Efficiency of *Moringa Oleifera* and Polyaluminium chloride for sludge thickening

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Abstract

The viability of using *Moringa Oleifera* seed extract as a plant based coagulant in comparison to Polyaluminium Chloride a commonly used chemical coagulant for the thickening of activated sludge was investigated. *Moringa Oleifera* also known as the drumstick tree or horseradish is widely found throughout Mauritius. This tree is considered as a miracle tree by many researchers due to its numerous benefits ranging from purification of water to the manufacture of oil and biodiesels. To investigate the coagulant properties of the *Moringa Oleifera* and Polyaluminium Chloride, the zone settling test and the jar test were conducted. The zone settling tests and the jar tests showed a difference ranging from 2.1%-4.8% for the first 30 minutes for *Moringa Oleifera* and Polyaluminium Chloride which showed similar coagulant relationship. Thus *Moringa oleifera* was found to be as efficient as Polyaluminium chloride and can thus be easily used as a natural coagulant.

Keywords: *Moringa Oleifera; Polyaluminium chloride; activated sludge; natural coagulant; flocculation*

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1. INTRODUCTION

Water issue is definitely one of the most important factor that is related to the human development as human lives are very dependent on it (Antov et al. 2012). Mauritius has a successful development history which is largely due to the exceptional use of trade for sugar and clothing exports. Water is very crucial in sustaining a continuous improvement trend in the development of a country. In 2012, an average of 800 million m^3 total water consumption was estimated. Due to the high water consumption of the agricultural sector and severe drought faced by the country in the past three years, Mauritius has to seriously consider collecting used water from the other sectors as a resource that can be reused rather than using potable water to be able to meet the population's demand.

Wastewater contains a large amount of biosolids and residuals (Metcalf & Eddy, 2003) which account for a major portion of the cost of wastewater treatment (WWT) and requires significant technological challenges (Niu et al. 2003). Therefore, cost effective and sustainable solutions must prevail by focusing researches on primary natural sources so as to decrease the dependency on the use of chemical additives for WWT leading to an improvement in treatment facilities. This is why the use of a natural coagulant for WWT has been studied so as to bring down the cost of treatment.

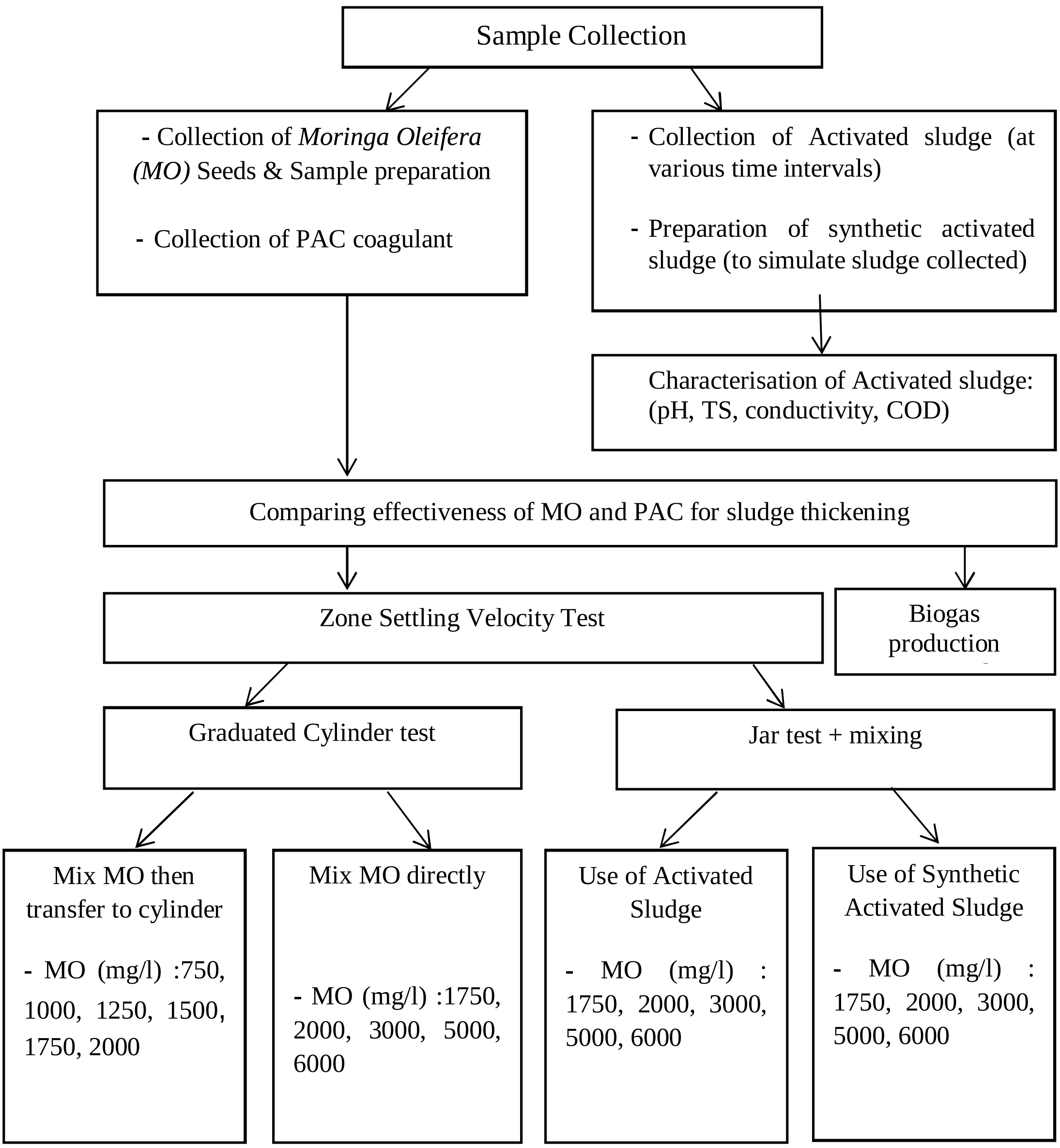
Sludge consists of all the solid by-products and the resulting liquid from the WWT (Andreoli et al., 2007). The reduction of sludge volume is the most important process in sludge treatment as it reduces the cost of transportation and handling (Qi et al. 2011). So, the greater the efficiency of the liquid/solid separation and the rate at which it occurs, the more successful is the sludge management. The sludge thickening and disposal cost of a wastewater treatment plant may account up to 50% of the total treatment cost (Appels et al. 2008). Thickening is a method employed for the removal of a large portion of water thus, increasing the solid content. Its main working principle is to allow suspended particles to settle under the action of gravity (Metcalf & Eddy, 2003). However, thickening is not only dependent on the equipment specifications but also upon the settling characteristics of the suspension in the sludge (Grassia et al. 2014). This, the settling velocity based on Stokes law (Vahedi and Gorczyca, 2014) was considered and tested for the natural and chemical coagulant under study.

