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Sustainable use of natural and chemical coagulants for contaminants removal from palm oil mill effluent: A comparative analysis

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ABSTRACT

This article aimed at determining the optimum coagulant dose for various coagulants. This is to ascertain coagulant with the potential for higher removal of contaminants. By fixing the initial pH, settling time, coagulant aid dose, rapid mixing speed & time, slow mixing speed & time as constant parameters, the study assessed the process efficiency in terms of percentage removals for TSS, oil & grease, COD, NH_3-N, turbidity and colour. The results indicated that the optimum dosage for $FeCl_3$, *moringa oleifera*, aluminum sulphate, chitosan and zeolite was found to be 1000, 2000, 4000, 400 and 1000 mg/L, respectively. Results were analysed using the one-way analysis of variance (One-Way ANOVA) of Statistical Package for Social Sciences (SPSS) Version 17 where P-values for all contaminants tested across various coagulants and their dosages found to be <0.05. Thus, the null hypothesis is discredited which indicate there is significant improvement in the removal efficiencies.

1. Introduction

Palm oil is a vegetable oil fit for human consumption. It is extracted from the mesocarp of the fruit of an oil palm species called Elaeis guineensis [1]. As can be seen in Fig. 1, the tree is naturally brown and seed reddish in colour because of a high beta-carotene content.

Palm oil production in 2011 was 19.8 million tons as oil palm currently occupies Malaysia's largest acreage of farmland [2]. Over the past few years, the total oil palm cover has risen with a corresponding rise in the manufacturing of palm oil. This results in generating palm oil waste as a by-product of the milling method. The processing of new fruit bunches of palm oil as outlined in Fig. 2, leads to the generation of distinct kinds of residues. Environmental Engineers classified Palm oil mill effluent (POME) as a difficult waste among industrial wastes if poorly released into the environment. POME was recognized in Malaysia as a significant cause of water pollution [3]. Therefore, it is important to find efficient and economical ways to remove all contaminants from water [4]. Several conventional treatment methods were reported to have been used by palm oil mill companies where biological treatments of facultative or anaerobic digestion become the most frequently used [5].

However, these biological treatment systems [6] generate sludge that must be properly discharged [7]. They also require adequate maintenance and tracking as the procedures depend exclusively on microorganisms to disintegrate the pollutants. In the treatment of POME, findings revealed that using the condensation mechanism in addition to biological treatment would enhance the treatment efficiency [8].

Hashimov et al. [9], evaluated air-floatation system as a physical treatment method on a pilot plant scale where tiny bubbles of air carrying suspended solids were discharged in the effluent.

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Fig. 1. An oil palm tree.

However, the system turned out to be very inefficient and unreliable.

Najib et al. [12] reported that the most common method used in Malaysia for POME treatment is the ponding system. However, the desludging process of POME pond itself is very costly as the current cost is about RM100, 000 per pounds, which does not include the cost of maintenance and utilities for each pond. Apart from the cost implication, the climate will also affect the treatment process and is dangerous to the environment if the pond overflows. The magnitude of the effect of pond overflow depends on the waste characteristics, which will determine its impact on the surroundings. Therefore, it becomes necessary to consider all the different aspects of waste.

Application of these technologies is often difficult in adhering to the effluent discharge regulations by the Malaysian Department of Environment [13] because POME treatment needs an effective and sound system to face contemporary challenges of environmental protection and economic viability. Therefore,

