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Pretreatment of palm oil mill effluent (POME) using *Moringa oleifera* seeds as natural coagulant

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Abstract

Moringa oleifera seeds, an environmental friendly and natural coagulant are reported for the pretreatment of palm oil mill effluent (POME). In coagulation–flocculation process, the *M. oleifera* seeds after oil extraction (MOAE) are an effective coagulant with the removal of 95% suspended solids and 52.2% reduction in the chemical oxygen demand (COD). The combination of MOAE with flocculant (NALCO 7751), the suspended solids removal increased to 99.3% and COD reduction was 52.5%. The coagulation–flocculation process at the temperature of 30 °C resulted in better suspended solids removal and COD reduction compared to the temperature of 40, 55 and 70 °C. The MOAE combined with flocculant (NALCO 7751) reduced the sludge volume index (SVI) to 210 mL/g with higher recovery of dry mass of sludge (87.25%) and water (50.3%).

Keywords: *Moringa oleifera* seeds; POME; Coagulation–flocculation; Suspended solids; COD

1. Introduction

Palm oil mill effluent (POME) is a voluminous, high biochemical oxygen demand (BOD) liquid waste normally discharged at 75–85 °C. It is a colloidal dispersion of organics with an unpleasant odour. This polluting effluent has total solids content of 5–7% of which a little over half is dissolved solids, and about the other half being a mixture of various forms of organic and inorganic suspended solids. This property, coupled with its high BOD loading and low pH, makes it not only highly polluting but also extremely difficult to treat by conventional methods [1].

The current treatment technology of POME typically consists of biological aerobic and anaerobic digestion. Biologically treated effluent is disposed of via land application system, thus providing essential nutrients to the growing plants. This method may be good choice for the disposal of treated effluent. However, considering the rate of daily wastewater production, it is doubtful that the surrounding plantations receiving it could efficiently absorb all the treated effluent [2]. Furthermore, biological treatment systems need proper maintenance and monitoring as the processes rely solely on microorganisms to break down the pollutants. The microorganisms are sensitive to the changes in the environment and thus great care has to be taken to ensure that a conducive environment is maintained for the microorganisms to thrive in.

Different treatment methods have been reported by many researchers for POME treatment [3–5]. Oswal et al. [3] treated POME using tropical marine yeast, *Yarrowia lipolytica* NCIM 3589 and 95% of chemical oxygen demand (COD) reduction was achieved with a retention time of 2 days. Nik Nurulaini et al. [4] reported that the chemical coagulation is the fastest way to reduce the organic load of the POME to an acceptable and economical level. Thereby it can be treated using conventional treatment systems. Borja and Banks [5] carried out studies on a laboratory—scale anaerobic filter (AF) and a fluidized-bed reactor (FBR) and compared their performance for treatment of POME.

There are many palm oil mills, which failed to comply with the Department of Environment (DOE) standard discharge limits even though they have applied biological treatment system in their mills. Therefore, an alternative POME treatment system is required to meet DOE standard discharge limits. A technological shift from biological treatment and chemical

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treatment to coagulation–flocculation treatment employing an environmental friendly coagulant could lead to improved effluent treatment as well as gaining benefits through the recovery and recycling of water to the plant with minimum treatment.

Moringa oleifera is among the 14 species of trees that belong to the genus *Moringaceae* (syns. *Moringa pterygosperma Gaertn.*). *Moringa* is native to North India but is now found throughout the tropics and is the best known of all the species [6], commonly known as the 'horse-radish' tree or 'drumstick' tree [7–9]. *M. oleifera* is a multi purpose tree with most of its parts being useful for a number of applications.

Many coagulants are widely used in the conventional wastewater treatment processes [10]. These coagulants can be either inorganic (e.g., aluminium sulfate and polyaluminium chloride or PAC), synthetic organic polymers (e.g., polyacrylamide derivatives). These coagulants are used for various purposes depending on their chemical characteristics [11]. Aluminium sulphate (Alum) is the most widely used coagulant in water and wastewater treatment [12]. High level of aluminium concentrations in water may also have human health implications [13]. Many developing countries can hardly afford the high costs of imported chemicals for water and wastewater treatment. In this context, environmental friendly coagulant presents a viable alternative for treatment of the wastewater.