Amongst other methods used in sludge management before disposal, anaerobic digestion is considered to be more efficient as the process stabilises the sludge by removing further organic matter, reduces the volumes of the sludge, decreases odour, while generating methane (Duan et al. 2012; Young et al. 2013). Consequently, the biogas production potential via anaerobic digestion using both types of coagulant has also been studied and compared.

Sludge conditioning is a necessary step where the addition of coagulants and flocculants (Pillai, 2004) to the sludge, help it to agglomerate into larger, denser particles thus increasing their size (Hu et al. 2006; Qasim et al. 2002). The addition of the conventional chemical coagulants namely alum ($AlCl_3$), polyaluminium chloride (PAC), ferric chlorides ($FeCl_3$) and synthetic organic polymers (Kang et al. 2003) have already proven their effectiveness as coagulants, nevertheless there exists many disadvantages associated with their usage in the treatment plants. Some of these drawbacks are that chemical coagulants are relatively expensive to acquire, and are considered to be ineffective at low temperature. There are also chemical coagulants which produce a larger amount of sludge and have the potential of affecting the environment quality (Tatsi et al. 2003). Lastly, there is strong evidence linking the use of aluminium based coagulant to the development of Alzheimer's disease (Ganvir and Das, 2011). Hence, the performance of natural coagulant as an alternative to chemical coagulant has been studied in this project.

The core aim of this study consists of investigating the possibility of using MO seed extract as a natural coagulant with the objective to potentially replace PAC (conventional chemical based coagulants) in the thickening of activated sludge (AS). The MO is widely found throughout India, Asia, Sub Saharan Africa and Latin America (Sanghi et al. 2002) as well as in Mauritius. It contains active cationic proteins (Ghebremichael et al. 2005) which are positively charged and can therefore act promptly as a coagulant by adsorbing the negatively charged particles and neutralising them, enabling the particle to agglomerate (Ndabigengesere et al.1995). For this research project, the gravity thickening and AD treatment processes will be considered for the determination of the effectiveness of each coagulant.

2. MATERIALS AND METHODS



To investigate the efficacy of the natural coagulant, *Moringa Oleifera*, in comparison with chemical coagulants for activated sludge thickening, a series of tests were performed. All the tests were mainly adapted to the APHA 1998 standard methods. Three phases of practical works were involved; in the first phase, the zone settling rate was investigated for both natural and chemical coagulant with a graduated measuring cylinder. In the second stage, the settling rate was investigated by jar test with slow mixing. In the third phase, an anaerobic digestion was done to monitor the biogas produced daily.

2.1 Preparation of materials

2.1.1. Activated sludge

The activated sludge for the present study was obtained from the Airport of Mauritius Limited's sewage treatment plant, upon request made to Manser Saxon Contracting Limited, who is responsible for the proper operation and maintenance of the plant. Sampling of the sludge was carried out at the outlet of the aeration tank prior to the secondary settling tank and was free form any chemical additives. These experiments were conducted within 7 days after sampling (Niu et al. 2013). The samples were collected at different time during the experimental works. This corresponds to a number of different batches with a total solid concentration which ranges from 4750 to 7600 mg/L, pH of 6.8 to 7.4, conductivity of 463 to 710 s/m and a COD value of 515 to 852 mg/l.

2.1.2. Synthetic sludge

A batch of synthetic sludge was prepared to test the effectiveness of the coagulants. In order to simulate the desired turbidity of an activated sludge, 7.6 grams of soil and 1 litre of distilled water was mixed together to prepare an artificial sample of total solid concentration of 7600 mg/l and a pH of 6.4 and was left overnight to allow the small particles to dissolve in the water.

2.1.3. Poly aluminium chloride coagulant (PAC)

PAC was provided by Manser Saxon Contracting Limited in powdered form with an aluminium concentration of 17%. The powder is of a pale yellow colour and gives a yellow solution when dissolved in water with a pH of 1.9 – 2.7. Some preliminary tests were undertaken to estimate the concentration of PAC needed to treat 1 litre of AS. It was found that its optimum value was around 22 mg of PAC.