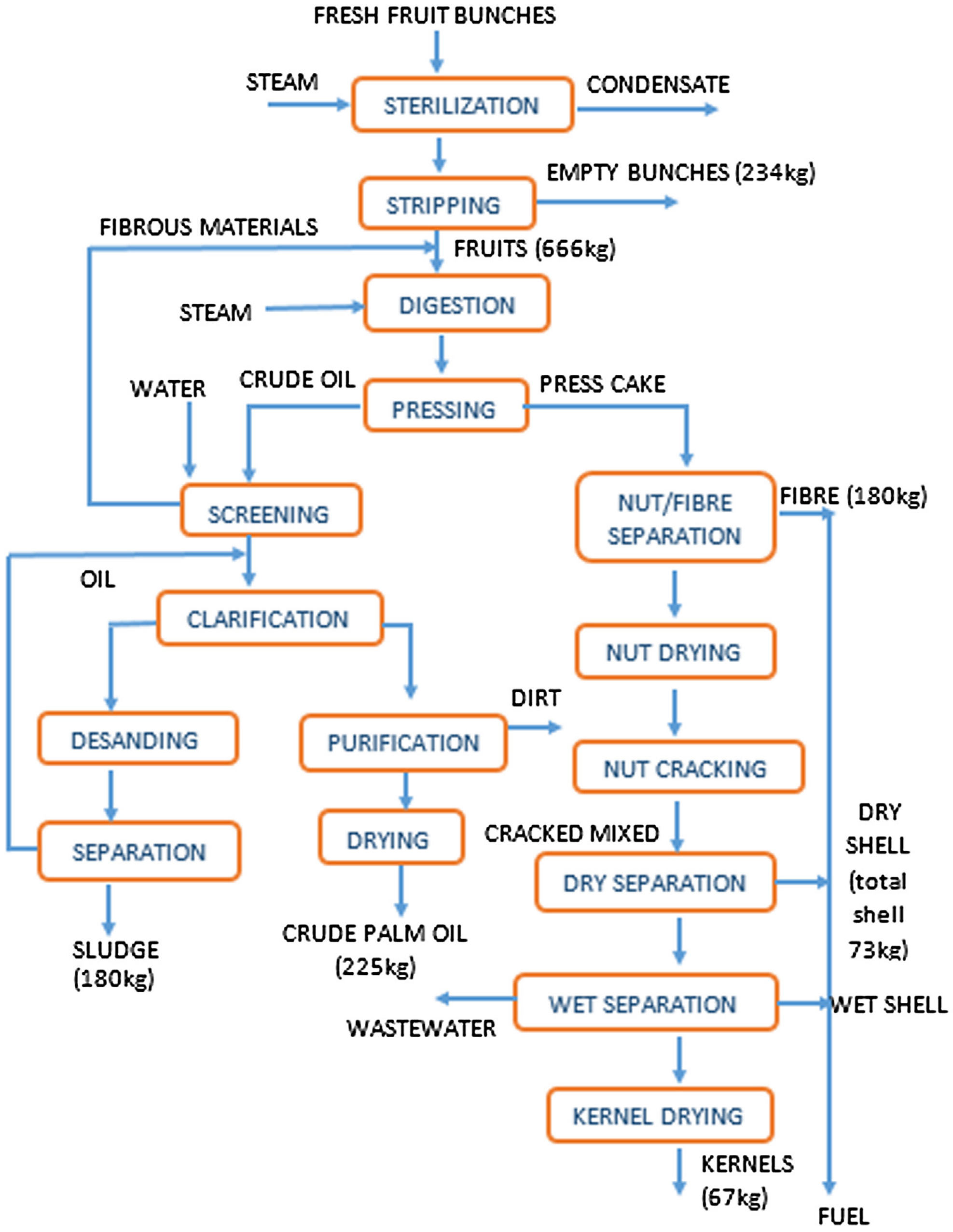

Fig. 2. Flow chart for the palm oil extraction process [10,11].

Table 1
Effectiveness of different coagulants in contaminant removal.

Coagulant	pH	Concentration Range	Removal (%)	References
Aluminium Sulphate	4–8	1–6 g/L	82 SS 90 Turbidity	[2]
Aluminium Sulphate	4	90–540 mg/L	66 BOD 92.3 TSS 78.6 COD	[19]
Aluminium Sulphate	4–9	1–7 g/L	93.01 Turbidity 95.04 Oil	[20]
Alum + Anionic Polymer	4.5	0– 600 mg/L	93 SS 58 BOD 48 COD	[21]
Chitosan-magnetite nanocomposite particles	4.5	40–600 mg/L	97.6 TSS 62.5 COD 98.8 Turbidity	[22]
Chitosan	3–6	0.08–8 g/L	99 SS 99 Residue oil	[23]
Alum + Chitosan	4.5	1–8 g/L Alum + 0.4 g/L chitosan fixed	61.00 COD 99.08 TSS 99.98 Turbidity	[24]
Moringa Oleifera	5	1–5 g/L	98.99 SS	[25]
Moringa Oleifera	4–9	0.5–6 g/L	99.2 SS 52.5 COD	[26]
Anionic Polymer	7–9	5 mg/L	73 COD 95 TP 97 TSS	[27,28]
Ferric chloride and Alum	7	100–500 mg/L	83 COD 95 Turbidity	[29]
Ferric chloride	4–12	0.5–3 g/L	87 COD	[30]

research and the use of new methods and technologies are still necessary as this study relates to wastewater management for sustainable development [14,15]. Coagulation-flocculation is the most commonly used, relatively cheap and promising new technology in wastewater treatment systems [16,17]. It is widely employed as illustrated in Table 1, to reduce pollutants concentration in POME. Nonetheless, findings revealed that coagulation could be the cause of various health problems if poorly managed. This is due to the presence of too much aluminium and iron salt. Toxic impacts of metals in the form of allergies, tumours and cancers have been reported [18].

Aluminium sulphate (alum) is the most popularly used coagulant in wastewater treatment, because of its accessibility, cost-effectiveness and an established efficiency. Sadly, research has revealed that its large consumption can contribute to the growth of neurodegenerative disorders [21]. The study also revealed that environmental friendly natural coagulants such as cactus, *moringa oleifera*, wheat germ and chitosan can be developed and used nowadays [31].

To reduce the adverse impacts of these salts during and after POME treatment, chitosan, *moringa oleifera*, zeolite and ferric chloride would partly replace aluminium sulphate (alum). The study would then investigate the partial substitution capacity of alum with the aforementioned coagulants in contaminants removal through the method of coagulation-flocculation.

The coagulation-flocculation is a pre-treatment method can significantly reduce the total pollution strength of the effluent before biological treatment.

2. Methodology

2.1. Wastewater sampling

The methodology used for this study began with wastewater sample collection followed by its characterisation, purchase of coagulants and coagulant aid, apparatus and reagents preparation, coagulation-flocculation, determination of optimum coagulants dosages and finally the determination of removal efficiencies for colour, turbidity, COD, TSS, NH_3-N, oil & grease. The process flow is summarised on Fig. 3. Below.