The use of *M. oleifera* seeds would be viable replacement to the conventional coagulants. Earlier studies recommended the use of *M. oleifera* seeds extract as coagulant for water treatment in African and South Asian countries [14]. The turbidity removal by *M. oleifera* coagulant (MOC) as primary coagulant was up to 80–99% for both raw waters and synthetic turbid waters [15–17]. Ndabigengesere et al. [17] reported that *M. oleifera* is an effective natural coagulant that can be used in water treatment in two principal crude forms: shelled or non-shelled dry seeds. The action of *M. oleifera* as a coagulant lies due to presence of water-soluble cationic proteins in the seeds. In addition, it is possible to extract an edible quality of oil from the *Moringa* seeds before using as the coagulant. As by product, nearly 25% oil could be extracted from *Moringa* seeds. This oil could be utilized as a source of edible oil for human consumption. It also contains a high ratio of monounsaturated to saturated fatty acids and ideal substitute for highly monounsaturated oils such as olive oil in diets [18].

The main objective of the present study is to utilize *M. oleifera* seeds after extraction of oil as natural coagulant for the POME pretreatment with minimum suspended solids and organic matter present in the treated POME. The effects of important process parameters such as pH, flocculant dosage (NALCO 7751), *M. oleifera* extract (MOAE) dosage and temperature were studied for the removal of suspended solids and COD reduction. The sludge volume index (SVI), % recovery of dry mass of sludge and % recovery of water after POME treatment were also estimated. The present study also compared the performance of *M. oleifera* seeds extract (MOAE) with aluminium sulphate (alum) in the coagulation of POME.

2. Materials and methods

2.1. Palm oil mill effluent samples

Samples of POME in the present study were obtained from United Palm Oil Mill, Nibong Tebal, Penang at a temperature ranging from 75 to 90 °C and cooled to room temperature before used for experimental study. POME samples were characterized and its composition is presented in Table 1. Raw POME is a brown coloured suspension, which is slightly acidic and consists mainly 94–96% of water. Freshly discharged POME is viscous and oily with obnoxious odour. POME characteristics vary depending upon the time of sample withdrawal. This might be due to the method of the processing, the quality of the fresh fruits and the time of the collection of the POME. Although the characteristics of POME could vary but, in order to minimize the effect of different characteristics of POME, the experiments were repeated with different samples of POME to obtain the average results. APHA standard methods of examination of water and wastewater were followed in the analysis of samples during the experimental study [19].

2.2. Coagulant preparation

The dry *M. oleifera* seeds were obtained from Nibong Tebal area of Penang State, Malaysia. The seed wings and coat were removed manually, good quality seeds were then selected, and the kernel was grounded to a fine powder using an ordinary electric blender (Model National MX-798S). Oil present in the dry *M. oleifera* seeds was extracted with *n*-hexane (96% purity) as a solvent using Soxhlet apparatus. The extraction was carried out for nearly 8 h. Stock solution of the *M. oleifera* cake after extraction of oil (MOAE) was prepared by dissolving 5 g of the dried cake in 100 mL distilled water. The mixture was blended for 2 min to extract the active ingredients. Finally, the resulting suspension was filtered through a muslin cloth. The flocculant (NALCO 7751) was obtained from Merck Sdn. Bhd., Malaysia [20]. The chemical description of milky white liquid flocculant (NALCO 7751) is based on water-soluble polymer, ammonium sulfate and inorganic acid(s). The material safety data sheet (MSDS) of this flocculant shows that it is non-hazardous and biodegradable. Thus, this flocculant is safe and suitable for POME treatment. The stock solution of aluminium sulphate (alum) powder (Envilab Sdn. Bhd., Malaysia) was prepared by dissolving 5 g of $Al_2(SO_4)_3 \cdot 18H_2O$ in 100 mL distilled water.

Table 1
Typical characteristic of palm oil mill effluent

Parameters	Range	Average value
Temperature (°C)	75–90	80
pH	4.0–4.8	4.5
Suspended solid, SS (mg/L)	11,500–22,000	17,927
Total solid, TS (mg/L)	36,500–42,600	39,470
Chemical oxygen demand, COD (mg/L)	30,000–50,400	40,200
Oil and grease (mg/L)	1300–4700	2658
Total Kjeldahl Nitrogen, TKN (mg/L)	660–890	800

Polyaluminium chloride (PAC) (supplier; Envilab Sdn. Bhd., Malaysia) was also used for comparison in the pretreatment of POME in terms of sludge volume index (SVI) value.