2.1.4. *Moringa Oleifera* (MO)

Mature seeds were extracted from the MO pods (and seeds with no sign of discoloration and softening were selected). The kernels were then extracted from the winged seeds. These kernels were grounded and sieved to 600 m to enable maximum solubility of the active components in water and solutions prepared were kept under refrigerated conditions to avoid any ageing effects such as change in pH, coagulation property amongst others (Pritchard et al. 2010).

Table 1: Stock concentration of MO

Concentration, mg/l	**15,000**	**20,000**	**25,000**	**30,000**	**35,000**	**40,000**
Mass of MO seed powder used, g	3.75	5.00	6.25	7.50	8.75	10.00
Volume of distilled water used, ml	250	250	250	250	250	250

2.2 Zone settling velocity test

The zone settling velocity test was performed to compare the effectiveness of the different coagulants by determining the percentage reduction of the solids/liquid interface and the settling velocity of the solids. This method was selected as several studies have used these procedures to evaluate the effect of sludge conditioning using different coagulants. High concentrations of suspended solids is known to settle in the zonal settling where the coagulated particles form a compact mass and settle as 1 unit. This zone can be identified by the distinct interface between the solid settled and the supernatant liquid. The settling rate was evaluated by measuring the height of the sludge interface against time along which the interface reduction was also calculated.

2.2.1. Batch 1

50 ml of MO was transferred to 1 litre of activated sludge and was stirred for 2 minutes and then transferred in a cylinder. The height of the liquid/ solids

interface was recorded every one minute interval over a 30 minutes period. The experiments were repeated with other concentration of MO stock solution.

Table 2: Concentration of different coagulant used, during experiment 1 (Batch 1)

Volume of sludge used, L	**1**	**1**	**1**	**1**	**1**	**1**
Stock solution concentration of MO, mg/l	15,000	20,000	25,000	30,000	35,000	40,000
Volume of stock solution used, ml	50	50	50	50	50	50
Dosage of MO to treat sludge, mg/l	750	1000	1250	1500	1750	2000
Stock solution concentration of PAC, mg/l	2200	2200	2200	2200	2200	2200
Volume of stock used, ml	10	10	10	10	10	10
Dosage of PAC to treat sludge, mg/l	22	22	22	22	22	22

2.2.2. Batch 2

MO seed powder was added directly to the activated sludge sample because a dosage of more than 2000 mg/l MO tends to produce a high saturated mixture. Different masses of MO powder ranging from 1.75 g to 6 g were added to treat 1 litre of AS sample. The interface height at intervals of 1 minute was recorded but the settling period was extended to 5 hours to be able to observe any change in the settling trend. This dosage was compared with the optimum concentration of PAC needed and a control with no additive.

Table 3: Concentration of different coagulant in experiment 2 (Batch 2)

Volume of sludge used, L	**1**	**1**	**1**	**1**	**1**	**1**
Mass of MO powder used, g/l	1.75	2.0	3.0	4.0	5.0	6.0
Dosage used to treat sludge, mg/l	1750	2000	3000	4000	5000	6000
Stock solution concentration of PAC, mg/l	2200	2200	2200	2200	2200	2200
Volume of stock used, ml	10	10	10	10	10	10
Dosage of Pac to treat sludge, mg/l	22	22	22	22	22	22

2.3 Jar test

The jar test is a very determinant procedure to identify the action of *Moringa Oleifera* seed extract on the activated sludge due to continuous mixing. The standard methods suggested the use of a jar test apparatus with 6 mixing mechanism. However, due to lack of apparatus, a different set up was considered with the use of 1 mixer with a marine- type pitched-blade axial-flow impeller with 3 blades. Normally, the coagulation and flocculation effect of any coagulant is conducted by the jar test experiment and many experimental works have adopted this method (Bhuptawat et al. 2007; Kim et al. 2013; Pritchard et al. 2010). The jar test requires different combination of slow and rapid mixing processes prior to the sedimentation process. Katayon et al. (2007) stated that in the speed of rotation must be changed accordingly to promote flocculation.

2.3.1. Batch 1

One litre of activated sludge was added to a beaker and the agitation was set at 20 rpm. The required dosage of MO was added to the sludge. The mixer was then agitated at a higher speed of 120 rpm for 2 minutes, followed by a slow mixing of 80 rpm for 10 minutes and finally at 20 rpm for the rest of the experiment

(Bhuptawat et al. 2007; Katayon et al. 2007). The sludge was then allowed to settle at 20 rpm for 5 hours.

Table 4: Concentration of coagulants used in jar test 1

Volume of sludge used, L	1	1	1	1	1
Mass of Mo used, g	1.75	2	3	5	6
Dosage of MO used, mg/l	1750	2000	3000	5000	6000
Stock solution concentration of PAC, mg/l	2200	2200	2200	2200	2200
Volume of stock used, ml	10	10	10	10	10
Dosage of Pac to treat sludge, mg/l	22	22	22	22	22

2.3.2. Batch 2

A synthetic sludge sample of 7600 mg/l solid concentration was also evaluated with the jar test experiment. Given that, a lot of difficulty was experienced while measuring the height of the solid/liquid interface, a total solids test was performed instead, to obtain the amount of coagulant needed to have the efficient sedimentation process. The experiment was performed without the use of the continuous mixing mechanism because at the lowest speed, 20 rpm, the agitation seemed to influence the proper settling process of the synthetic sludge by re-suspending the solids that settled out. The dosage used was the same as in experiment 1 (for zone settling velocity test).