Wastewater used for this study was POME obtained from an Oil Palm Mill located in Malaysia. The POME sample was stored in a labelled, thermal resistant plastic container, sealed and later taken to the laboratory. Samples cooled for preservation at approximately 4 °C to avoid biodegradation due to microbial action [32]. Sufficient quantity was withdrawn from the preserved sample after it is allowed to reach room temperature (27–30 °C), analysed for their characteristics and chemical properties before the start of the experiments. 500 ml of fresh POME were characterized and then used in the jar tests [32]. The characterization focused on the following parameters: pH, DO, TSS, BOD, COD, NH_3-N, oil & grease, turbidity, colour and temperature.

2.2. Experimental materials

Collection, preservation, characterization and analysis of samples [33,34] before, during and after treatment require several apparatus and reagents. The following apparatus were used in this study; Separator funnel, Filter paper, Test tubes, Drying Oven, Thermal resistant plastic container, A stirring machine with six paddles or magnetic stirrer, 100 push-pull syringe pump, HACH DR6000 Spectrophotometer, analytical balance, Stopwatch, desiccator, digital reactor block (DRB 200), HQ440d HACH pH Meter, GAST DOA-P404-BN filtration Apparatus, DAIKI Sciences SHAKER, aluminum weighing dishes, scale for weighing chemicals particle size analyzer brand CILAS, pipets and flocculator. Fig. 4 is a pictorial view of some equipment's utilized.

Reagents used in this study were; n-Hexane, petroleum ether, acetic acid, sulphuric acid, sodium hydroxide, potassium dichromate, mercury powder, aluminium sulphate, ferric chloride, zeolite, chitosan powder, *moringa oleifera* seeds and distilled water.

2.3. Preparation of samples

Laboratory grade $Al_2(SO_4)_3{\cdot}18H_2O$ and $FeCl_3$ were obtained after which stock solutions were prepared by following the USEPA procedure for enhanced coagulation [35].

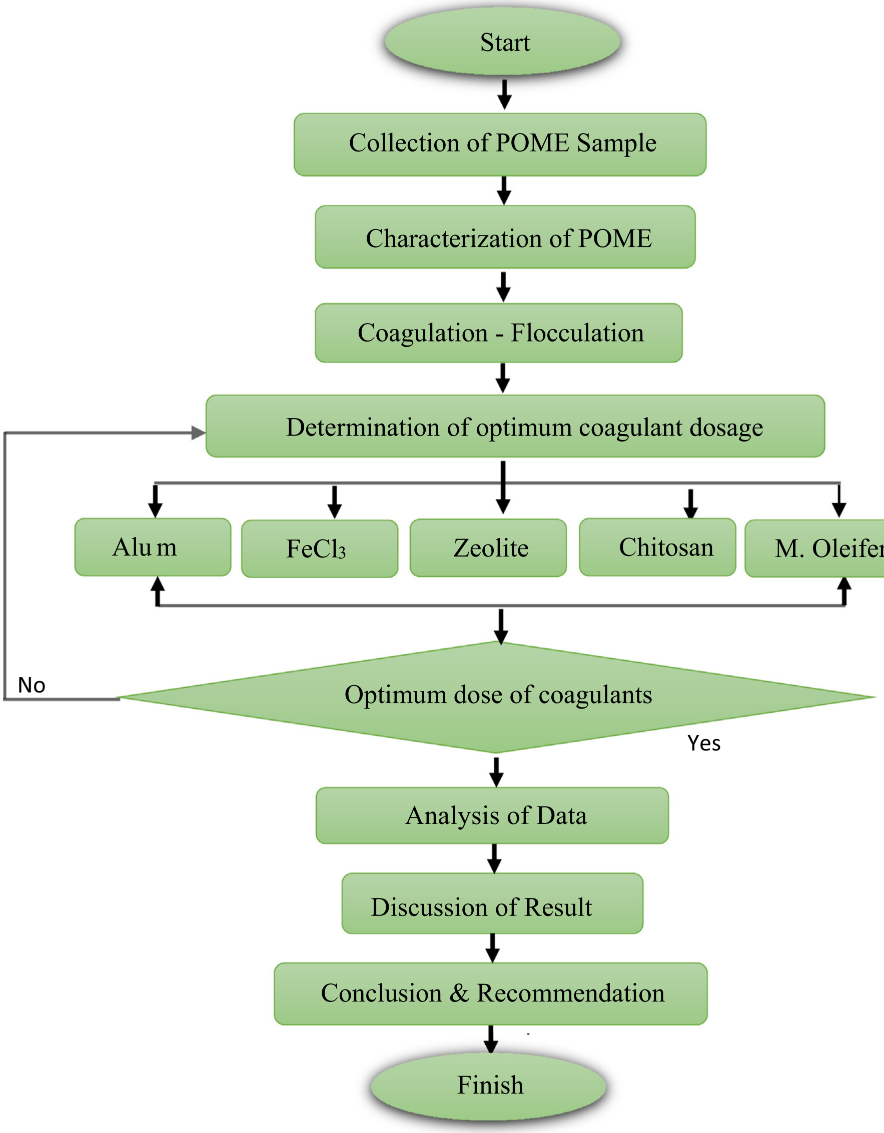

Fig. 3. Flowchart for the study outline.


pH Meter
Filtration Apparatus
Dessicator
Digital Reactor Block
Jar test apparatus
Shaker
Spectrophotometer
AAS Machine
Turbidimeter

Fig. 4. Laboratory facilities utilised.