2.3. Coagulation–flocculation process

The 600 mL beaker was filled with 500 mL of POME for each test run. The pH value of each Jar test (Stuart Science Flocculator model, SWI) was adjusted to the desired value by using either sulphuric acid (3 M) or potassium hydroxide (5 M) within the range of 4–9; *M. oleifera* dosage (MOAE) was varied from 500 to 6000 mg/L and POME sample was agitated at 150 rpm for 5 min (rapid mixing). The speed of mixing was then reduced to 30 rpm for 30 min (slow mixing) after adding the flocculant (NALCO 7751) dosage varying from 500 to 9000 mg/L. The addition of flocculant (NALCO 7751) helped to increase the performance of coagulation–flocculation process by agglomeration of suspended particles during the POME pretreatment. The contents of each beaker were then allowed to sediment with the settling time of 90 min. The Jar test was also repeated using alum alone for comparison purposes with *M. oleifera* after oil extraction (MOAE). The effect of temperature was also studied in the coagulation–flocculation process because POME coming out from the palm oil mills is generally under hot conditions with the temperature varying from 50 to 70 °C.

2.4. Analysis

The suspended solids concentration of the supernatant was determined by a turbidity measurement with the help of turbidity meter, model WTW Turb 350 IR. The pH value of supernatant was measured using a Mettler Toledo 320 pH meter. The chemical oxygen demand (COD) was determined by the closed reflux, colorimetric method using APHA standard methods of examination of water and wastewater [19]. In the present study, suspended solids removal, COD reduction and sludge volume index (SVI) are defined as follows:

$$\text{suspended solids, SS removal (\%)} = \frac{\text{SS}_{\text{raw POME}} - \text{SS}_{\text{after treatment}}}{\text{SS}_{\text{raw POME}}} \times 100\% \quad (1)$$

$$\text{COD reduction (\%)} = \frac{\text{COD}_{\text{raw POME}} - \text{COD}_{\text{after treatment}}}{\text{COD}_{\text{raw POME}}} \times 100\% \quad (2)$$

$$\text{sludge volume index, SVI (mL/g)} = \frac{\text{volume of sludge in mL}}{\text{weight of sludge after 30 min settling time}} \quad (3)$$

The sludge (solid) after sedimentation was dewatered in the filter and dried in the oven (Model ULM 500, Memmert) for 24 h at 105 °C. The sample was cooled in a desicator for about 30 min. The process of drying (1 h for repeat) and cooling steps were repeated until the weight was constant to the nearest 0.1 mg. The percentage recovery of dry mass of sludge and water are defined as:

$$\text{recovery of dry mass of sludge (\%)} = \frac{\text{dry mass of sludge (solid) recovered after treatment}}{\text{mass of sludge (solid) present from in the POME}} \times 100\% \quad (4)$$

$$\text{recovery of water (\%)} = \frac{\text{volume of supernatant after POME treatment}}{\text{volume of POME before treatment}} \times 100\% \quad (5)$$

Total Kjeldahl Nitrogen (TKN) analysis was done in two steps using BÜCHI Digestion Unit K-424 and BÜCHI Distillation Unit B-324 respectively. The oil and grease analysis was done using a Rotary Evaporator (model R-114, BÜCHI, Switzerland) equipped with a BÜCHI Vacuum System (model B-169) and BÜCHI Water Bath (model B-481). *n*-Hexane was used as a solvent for the extraction of oil and grease.

3. Results and discussion

3.1. Coagulation–flocculation process

3.1.1. Performance of M. oleifera seeds (oil extracted) combined with flocculant (NALCO 7751) and alum as a comparative study

M. oleifera seeds after oil extraction (MOAE) were used in the present study as coagulant based on the preliminary experiments. The efficiency of the coagulation–flocculation process was studied using *M. oleifera* (MOAE) alone as well as combined with the flocculant (NALCO 7751) in order to improve the removal efficiency of suspended solids and COD reduction. The performance of MOAE and alum alone was compared for their performance in coagulation–flocculation process of POME pretreatment.