2.4. Batch anaerobic process

A batch anaerobic type digestion process was set up to determine the amount of biogas generated when 1 litre of the AS sample is treated with different concentration of coagulants at 25$^{\circ}C$. Three 1 litre AS sample were measured and transferred to three different conical flasks. Two of the samples were treated with PAC (22mg/l), MO (5000 mg/l) and one was left untreated (control). Two

replicates of each sludge samples were prepared so as to serve as cross reference treatment. The mixtures were mixed vigorously. The pH of each sample was recorded. The conical flasks were sealed with rubber stoppers with a connecting tube attached to them. Each bio-digester was connected to a measuring cylinder which served the purpose of gas collectors. The cylinders were filled with water to their edges and then inverted in a plastic container filled with water. This was done to seal the bottom of the gas collector to be able to collect the biogas by downward water displacement. The biogas generated was monitored on a daily basis. The experiment was monitored for 30 days (1 month).

3. RESULTS AND DISCUSSION

3.1 Zone settling velocity test

3.1.1. Batch 1

The experiment 1 of the zone settling velocity test was conducted to find the percentage reduction of the solid/liquid interface height and the settling rate for different samples treated with coagulants under the action of sedimentation. The percentage reduction term refers to the height of the supernatant liquid over the total height of the liquid column. The percentage reduction has been calculated by using:

$$\%\,Height\ Reduction = \frac{(Final\ height - Initial\ height)}{Total\ height\ of\ sludge}$$

This experiment showed that a greater percentage reduction was observed for samples treated with MO. Fig. 1 shows the percentage of the height reduction achieved when activated sludge sample was treated with their respective coagulant concentrations for 30 minutes.

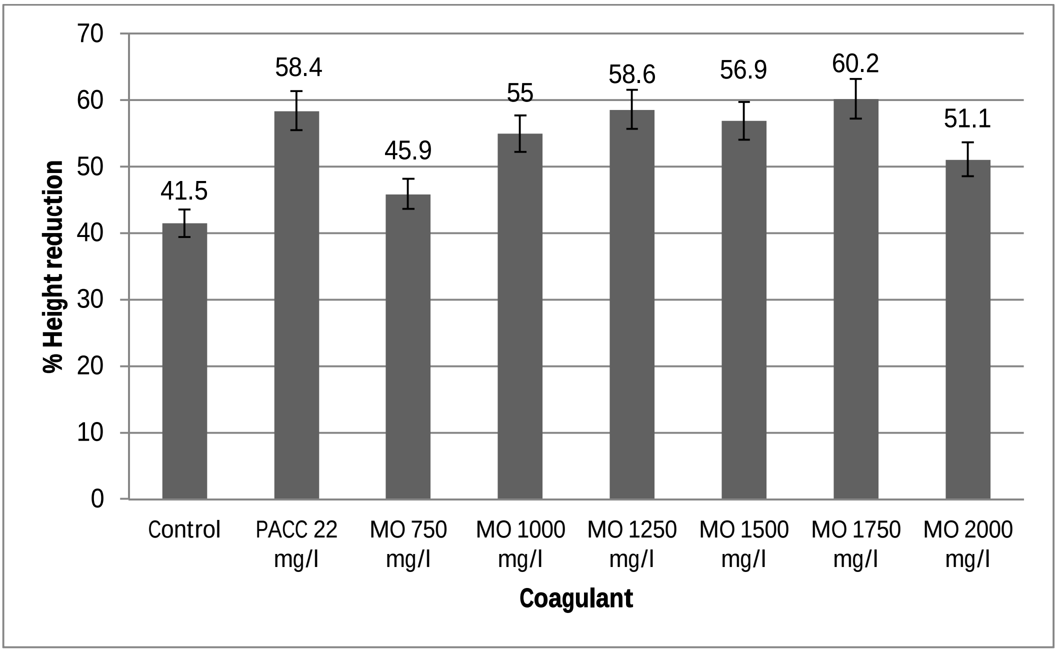


Fig. 1 *Percentage reduction of total height from surface for 30 minutes*

It was observed that the highest percentage of reduction which was 60.2% was achieved in sludge samples treated with 1750 mg of MO which was even greater than PAC (58.4 %). Similarly, as indicated by the percentage reduction, the other dosages of MO also resulted in a higher amount of sedimentation when compared to the control (no coagulant additives) sample (41.5% height reduced). This settling trend implies that the MO seed extract contains some coagulant property.

The zone settling velocity was computed using the following equation:

$$ZSV^{1} = \frac{change\ in\ height\ interface\ (mm)}{time(min)}$$

From the results obtained in Table 5, it can be deduced that the addition of MO in activated sludge samples has some positive effects on the settling rate of the solids particles. So, it can be said that, the cationic electrolytes found in the MO

[1] ZSV – Zone Settling Velocity

seed extract have been able to neutralise the negatively charged suspended particles thus promoting agglomeration of the particles. Therefore, this results in an increase in the settling rate. However, despite that the MO had the highest percentage of reduction, it was also observed that the sludge treated with PAC generates a clearer supernatant compared to the MO. The untreated sample (control) had a greenish colour supernatant indicating the presence of suspended particles

Table 5: Zone setting velocity of the different coagulant loading

	Zone settling velocity, for 30 minutes	
Coagulant	mm/min	cm/min
Control	4.73	0.473
PAC 22 mg/l	6.73	0.673
MO 750 mg/l	5.53	0.553
MO 1000 mg/l	6.63	0.663
MO 1250 mg/l	7.07	0.707
MO 1500 mg/l	6.87	0.687
MO 1750 mg/l	7.27	0.727
MO 2000 mg/l	6.17	0.617

3.1.2. Batch 2

This experiment showed that for the active phase (first 30 min) 22 mg/l PAC performed better than MO which is the contrary of what has happened in the previous experiment (Batch 1). The sample treated with 22 mg/l PAC had a greater percentage reduction (60.5%) than all the other coagulants for the first 30 min. However, the MO dosage of 1750 mg/l generated a higher percentage reduction after 5 hours which resulted in only a difference of 4.8 % reduction between the PAC and 1750 mg/l MO during the active phase. This MO concentration was the second highest reduction obtained as per Fig. 2.