Fresh fruit bunches
Pure palm oil solution
Alum crystals
Zeolite crystal
Chitosan flake
Chitosan powder
Dry MO seeds
Fresh MO seeds
$FeCl_3$ Powder

Fig. 5. Fresh fruit bunches, extracted POME and coagulants.

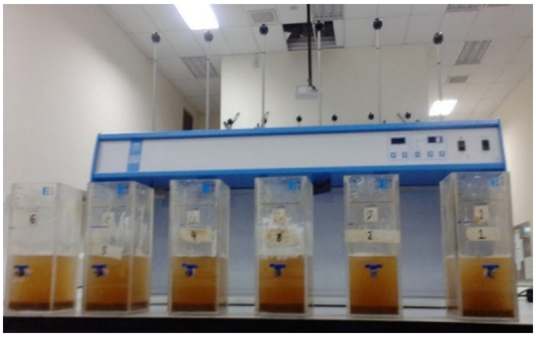

Fig. 6. POME coagulation process.

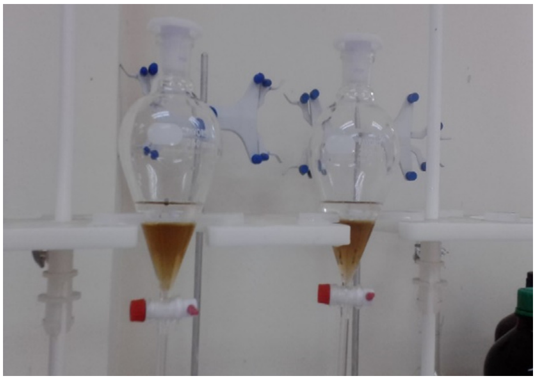

Fig. 7. Oil extraction process.

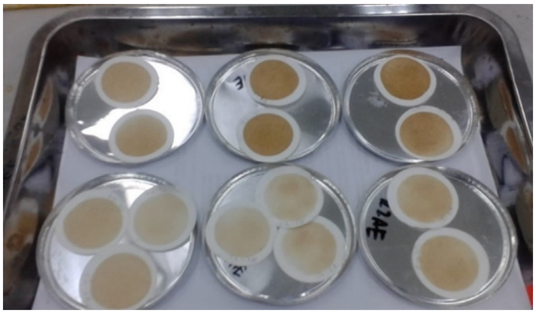

Fig. 8. Dried filter paper with residue.

A mining company supplied the Zeolite samples utilised. The crushed rock-like form of the original zeolite was ground as fine as possible using a crusher and a Ball Mill. It was further pulverised and sieved to obtain particle sizes of 63 μm. The zeolite was then submerged for 24 h in 1 M aqueous NaCl to enhance its cation exchange capacity. Material sample washed with distilled water, rinsed and subsequently placed at 105^{O}C for approximately 24 hrs in an oven to clear it of impurities. Dried for two hours in a desiccator before use, sample characterized by X-ray diffraction (XRD).

The study used the purchased powdered chitosan displayed in Fig. 5 for the experimentation purpose. Stock solution was prepared by dissolving 1.5 g of chitosan powder in 150 ml of 0.1 M HCl solution. The solution agitated with a magnetic stirrer at 100 rpm to ensure complete dissolution. Further dilution with 150 ml of distilled water produced a solution comprising 5.0 g/l chitosan per ml of solution.

The acquired *Moringa oleifera* dry seeds, was cleaned and ground to a fine powder and then screened through 0.8–2.5 mm mesh. Soxhlet apparatus magnified the extraction of dried *moringa oleifera*. It was carried out for about 8 h and followed by the preparation of the stock solution for *moringa oleifera* cake after extracting oil through the dissolution of 5 g of the cake in a 100 ml distilled water. Extracting the highly active coagulant agents required a blender and the mixture stirred for about 120 s. *Moringa oleifera* seeds pastes were filtered using the Muslin cloth before adding into POME sample [25].

2.4. The jar test

The study used the standard jar test device displayed in Fig. 6 during the investigation to coagulate fresh POME using various types of coagulants. The POME samples were homogeneously mixed and fractioned into beakers each containing 500 ml of suspension and subsequently measured for COD, BOD, DO, TSS, NH_3-N, Oil & grease, Turbidity and Colour to represent the initial concentration.

Coagulation experiment conducted with jar test began with coagulation, flocculation and settling respectively using two-stages of mixing which are rapid and slow mixing. Rapid mixing at the beginning to expedite interactions with colloidal coagulant known as the destabilization of colloids. Slow mixing is necessary to allow the combined particles to form larger particles and settle quickly [36]. Previous studies justified the fixing of rapid mixing speed and time, slow mixing speed and time alongside settling times.

Original pH of 4.51 also fixed as reported that, coagulation of POME is best at original pH. Hence, the study determined the optimum dose of various coagulants.

Six different doses of aluminium sulphate coagulant (1000, 2000, 3000, 4000, 5000 and 6000 mg/L) were poured into beakers containing raw POME and rapidly mixed at a speed and time of 250 rpm and 3 min, respectively. Slow mixing speed and time of 30 rpm and 30 min adopted. The suspension was then allowed to settle for 60 min [37]. 5 ml of an anionic polymer was added to each sample during the slow mixing period [27,28]. Samples withdrawn from the top of the supernatant from each beaker to measure COD, TSS, NH_3-N, oil & grease, colour and turbidity. Carefully handling TSS determination and oil extraction process as displayed in Figs. 7 and 8, tests were run in triplicate and the average of each data used for further analysis [19]. The tests were also performed using the original pH values and at ambient temperature [31].