Coagulants (MOAE or alum) with charges opposite of the suspended solids are added to the POME wastewater to neutralize the negative charges on dispersed non-settleable solids. When the charges are neutralized, the small suspended particles are capable to interact together through rapid mixing. Once the coagulation process was completed, flocculation processes start to take place. The flocculant (NALCO 7751) used has high molecular weight containing a long chain of polyelectrolyte. This polyelectrolyte could generate a ‘macroflocs’ particles with slow mixing, resulting in the interaction with the suspended solids [10]. Finally, when the floc reached its optimum size and strength, the wastewater is subjected to the sedimentation process.

3.1.1.1. Optimum pH. In the present study, the effect of pH was studied in the range of 4–9 using MOAE and alum. The flocculant (NALCO 7751) was also used during the coagulation process. The concentration of stock solution of MOAE and alum was 50,000 mg/L respectively and flocculant (NALCO 7751) as

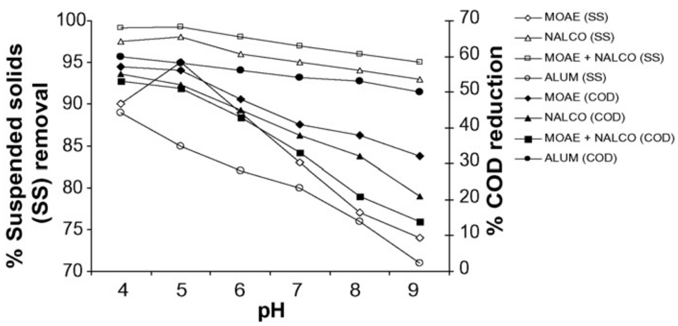

Fig. 1. Effect of pH on the removal of suspended solids and COD reduction in POME pretreatment. Experimental conditions; 5000 mg/L of MOAE, alum or flocculant (NALCO 7751) dosage, 90 min of sedimentation time and 30 °C of temperature.

100,000 mg/L. The experiments were performed with a fixed coagulant dosage of 5000 mg/L.

Fig. 1 shows the effect of pH on the removal of suspended solids. At low pH, the solution appeared clear but showed the presence of very small colloidal particles. As the pH increased towards alkaline value, the POME turned into a darker color due to the presence of higher suspended solids and the removal became poorer. It can be seen from the figure that MOAE and alum alone gave the reduction of suspended solids as 95% at pH 5 and 85% at pH 4, respectively. *M. oleifera* contains short chain cationic polyelectrolyte, which helps in the removal of suspended solids through electrostatic patch mechanism (surface phenomena) [21]. The electrostatic patch mechanism involves the surface contact of charges between *M. oleifera* and suspended solids particles resulting in coagulation process. But the positive charges present in alum were not enough to neutralize the charges in POME wastewater. Therefore, the removal of suspended solids was reduced after using alum alone.

The flocculant (NALCO 7751) alone resulted in 98% removal whereas the combination of *M. oleifera* (MOAE) with flocculant (NALCO 7751), the removal of suspended solids was improved to 99.2%. The removal of suspended solids increased due to flocculation process. The flocculant (NALCO 7751) has a high molecular weight, high cationic charge and large polymeric molecules. This result shows that the charges of suspended solids present in the POME probably not effective in coagulation process with pH changes and thereby the suspended solids removal decreased with the increase of pH. At higher pH, the colloidal particles could be negatively charged while at lower value of pH, the particles are positively charged. The charge balance is actually associated with changes in H^+ and OH^- ions to maintain the ion balance with water at different pH [4].

Fig. 1 also shows % COD reduction against pH during coagulation–flocculation process. It is observed that *M. oleifera* after oil extraction (MOAE), flocculant (NALCO 7751) alone or combination of both and alum alone gave maximum COD reduction at pH value of 4. The COD reduction decreased with the increase of pH with and without flocculant (NALCO 7751). The COD reduction drop off was due to the concentration of OH^- ions, which was high enough to compete with organic molecules from POME for adsorption process. In addition, at high pH the charge of the coagulating species will become less positive and as a result, less attracted to anionic organic compounds. But, at low pH the anionic organic molecules from POME react directly to form insoluble complexes.