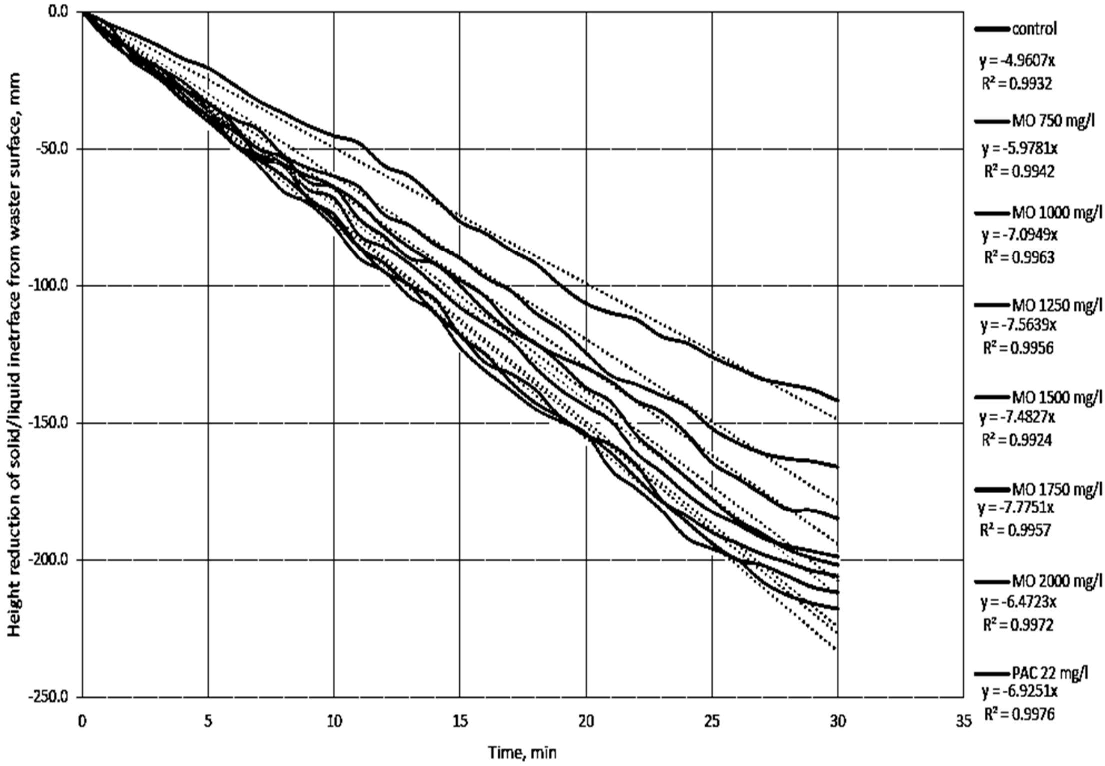


Fig. 2 *Height of solid/liquid interface against time for different coagulant concentration*

According to Fig. 2, a linear trend was observed for the first 27 minutes of settling. This observed regime clearly indicated a zone settling curve. This shows that the two coagulants have a more or less similar effect in the sedimentation process for the first 30 min. The PAC had a lower reduction percentage as it was noted that after approximately 2 hours of settling, the settled particles tend to re-suspend themselves back into the supernatant. This indicates that the strength of the floc formed is weaker than that of MO seed extract. Although PAC over performed MO, the latter is considered to be a better option. That is, from an environmental and cost economic point of view, the small difference in efficiency can be overlooked.

The main difference between the previous experiment and this one was the percentage of height reduction that occurred for the 30 min settling. The differences may have resulted because of the changing concentration of different samples. This was because the activated sludge was sampled on different days and the concentration of total solids was very dependent on the loading rate of the wastewater treatment plant which varies constantly. The total solid concentration of the sample used for this experiment was about 5300 which is lower than that used in the previous experiment (6400 mg/l).