According to several studies [17,18], it showed that the effective coagulation process of POME can be done under the original POME pH of 4.0–5.0. Evaluation of the process performance for determi-

Table 2
Coagulants and coagulant dosages.

Coagulants	Coagulants dosages (mg/L)					
Alum	1000	2000	3000	4000	5000	6000
Ferric Chloride	500	1000	1500	2000	2500	3000
Zeolite	200	400	600	800	1000	1200
Chitosan	250	300	350	400	450	500
Moringa oleifera	500	1000	2000	3000	4000	5000

nation of optimum dose for alum was based on the highest percentage of NH_3-N, COD, TSS, oil & grease, colour and turbidity removal from the sample.

The coagulation-flocculation procedure was repeated using different doses of ferric chloride, zeolite, chitosan and *moringa oleifera* coagulant as indicated in Table 2 below.

2.5. Methods

The performance of the various coagulants after conducting the jar test was measured based on NH_3-N, COD, oil & grease, turbidity, colour and TSS removal following standard methods [32]. Table 3 highlights the parameters checked and described the method used for each parameter.

3. Result analysis and discussion

3.1. Characterization of raw POME

The results of the initial characteristic of fresh POME are presented in Table 3 below.

Usually, wastewater biodegradability is determined by the BOD/COD proportion. Wastewater with a BOD/COD proportion above 0.5 is quite biodegradable and can be efficiently handled biologically. However, if it is within the range of 0.3–0.5, seeding is needed to biologically treat the sample because the method will be comparatively slow as it requires time to acclimatize the microorganisms that assist in the process of degradation [38].

Except for pH, it can be concluded that all values obtained in Table 4 above were beyond permissible limits as cited by [39]. The study further conducts experimental investigations on the influences of different coagulants the selected contaminants [40].

3.1.1. The optimal dose for $Al_2(SO_4)_3$

Fig. 9 shows the results of the removal efficiencies at different doses of $Al_2(SO_4)_3$ for TSS, Turbidity, COD Oil & Grease, NH_3-N and Colour along with the percentage sludge volume in the POME treatment. From the graph, it showed that the increase of alum dose improves the effectiveness of removal until the attainment of optimum dose where the effectiveness begins to decline. Alum dose of 4000 mg/L provides the largest percentage removals for TSS, Turbidity, NH_3-N and COD as 98.72%, 98.68%, 98.46% and 75.01%, respectively while the dose of 3000 mg/L provides highest removal percentages of oil & grease and colour as 97.97% and

Table 3
Parameters and methods.

Parameters	Method
pH	APHA Standard Method 4500
TSS	Standard Method 2540D
Turbidity	Standard Method 2130B
Colour	USEPA, Method 8025
COD	USEPA Method 8000
NH_3-N	Nessler Method, USEPA Method 8038
Oil and Grease	Hexane Extractable Gravimetric Method, USEPA Method 10056

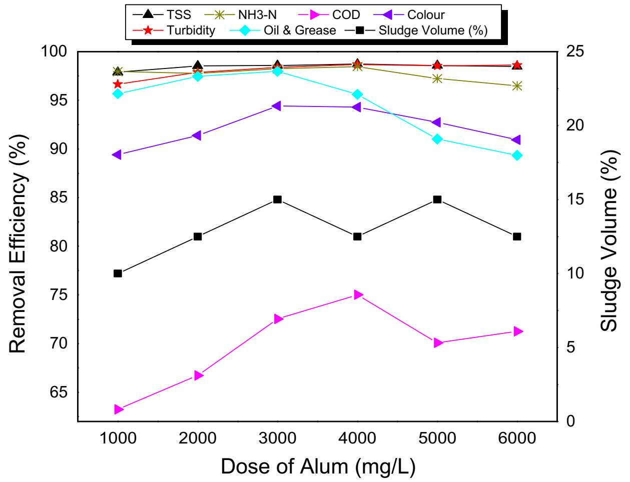

Fig. 9. Contaminants removal efficiencies by Alum.

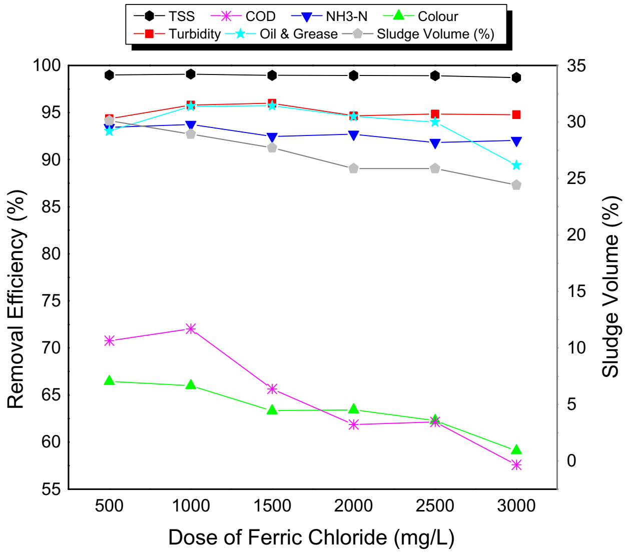

Fig. 10. Contaminants removal efficiencies by Ferric chloride.