The usage of *M. oleifera* after oil extraction (MOAE) alone as a primary coagulant generally does not increase the size of the suspended solids. MOAE addition to POME wastewater only destabilized the particles and settle down the suspended solids in the bottom. In order to increase the size of suspended particles, the flocculant (NALCO 7751) is added which promotes the faster aggregation of colloids by the formation of bridge between the suspended solids and formation of particles of sufficient size that could be easy and faster settled. Thus, flocculant (NALCO 7751) helped in the formation of large flocs and thereby the removal of suspended solids and COD reduction were increased.

3.1.1.2. Optimum flocculant (NALCO 7751) dosage. Fig. 2 shows the effect of different dosages of the flocculant (NALCO 7751) over the suspended solids removal at an optimum pH 5. The optimum dosage of a flocculant (NALCO 7751) was determined when there was no significant increase in the removal efficiency with further addition of flocculant (NALCO 7751). The optimum dosage was observed around 7000 mg/L and further addition, there was no change in the suspended solids removal. Reduction in the removal efficiency at higher dosage of flocculant (NALCO 7751) was due to its electropositive property. Cationic polyelectrolyte used as a flocculant (NALCO 7751) in this study actually replaced the anionic groups on POME colloidal particles. Over dosages can cause restabilization of the particles and consequently hindered the formation of flocs.

The variation of flocculant dosage over the COD reduction during the coagulation–flocculation process is also presented in Fig. 2. The efficiency of the COD reduction initially increased with the increase in the addition of flocculant (NALCO 7751) and further increase in the dosage up to 7000 mg/L, COD reduction dropped. The combination of *M. oleifera* after oil extraction (MOAE) with flocculant (NALCO 7751) gave better performance in COD reduction. In both cases, flocculant (NALCO 7751) shows a reversal effect at higher dosage beyond the optimum value. This was probably due to the charge reversal phenomenon of flocculant, where colloidal stability

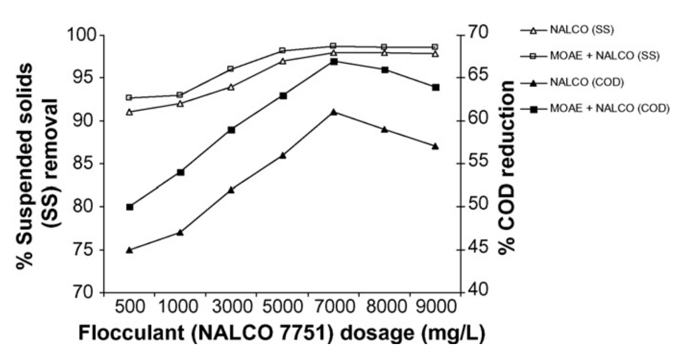

Fig. 2. Effect of flocculant (NALCO 7751) dosage on the removal of suspended solids and COD reduction in POME pretreatment. Experimental conditions; pH 5, MOAE dosage = 5000 mg/L, 90 min of sedimentation time and 30 °C of temperature.

gets destabilized once the flocculant charge concentration was higher than the total charge of the colloids present in POME.

3.1.1.3. Optimum coagulants (M. oleifera and alum) dosage. The optimal pH was pH 5 for *M. oleifera* (MOAE) alone and coagulant combined with flocculant (NALCO 7751) with an optimal flocculant dosage of 7000 mg/L. The optimal pH for alum alone was pH 4 and applied in the present studies. Experiments were performed varying the *M. oleifera* (MOAE) and alum dosage between 500 and 6000 mg/L in order to determine the optimal dosage loading during the coagulation–flocculation process. The presence of oil in the seeds could form an emulsion or film coating, which inhibits the surface of reaction and thus reduces floc formation [22]. Therefore, extraction of the oil from the seeds enhanced the suspended solids removal resulting in better coagulation process. The presence of primary aliphatic amines as functional group in the MOAE also helped to improve the coagulation process for suspended solids removal. Furthermore, the *M. oleifera* seeds after oil was extraction (MOAE) gave 25 wt.% of edible oil as a side product [18], which made this coagulant more economical in its usage.

