be representative for the purpose of this part of the study.

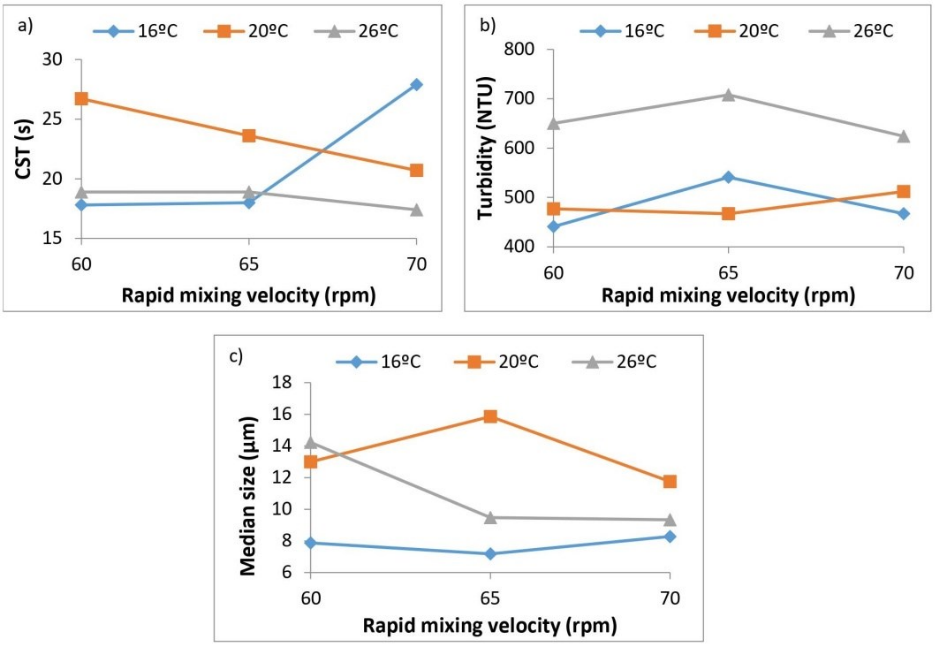

Figure 5 Impact of different temperatures and mixing velocities on synthetic sludge dewaterability indicated by (a) capillary suction time (CST), (b) turbidity and (c) median floc size using ferric chloride as a coagulant and an axial mixer

Figure 5 indicates that at diverse temperatures, ferric chloride has different effects on CST, turbidity and the floc size. No effect linked to synthetic sludge dewaterability was witnessed. The relatively high CST at elevated rapid mixing values is statistically not significant (Figure 5a). The turbidity and particle size findings confirm that synthetic sludge dewaterability is virtually unaffected by temperature.

4. Conclusions and Recommendations

Findings illustrate that CST values are altered by differences in temperature (between 16 and 26°C) for the coagulants alum and *M. oleifera*. An increase in temperature lowers the CST value, which can be explained by the change in synthetic sludge viscosity. In comparison, ferric chloride is virtually unaffected by temperature, which has been confirmed by turbidity and floc size results. If temperature fluctuations are between 20°C and 26°C, an axial mixer and ferric chloride should be used to obtain stable results. *M.oleifera* performed better at higher temperatures. Further investigations should explore more the relationship between other variable combinations, such as temperature and *M. oleifera*, using wider numerical ranges. A study on the deterioration of *M. oleifera* solutions is also recommended. Synthetic sludge has been used for reference purposes and to keep the number of variables low. Further research should also look at the assessment of dewaterability tests as a function of more specific sludge types obtained directly from the industry. The relationship between CST, specific resistance to filtration and other sludge dewaterability tests should be assessed for real sludges under dynamic environmental boundary conditions. Finally, the authors recommend to develop the CST test further to create a new sludge dewaterability test that addresses identified shortcomings with the CST such as temperature dependency.

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References

Ahmed, T., Kanwal, R., Hassan, M., Ayub, N., Scholz, M., 2010. Coagulation and disinfection in water treatment using *Moringa.Water Management*, Volume 163(8), pp. 381–388

Bektas, N., Akbulut, H., Inan, H., Dimaglo, A., 2004. Removal of Phosphate from Aqueous Solutions by Electro Coagulation. *Journal of Hazardous Materials*, Volume 106(2–3), pp. 101–105

Bhatia, S., Othman, Z., Ahmad, A.L., 2007. Coagulation–flocculation Process for POME Treatment using *Moringa oleifera* Seed Extract: Optimization Studies. *Chemical Engineering Journal*, Volume 133(1-3), pp. 205–212

Duan, J., Gregory, J., 2003. Coagulation by Hydrolysing Metal Salts. *Advances in Colloid and Interface Science*, Volume 100–102, pp. 475–502

Diaz, C.B., Barrera, G.M., Gencel, O., Martinez, L.A.B., Brostow, W., 2011. Processed Wastewater Sludge for Improvement of Mechanical Properties of Concrets. *Journal of Hazardous Materials*, Volume 192(1), pp. 108–115