Table 4
Characterization of the POME.

Parameter	Sample A	Sample B	Sample C	Mean
pH	4.50	4.51	4.51	4.51
Temperature °C	47.8	49.5	45.9	47.7
TDS (mg/L)	46,470	45,950	46,400	46,273
TSS (mg/L)	25,425	26,735	28,940	27,033
Turbidity (NTU)	26,670	26,580	26,520	26,590
BOD_5 (mg/L)	23,940	23,870	25,290	24,367
COD (mg/L)	73,302	72,226	78,529	74,686
BOD_5/COD	0.33	0.33	0.32	0.33
Colour (Pt.Co)	8157	8021	8101	8093
NH_3-N (mg/L)	523.31	520.58	514.75	520
Oil & Grease (mg/L)	6420	7310	9430	7720

94.41%, respectively. It can be concluded that the optimum $Al_2(SO_4)_3$ dose is 4000 mg/L with 12.5% as the percentage sludge volume.

3.1.2. The optimal dose for ferric chloride

Fig. 10 shows that increased dosage of ferric chloride increases the effectiveness of removal until it reaches the optimal dose. Afterwards, the efficiency of removal starts to decrease as the dose of ferric chloride increases. Ferric chloride dose of 1000 mg/L provides the largest removal percentages for TSS, NH_3-N and COD as 99.09%, 93.74% and 72.04% respectively while dose of 1500 mg/L provides highest removal percentages of oil & grease and turbidity as 95.73% and 95.99% respectively, even though no much difference from 95.67% and 95.79% obtained at the dose of 1000 mg/L. Therefore, the differences between oil & grease and turbidity will be ignored and consider the results of 1000 mg/L since it is a lower dosage. Colour achieved the best removal efficiency of 66.44% at 500 mg/L. It subsequently decreased as the $Fecl_3$ dose increases. The highest dose of 3000 mg/L resulted to as least as 24.42% sludge volume reduction. From these results, 1000 mg/L represents the optimum dose for $FeCl_3$ with best performance in TSS, NH_3-N, COD, oil & grease, turbidity and removal.

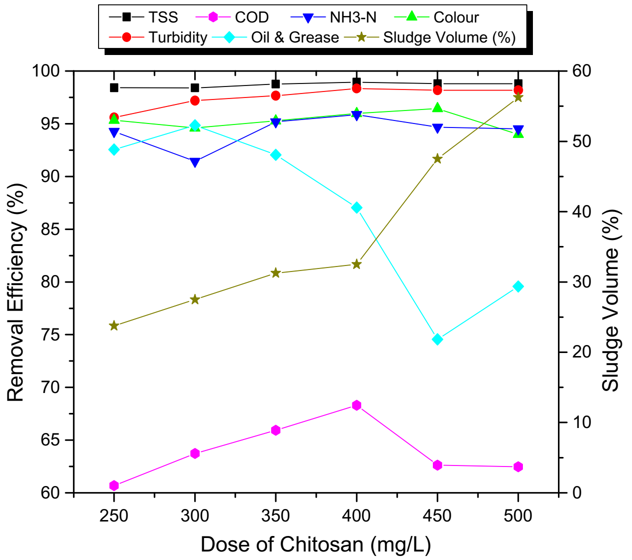

Fig. 11. Contaminants removal efficiencies by Chitosan.

3.1.3. The optimal dose for chitosan

Chitosan like most other coagulants, showed removal efficiencies until the realization of optimum dose. From Fig. 11, it can be observed that the dose of 400 mg/L provides the largest removal percentages of TSS, Turbidity, NH_3-N, COD as 98.95%, 98.35%, 95.88% and 68.31% respectively as cited by [31]. At 450 mg/L, colour attained the highest removal of 96.44%. Since the difference between these results and the ones obtained at 400 mg/L is 0.46%, the study concludes that colour also has good removal efficiency at 400 mg/L. A dose of 300 mg/L provides the highest removal for oil & grease at 94.86% with a wide margin compared to that at 400 mg/L. As chitosan dose increases up to 400 mg/L, percentage sludge volume kept increasing with a smaller gap. However, with an increase of 50 mg/L, percentage sludge volume rises with a much higher gap from 32.5% to 47.5%. At a dose of 400 mg/L, most parameters evaluated obtained best removal efficiencies. pH, zeta potential, acidity, rapid & slow mixing speed, rapid & slow mixing time, adsorption properties (isotherm, thermodynamics, kinetics) [16] influenced the concentration of the dosage. Therefore, 400 mg/L is the optimum dose required for the treatment of POME.