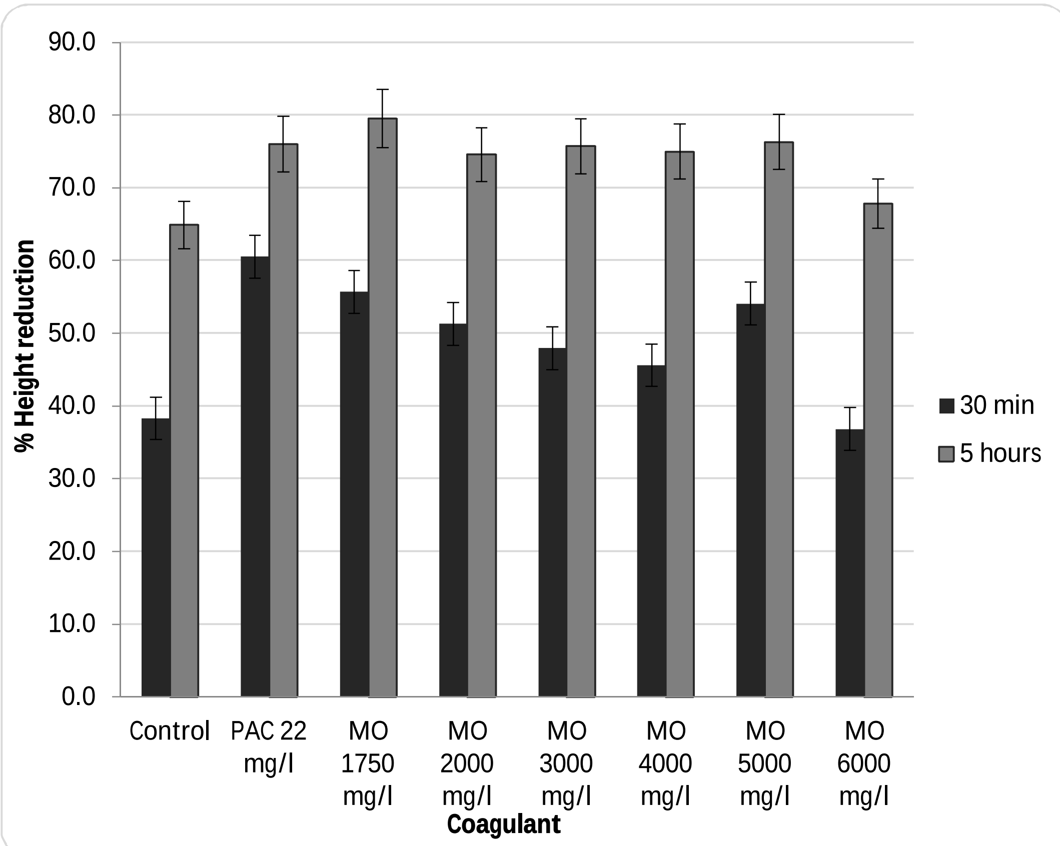


Fig. 3 *Percentage of height reduction for 30 minutes and 5 hours*

3.2 Jar test

3.2.1 Batch 1

This experiment was performed to obtain a more consistent result compared to the ZSV test by providing a continuous stirring mechanism. The maximum percentage reduction was found to be 22 mg/l of PAC for both the 30 minutes and 5 hours of settling. The difference between the second best reduction percentage was only 2.1 % and 2 % for MO of 1750 mg/l and the PAC at 30 min and 5 hours respectively. These findings again demonstrated the similar relationship of both the MO and PAC as the previous experiments. Yet again these differences were very minimal, thus the use of MO as coagulant can be considered to be the feasible option of replacing PAC by natural coagulant to thicken the activated sludge. The percentage reduction of the solid/liquid interface of the different coagulants dosages are illustrated in Fig. 4

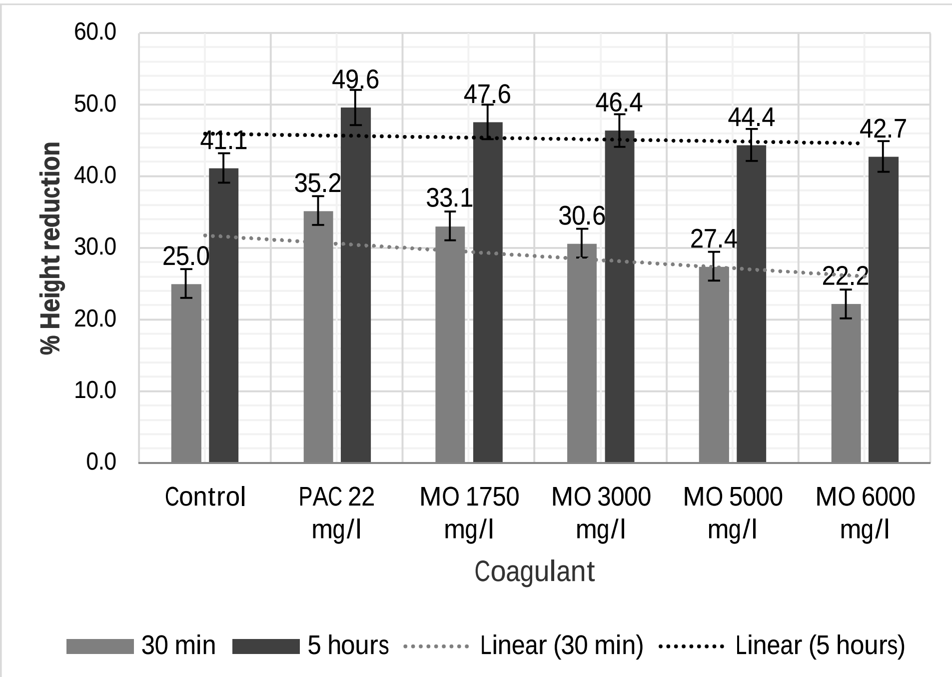


Fig. 4: Percentage reduction of total height from surface for 30 minutes and 5 hours

A total solid test was done every 30 minutes to evaluate the percentage of total solid that remained in the supernatant over the settling period of 5 hours. Fig.5 shows the percentage of total solids remaining in the supernatant. The trends of the graphs corresponded well with the regime explained earlier. That is, the more active phase of the settling period was the first 30 min, with 22 mg/l PAC to have the lowest percentage of total solids in the clear liquid zone but in the 5 hours of settling MO produced a clearer liquid than PAC. This is because, sample that are treated with PAC, tend to re-suspend the settled solids thus increasing the amount of solid content in the liquid as shown by the trend of PAC