Fig. 3 shows the suspended solids removal was 95% for *M. oleifera* (after oil extraction) alone at the dosage of 6000 mg/L. The addition of *M. oleifera* (MOAE) dosage exceeding the optimum value did not change the suspended solids removal. At alum dosage of 6000 mg/L, the removal of suspended solids was 89% and lower than MOAE. The use of alum normally increases the sulfate ions and total solids in the effluent create a setback to the wastewater treatment in the broader sense [23]. The predominant mechanism of the coagulation with *Moringa* appears to be adsorption and charge neutralization of the colloidal charges [17]. *M. oleifera* is a short chain low molecular weight and high charge density compound; the flocculation activity is due to the electrostatic patch charge mechanism. The positive charged proteins bind to the surface of the negatively charged particles. This led to the formation of negatively and positively charged particle surfaces. Due to particle collision enhanced by agitation, interparticle interaction between the differently charged sectors took place and resulted in the formation of flocs [21].

The combination of 4000 mg/L of *M. oleifera* (MOAE) dosage with the flocculant (NALCO 7751) resulted in the removal of suspended solids as 99.3%. The flocculant (NALCO 7751) has a high molecular weight compared to *M. oleifera* (MOAE). The rate of flocs formation in the presence of flocculant (NALCO 7751) was relatively fast resulting in the large size flocs, which could be easily settled. The flocs were more firm, bigger, dense and strong.

Fig. 3 also shows the COD reduction as the coagulant dosage was varied. The COD value is normally used to assess concentration of organic matter in wastewater. It does not however, provide information on the different organic compounds present in the sample. It can be seen that COD reduction of the POME dropped as the coagulant dosage increased. This was probably due to contribution of *M. oleifera* COD value. After the coagulation process, some of the organic matter remained in the supernatant, thus contributed to the final COD value. As depicted in the figure, the optimum dosage of the MOAE with increased in the reduction of COD was around 1000 mg/L.

M. oleifera seeds after oil extraction (MOAE) have the potential to become new source of environmental friendly and natural coagulant for POME treatment. It was found that the *M. oleifera* seeds after oil extraction (MOAE) alone gave a higher removal in suspended solids (95%) and COD reduction (52.2%) at dosage of 6000 mg/L. The combination of *M. oleifera* (MOAE) at dosage of 4000 mg/L with the flocculant (NALCO 7751), the removal of suspended solids was increased to 99.3% and COD reduction as 52.5%.

Fig. 3 shows that the COD reduction was increased with the increase of alum dosage. At 6000 mg/L of alum dosage the COD reduction was 66%. The increase in the COD reduction was due to the charge neutralization, which destabilized the colloids and caused settling of the metal cations together with organic anions [24].

3.1.1.4. The effect of temperature on coagulation–flocculation process. The effect of temperature using *M. oleifera* after oil extraction (MOAE) combined with flocculant (NALCO 7751) was studied on coagulation–flocculation for POME treatment. Fig. 4 show the effect of temperature on suspended solids removal and COD reduction during the coagulation–flocculation process. It can be observed from the figure that an increase the temperature from 30 to 70 °C reduced the efficiency of the

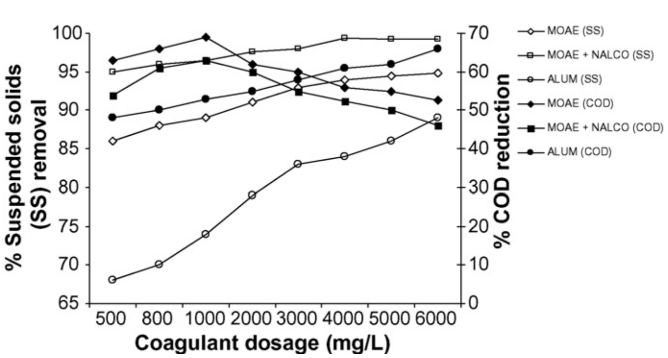

Fig. 3. Effect of *M. oleifera* and alum dosage on the removal of suspended solids and COD reduction in POME pretreatment. Experimental conditions; pH 5, flocculant (NALCO 7751) dosage = 7000 mg/L, 90 min of sedimentation time and 30 °C of temperature.