3.1.4. The optimal dose for Moringa oleifera

Fig. 12 shows the effect of different *moringa oleifera* doses in the removal of Oil & Grease, NH_3-N, Colour, TSS, COD and Turbidity along with the percentage sludge volume in the POME sample showed variability in their removal efficiencies. *Moringa Oleifera* dose of 2000 mg/L provides the highest removal percentages of TSS, turbidity, colour, NH_3-N, oil & grease as 95.42%, 88.30%, 90.15%, 89.81% and 87.05% respectively. A dose of 3000 mg/L provides greater removal percentages of 51.99% for COD while 2000 mg/L obtained 51.21% removal. The study concluded that

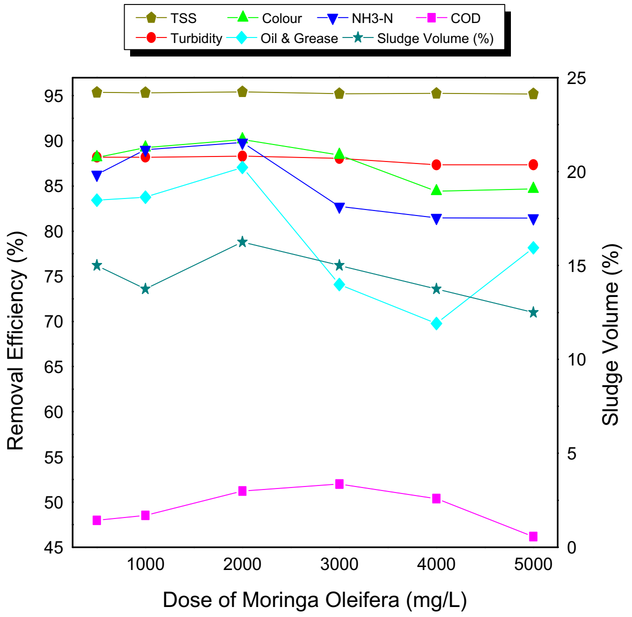

Fig. 12. Contaminants removal efficiencies by *Moringa Oleifera.*

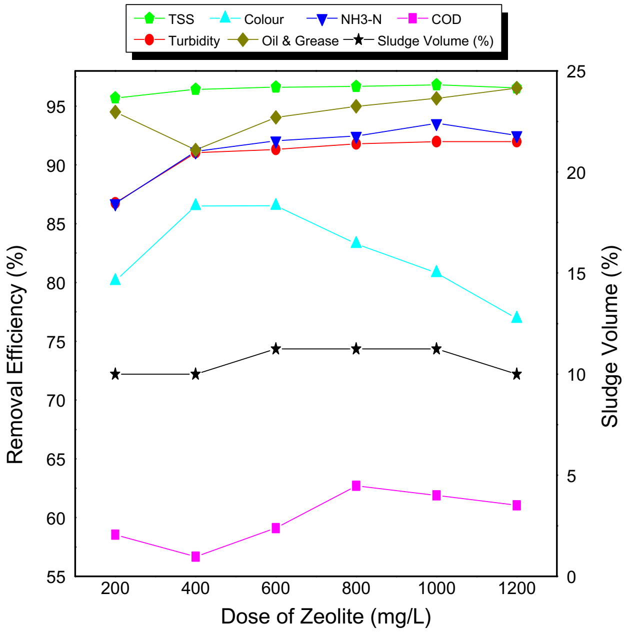

Fig. 13. Contaminants removal efficiencies by Zeolite.

2000 mg/L is the optimum dose of *moringa oleifera* even though it has the highest percentage sludge volume of 16.25%.

3.1.5. The optimal dose for zeolite

Fig. 13 shows that dosage of 1000 mg/L of Zeolite gave the highest removal percentages of TSS, Turbidity, NH_3-N, COD as 96.82%, 91.98%, 93.54% and 61.89% respectively where highest oil & grease removal of 96.54% was achieved at 1200 mg/L followed by 95.67% at 1000 mg/L. Colour removal was highest at 400 mg/L with 86.51% efficiency. At 1000 mg/L of Zeolite gave the optimum dose of zeolite with percentage sludge volume of 11.25%.

3.2. Comparison of optimum dose for various coagulants

In compliance with the objectives of this study, utilising five different coagulants to comprise both natural and chemical ones is paramount to obtain the optimum dose for each one. This was also to visualize and justify the dosages earlier used in the first phase of the study [41] where other coagulants were combined with alum.

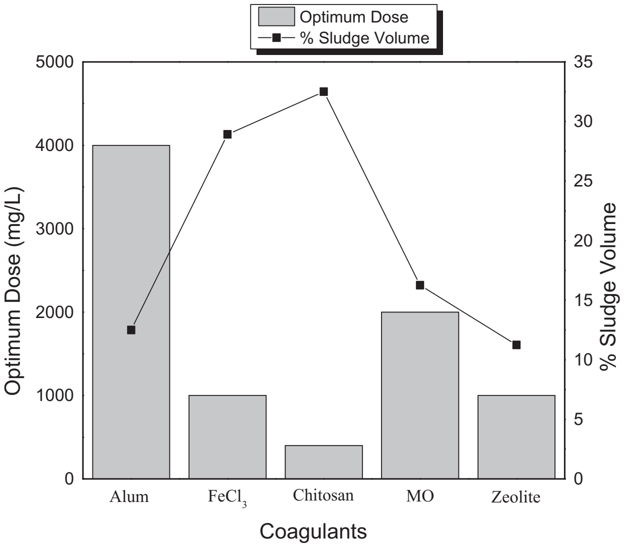

Fig. 14. Optimum dose of alum, $FeCl_3$, chitosan, moringa oleifera and zeolite for contaminants removal efficiencies as alongside sludge volume percentage.

Table 5
Comparison of the performance of natural coagulants.