Fitria, D., Swift, G.M., Scholz, M., 2013. Impact of Different Shapes and Types of Mixers on Sludge Dewaterability. *Environmental Technology*, Volume 34(7), pp. 931–936

Gao, B.Y., Cu, Y.B., Yue, Q.Y., Wang, B.J., Wang, S.H., 2005. Characterization and Coagulation of Polyaluminum Chloride (PAC) Coagulant with High Al_{13} Content. *Journal of Environmental Management*, Volume 76(2), pp. 143–147

Inam, M. A., Khan, K., Lee, K. H., Wie, Y. M., 2021. Removal of Arsenic Oxyanions from Water by Ferric Chloride-Optimization of Process Conditions and Implications for Improving Coagulation Performance. *International Journal of Environmental Research and Public Health*, Volume 18(18), 9812

Jin, B.,Wilén, B., Lant, P., 2004. Impacts of Morphological, Physical and Chemical Properties of Sludge Flocs on Dewaterability of Activated Sludge. *Chemical Engineering Journal,* Volume 98(1-2), pp.115–126

Karamany, H.E., 2010. Study for Industrial Wastewater Treatment using Some Coagulant. Fourteenth International Water Technology Conference, IWTC 14 2010, Cairo, Egypt

Kristianto, H., Paulina, S., Soetedjo, J.N.M., 2018. Exploration of Various Indonesian Indigenous Plants as Natural Coagulants for Synthetic Turbid Water. *International Journal of Technology*. Volume 9(3), pp. 464-471

Lee, C.H., Liu, J.C., 2001. Sludge Dewaterability and Floc Structure in Dual Polymer Conditioning. *Advances in Environmental Research*, Volume 5, pp. 129–136

Lubis, M., Fujianti, D., Zahara, R., Darmadi, D., 2019. The Optimization of the Electrocoagulation of Palm Oil Mill Effluent with a Box-Behnken Design. *International Journal of Technology*. Volume 10(1), pp. 137-146

Qi, Y., Thapa, K.B. and Hoadley, A.F.A., 2011 Application of Filtration Aids for Improving Sludge Dewatering Properties–A Review. *Chemical Engineering Journal*, Volume171(2), pp. 373–384

Rodrigues, A.C., Boroski, M., Shimada, N.S., Garcia, J.C., Nozaki, J., Hioka, N., 2008. Treatment of Paper Pulp and Paper Mill Wastewater by Coagulation Flocculation Followed by

Heterogeneous Photocatalysis. *Journal of Photochemistry and Photobiology A: Chemistry*, Volume 194(1), pp. 1–10

Sharfan, N., Shobri, A., Anindria, F.A., Mauricio, R., Tafsili, M.A.B., Slamet, 2018. Treatment of Batik Industry Waste with a Combination of Electrocoagulation and Photocatalysis. *International Journal of Technology*. Volume 9(5), pp. 936-943

Sawalha, O., Scholz, M., 2012. Impact of Temperature on Sludge Dewatering Properties Assessed by the Capillary Suction Time. *Industrial and Engineering Chemistry Research*, Volume 51(6), pp. 2782–2788

Scholz, M., 2005. Review of Recent Trends in Capillary Suction Time (Cst) Dewaterability Testing Research. *Industrial & Engineering Chemistry Research*,Volume 44(22), pp. 8157–8163

Tat, W.K., Idris, A., Noor, M.J.M.M., Mohamed, T.A., Ghazali, A.H., Muyibi, S.A., 2010 Optimization Study on Sewage Sludge Conditioning using *Moringa Oleifera* Seeds. *Desalination and Water Treatment*, Volume 16(1–3), pp. 402–410

Tchobanoglous, G., Franklin, L., Burton, H., Stensel, D., 2003. *Wastewater Engineering: Treatment and Reuse*. Mc Graw Hill, New York

Verrelli, D.I., Dixon, D.R., Scales, P.J., 2009. Effect of Coagulation Conditions on the Dewatering Properties of Sludges Produced in Drinking Water Treatment. *Colloids and Surfaces A: Physicochemical Engineering Aspects,* Volume348(1-3), pp. 14–23

Vilcaez, J., Yamada, R., Inoue, C., 2009. Effect of pH Reduction and Ferric Ion Addition on the Leaching of Chalcopyrite at Thermophilic Temperatures. *Journal of Hydrometallurgy*, Volume 96(1–2), pp. 62–71

Xiao, F., Huang, J.C.H., Zhang, B., Cui, C.W., 2009. Effects of Low Temperature on Coagulation Kinetics and Flocsurface Morphology using Alum. *Desalination*, Volume 237, pp. 201–213

Xiao, F., Ma, B., Yib, P., Huang, J.C.H., 2008. Effects of Low Temperature on Coagulation of Kaolinite Suspensions. *Water Research*, Volume 42, pp. 2983– 2992