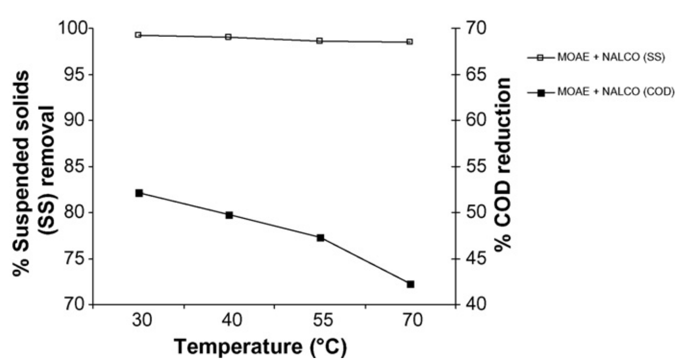

Fig. 4. Effect of temperature on POME pretreatment using MOAE with flocculant (NALCO 7751) on the removal of suspended solids and COD reduction. Experimental conditions; pH 5, MOAE dosage = 4000 mg/L, flocculant (NALCO 7751) dosage = 7000 mg/L, 90 min of sedimentation time.

coagulation–flocculation process for the removal of suspended solids and COD reduction.

The temperature effect may be due to the destabilization of charge on the suspended solids in POME wastewater. With increase in the temperature of POME and addition of the MOAE with flocculant (NALCO 7751), the floc particles become smaller compared to the particle size of flocs at the temperature of 30 °C. This might be due to the particle transport processes or particle collision rates and through the effect on viscosity (concentration) in POME. The floc strength becomes weaker with the increase of temperature and the 'macrofloc' could be easily broken.

3.1.1.5. Sludge volume index (SVI) of POME during coagulation–flocculation process. In general, the sludge volume index (SVI) depends on the choice of coagulant or flocculant and operating conditions during the coagulation–flocculation process. A lower value of SVI indicates a good settling sludge, which has a bigger floc size and need a shorter time for sedimentation process. The SVI values were calculated at the optimum dosages of MOAE, MOAE with flocculant (NALCO 7751), alum and combination of PAC with alum. Fig. 5 shows that MOAE alone gave the lower value of SVI (330 mL/g) at 30 min of settling compare to higher value (371 mL/g) of alum alone. MOAE with flocculant (NALCO 7751) gave SVI value of 287 mL/g and alum combined with PAC gave 314 mL/g for 30 min of settling time. The SVI values dropped further with increase of settling time of 90 min. The larger value of SVI in the case of alum alone and alum with PAC, compared to MOAE alone or with flocculant (NALCO 7751), can be explained by the production of aluminium hydroxide as a precipitate. In the case of MOAE alone or with flocculant (NALCO 7751), only initial suspended particles are agglomerated into larger and settleable flocs, but no additional precipitate is formed. Although, the value of SVI after using MOAE alone or with flocculant (NALCO 7751) were still high, it may be argued that *Moringa* sludge would be more economical to treat than alum sludge.

3.1.1.6. The percentage recovery of dry mass of sludge and water (after POME treatment). At different dosage of MOAE with flocculant (NALCO 7751) was selected to find out the highest percentage (%) recovery of sludge and water after POME pretreatment. The dry mass of sludge in 500 mL of raw POME was 22.35 g (after drying 24 h at 105 °C in the oven). Other parameters were kept constant at 7000 mg/L of flocculant (NALCO 7751) dosage, pH 5 and 90 min of sedimentation time. The flocculant (NALCO 7751) was added after dosing of MOAE. Fig. 6 shows that MOAE with flocculant (NALCO 7751) at dosage of 4000 mg/L recovered 87.25% of the sludge. At this dosage, the removal of suspended solids from POME was 99.3%. This figure also shows the % recovery of water at different dosage of MOAE after sedimentation process. The percentage recovery of water was remained constant with increasing of the MOAE dosage above 4000 mg/L (50.3% of water recovery). The increase in MOAE dosage increased the removal of suspended solids as well as the recovery of dry mass of the sludge and water after POME pretreatment.