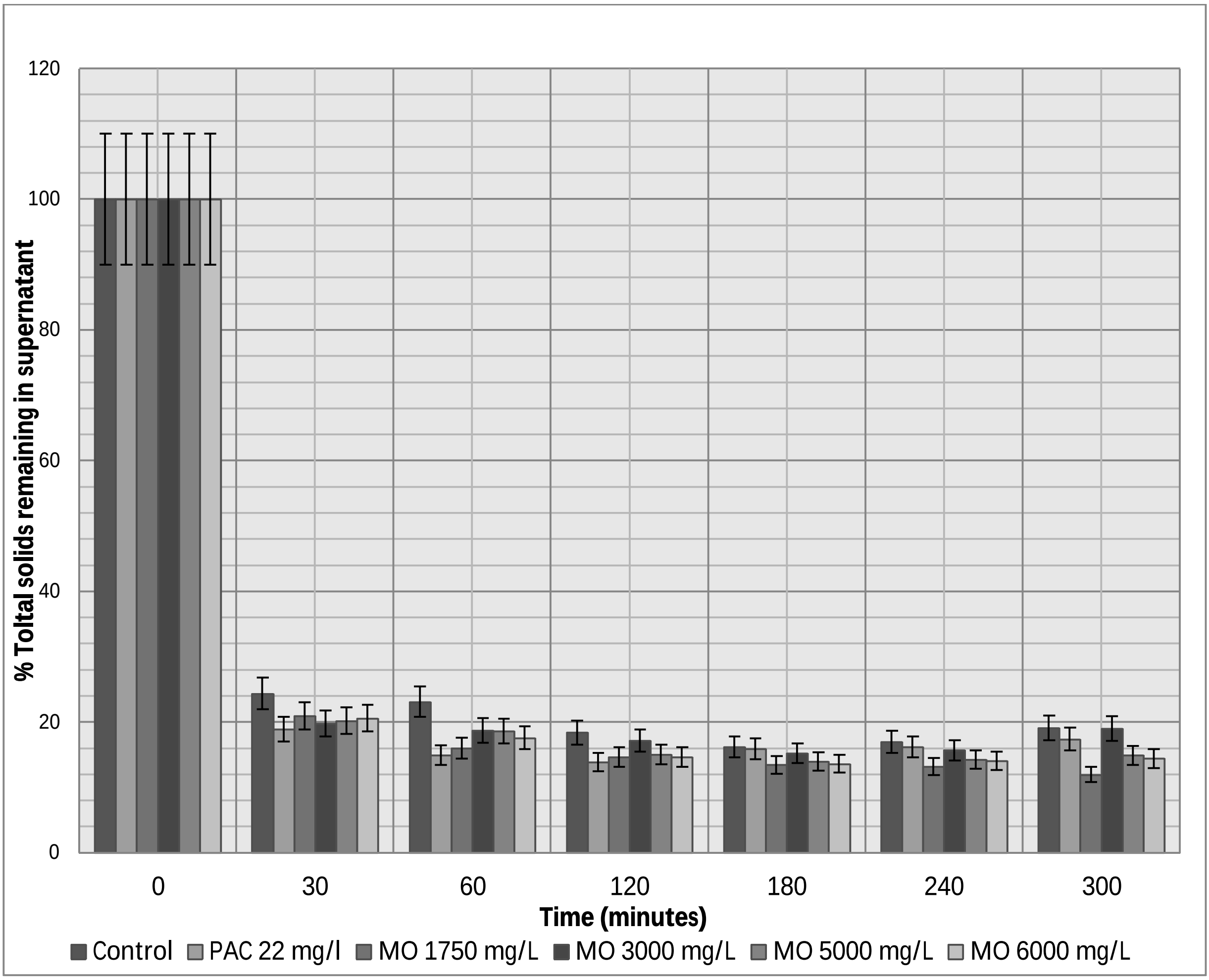


Fig. 5 Percentage total solids remaining in supernatant at varying time interval

3.2.2 Batch 2 (Synthetic sludge)

This test was mainly done to assess the efficacy of using MO seed extract on synthetic sludge prepared by adding soil. In this experiment, it was all contradictory to what has been concluded for activated sludge. That is, the one having the least amount of solids in the supernatant was the 5000 mg/l MO followed by 6000mg/l. This trend can be explained by considering the size of the particle. According to Qasim et al. (2002), if a particle has smaller size, the surface area per unit weight of solid increases. Therefore, a large amount of coagulant was required to neutralise the large area. The trend where larger amount of MO concentration was needed to treat the synthetic sludge indicated the presence of very small particles.

3.3 Anaerobic digestion

It was observed that (Fig. 6), there was no biogas generated from sludge treated with PAC coagulant. This could be because of the low pH measured when the PAC was added to the sludge. The overall pH of the sample was 2.3 which showed an acidic condition in the bio-reactor. This lead to an unfavourable condition for biogas generation in the reactor, hence no biogas was produced. According to Davis (2010), the degradation of organic matter during an anaerobic process is very dependent on the hydrolysis rate. This process involves the conversion of complex organic matter to simple form and works best at pH of about 6 - 8. Therefore, at a low pH such as that for the sample treated with PAC, biogas was not produced.