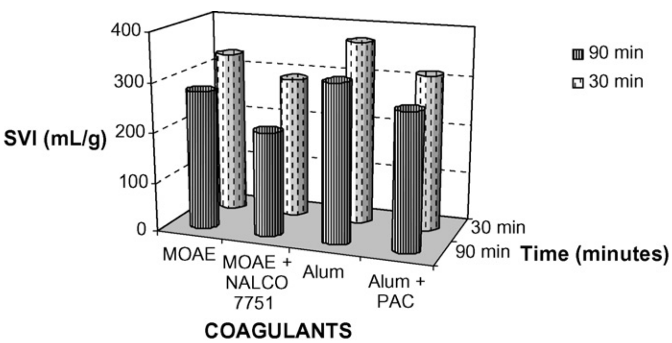

Fig. 5. Sludge volume index (SVI) produced with the different coagulants (alone and after combined with flocculant) used for the optimal conditions at 30 and 90 min of settling. Experimental conditions; pH 5, coagulant (MOAE or alum) dosage = 4000 mg/L with flocculant (NALCO 7751 or PAC) dosage = 7000 mg/L, MOAE or alum alone dosage = 6000 mg/L and 30 °C of temperature.

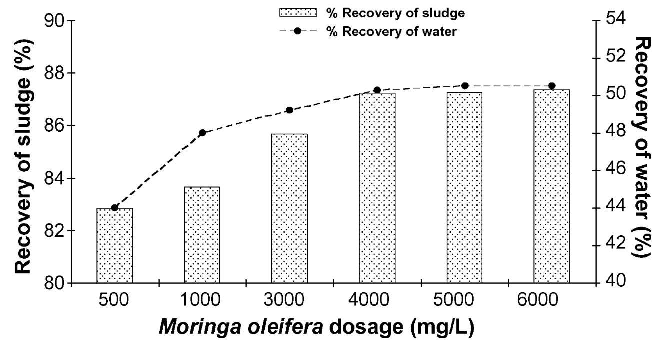

Fig. 6. Effect of *M. oleifera* with flocculant dosage on the percent recovery of sludge and water from POME during coagulation–flocculation process. Experimental conditions; pH 5, flocculant (NALCO 7751) dosage = 7000 mg/L, 90 min of sedimentation time and 30 °C of temperature.

3.1.2. Analytical profile of the treated POME

The POME treated with MOAE was sequentially treated with a flocculant (NALCO 7751) to remove the suspended solids and organic content in POME wastewater. Table 2 presents the analytical profile of a sample of POME before and after treatment. It is clear from the table that there was a substantial removal of suspended solids. The sequential treatments also brought a significant reduction in COD from 40,200 to 19,100 mg/L, which was 52.5% reduction from the original POME. It is observed that for the oil and grease, removal was close to 99%. The results also

Table 2
Analysis of the sample before and after treatment

Parameter	Raw POME	Treated POME	% removal
pH	4.5	5.0	–
Suspended solid (mg/L)	17,927	140	99.2
COD (mg/L)	40,200	19,100	52.5
Oil and grease (mg/L)	2,658	30	98.9
TKN (mg/L)	800	181	77.4

Conditions: T = 30 °C, pH 5; MOAE dosage 4000 mg/L; stirring speed 150 rpm and mixing time 5 min for rapid mixing; NALCO 7751 flocculant dosage 7000 mg/L; stirring speed 30 rpm and mixing time 30 min for slow mixing; sedimentation time = 90 min.

show that the value of TKN in coagulation–flocculation process of POME was reduced to 190 from 800 mg/L.

4. Conclusions

M. oleifera seeds after oil extraction (MOAE) have the potential to become new source of environmental friendly and natural coagulant for POME pretreatment. It was found that the *M. oleifera* seeds after oil extraction (MOAE) gave a higher removal in suspended solids (95%) and COD reduction (52.2%). The combination of *M. oleifera* (MOAE) with the flocculant (NALCO 7751), the removal of suspended solids was increased to 99.3% and COD reduction as 52.5%. The removal of suspended solids and COD reduction is affected by the operating temperature and best performance was observed at temperature of 30 °C. The highest reduction of SVI and highest recovery of dry mass of sludge and water were obtained when flocculant (NALCO 7751) was combined with MOAE. *M. oleifera* (MOAE) gave better performance compared to alum in the removal of suspended solids. This positive development of POME pretreatment with natural coagulant and biodegradable flocculant would be a paradigm shift in the management of POME treatment. Additionally, 25 wt.% an edible oil could be extracted from the seeds as a valuable product and oil extracted cake of *M. oleifera* could be used as an effective coagulant in POME pretreatment.

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