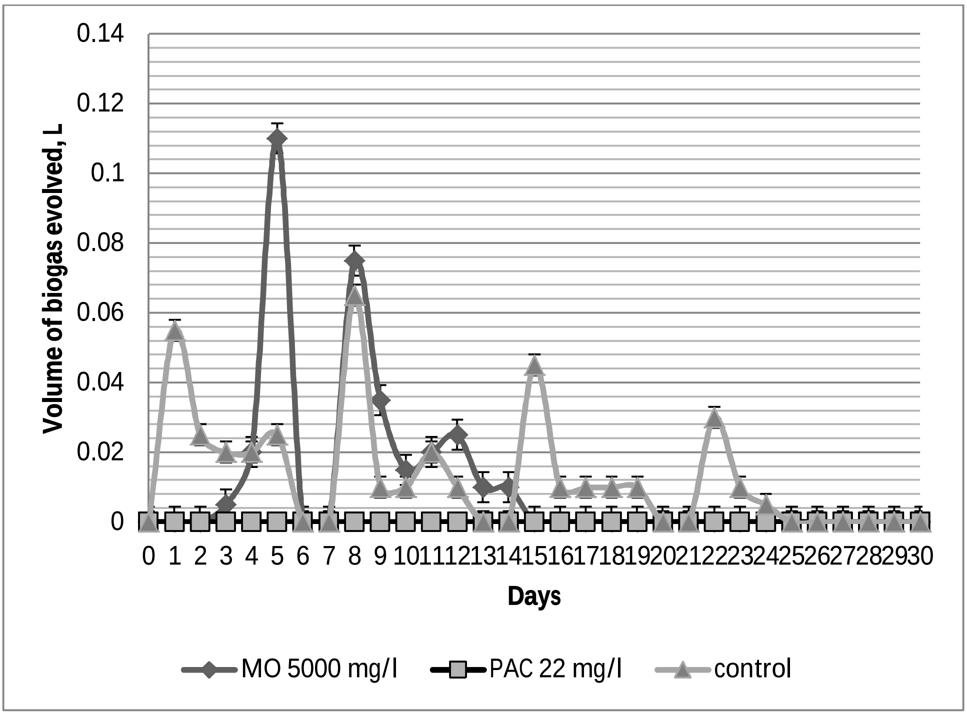


Fig. 6 *Volume of biogas generated from PAC and Moringa Oleifera*

On the contrary, sample treated with 5000 mg/l of MO produced more biogas than the control, for the first 10 days. The pH of the MO treated sample and the control were 5.8 and 6.6 respectively. As the pH of the control was more favourable to promote methanogenic bacteria activities (optimum pH range of

6.5 – 7.2) (Appels et al. 2008), the degradation proceeded with a decreasing rate till day 30. The high amount of biogas produced from the sample treated with MO during the first 10 days may be mainly because of the increase in organic matter which was achieved by the addition of the MO seed powder. Secondly, MO contains cationic proteins which are simple complex organic compounds. Thus, hydrolysis speeded up and other degradation processes took place more quickly to digest the simple organic matter already present. This trend was continued with a decreasing rate till day 15 as there was the degradation of the sludge.

Thus, if anaerobic digestion as sludge management was to be implemented in a wastewater treatment plant to stabilise the sludge, the use of MO will be clearly the most feasible option, if the production of biogas was desired. This would also allow the digested sludge to be used for land application in the agricultural sector due to its nutrient contents and as it would be free from chemical additives.

4. CONCLUSION

The usage of natural coagulants derived from plant-based sources represents a vital change in promoting sustainable development. From this study, Moringa Oleifera has been found to be an effective coagulant which can be used in the thickening of activated sludge in both the dry powdered seed form and water extract form. A series of tests were performed to evaluate the effectiveness of the *Moringa Oleifera* as a coagulant.

From the zone settling test, it was concluded that the activated sludge treated with MO seed extract of concentration 1750 mg/l resulted in a better sedimentation of the particles than PAC. The other concentrations of MO used also produced some significant settling results compared to the control. This clearly showed that the MO seed had the potential characteristics of a coagulant. This is because the cationic electrolyte in the seed extract has the ability to neutralise the negative charged particles causing them to agglomerate and form bigger and heavier particles resulting in an increase in the settling velocity. However, in another round of the zone settling test, the MO was added directly to the activated sludge. In this test, the PAC over performed the *Moringa Oleifera*. But the difference between the two coagulants with respect to the percentage reduction and settling velocity for the 30 minutes was only 4.8 % and 9 % respectively and this difference was minimal. Thus, it showed that the MO can also be used as a coagulant.

In the jar test experiment, the settling of the solids was promoted by a continuous stirring mechanism. The optimum concentration of MO to produce the best result was 1750 mg/l. The PAC resulted in a better sedimentation of the particles, but the MO also showed more or less the same effect on the activated sludge for a period of 30 minutes and 5 hours, with a small difference of 2.1 % and 2.0 % respectively. In the jar test, the MO has proven to be highly effective as well as the PAC. The total solid test performed during the jar test, showed that the MO floc strength was stronger as compared to the PAC. This was concluded by the fact that the total solids concentration increased after 2 hours of settling. This was because the settled solids of the sludge treated with the PAC tended to re-suspend themselves in the liquid.

Finally, during the anaerobic digestion test, the sludge treated with the MO produced a greater amount of biogas than the untreated sludge followed by the sludge with PAC. Practically no biogas was generated with the sludge treated with PAC as the resulting pH of the mixture was 2.3 which was too acidic. The pH of the control and the one with MO was closed to the optimum value for biogas production and their pH were 6.6 and 5.8 respectively.

To conclude, although the PAC over performed the MO, the MO can still be considered as a very good alternative to the use of PAC. This is because their differences in the effectiveness of sedimentation are minimal, which shows that they both have good properties as coagulants in the activated sludge thickening. Due to the procurement cost of PAC and the potential drawbacks, the MO can be the most sustainable option to substitute the use of chemicals as coagulant. Moreover, the use of MO for activated sludge thickening prior to an anaerobic digestion process, is more advantageous than PAC. In that way, more biogas will be generated that will ultimately be more economical to the plant.

Acknowledgement

This research study was conducted at the Airports of Mauritius Limited (AML) where the sludge produced in their normal process were tested with *Moringa Oleifera* and Polyaluminium Chloride (PAC). The PAC was provided by the Manser Saxon Contracting Limited.

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