Parameters removal efficiency (%)	Coagulants		
	Chitosan	M.O.	Zeolite
TSS	98.95	95.42	96.82
Turbidity	98.35	88.30	91.98
NH_3-N	95.88	89.81	93.54
COD	68.31	51.99	61.89
Colour	96.44	90.15	86.51
Oil & Grease	94.86	87.05	96.54

Fig. 14 below depicts that alum, despite being cheap, abundant and easy to handle, has the highest dose requirement having obtained 4000 mg/L as its optimum. *Moringa oleifera* had 2000 mg/L, chitosan 400 mg/L while both zeolite and $FeCl_3$ at 1000 mg/L. Zeolite is the highest towards sludge decrease with a minimum sludge quantity of 11.25%, accompanied by alum with 12.50%. However, chitosan that is very good in TSS and turbidity removal is least in sludge volume reduction with a percentage volume of 32.50%.

3.3. Effect of pollutants on coagulants performance

3.3.1. Total suspended solids (TSS)

From the results of the experiments conducted, 99.09% TSS removal attained from the fresh POME by $FeCl_3$ coagulant happens to be the highest compared to alum having 98.72%, which indicates that $FeCl_3$ is more efficient in TSS removal. Results in TSS removal showed significant reduction when $FeCl_3$ dose was 0.5–1 g/L, whereas, for a higher dosage, no traces of further TSS reduction. The supernatant pH gradually decreased with increasing coagulant dose. However, alum became the most efficient in the removal of natural organic matter at a dose was higher than 3000 mg/L.

3.3.2. COD, NH_3-N and Turbidity

All parameters analysed in this study except TSS removal proved more effective when treated with alum, which could be due to the presence of sulphate salt. Observation revealed the wide margin obtained for NH_3-N removal between alum and $FeCl_3$ with 98.46% and 93.74% respectively. The similar trend goes to all other parameters. Iron salts have high-performance efficiency in the removal of heavy metals. However, a major obstacle is the yellow colouration and corrosion, which led to the poor performance of $FeCl_3$ in terms of colour removal achieving 66.44% as the highest removal compared to 94.41% for alum. Removals of TSS, Turbidity, COD, NH_3-N were also high using chitosan. However, once the dose of chitosan gets further than the ideal state, the extraction efficiencies that could be due to the inversion of the surface load and the destabilization of the particles will reduce slightly. The next highest removal was by zeolite and lastly *Moringa oleifera* coagulants.

3.3.3. Oil & grease

Oil and grease best removal efficiencies achieved are 96.54%, 94.86% and 87.05% for zeolite, chitosan and *moringa oleifera* respectively. Table 5 presents a summary of comparison for the three natural coagulants in terms of removal efficiencies for POME. It also shows the difference in the effectiveness of oil removal and levels of oil at distinct dose levels. The table also detailed the difference in the performance of natural coagulants used in this study in terms of various parameters removal efficiency.

3.3.4. Colour

Chitosan, a biopolymer was highest in the removal of colour with a removal efficiency of 96.44%, followed by *moringa oleifera*

Table 6
P-values and F values of TSS, Turbidity and Colour for all Coagulants.

Coagulants	TSS		Turbidity		Colour	
	F	p-value	F	p-value	F	p-value
Alum	19.83507899	0.001228153	19.83904148	0.001227306	19.90822849	0.001212621
Ferric Chloride	18.69267832	0.001504819	18.78024981	0.001481121	19.50507058	0.001301274
Chitosan	52.35144642	2.80627E−05	52.35144642	2.80627E−05	53.65150886	2.52715E−05
Moringa Oleifera	12.21108761	0.005779988	12.28370076	0.005680668	12.28755093	0.005675459
Zeolite	15.61088902	0.002725595	15.90426871	0.002567511	16.34715342	0.002349253

Table 7
P-values and F values of NH_3-N, Oil & Grease and COD for all Coagulants.

Coagulants	NH_3-N		Oil & Grease		COD	
	F	p-value	F	p-value	F	p-value
Alum	19.84413535	0.001226217	19.90822849	0.001212621	20.17053173	0.001158832
Ferric Chloride	18.83407521	0.001466778	18.81030043	0.001473093	19.46804505	0.001309801
Chitosan	54.00393789	2.45731E−05	56.54108247	2.01743E−05	66.2837723	1.00955E−05
Moringa Oleifera	12.31107756	0.005643757	12.36767979	0.005568357	12.66595328	0.005190522
Zeolite	15.87284121	0.002583907	15.71218355	0.002669723	17.55391024	0.001858728

and lastly zeolite coagulants. This indicates that *Moringa* is a good colour removal in POME compared to zeolite. The study by [41] revealed the combination of aluminium and other coagulants resulted in increased cuts for COD, oil & grease, TSS, NH_3-N and turbidity as 77.65%, 98.32%, 99.69%, 98.54% and 99.61%, respectively.

3.3.5. Data presentation and statistical analysis

Performance evaluation of each coagulant is presented in tables and graphs using OriginPro. The results were statistically analysed using the One-way Analysis of variance (One-Way ANOVA) operated through SPSS software (Version 17) developed to determine the variance of the physicochemical parameters for all samples treated using various kinds of coagulants.

Tables 6 and 7 presented the P-values (level of significance) for all contaminants tested across various coagulants and their dosages. The values are all < 0.05 for treated Palm Oil Mill Effluent which implies that the mean ranks of samples are not equal and the Null hypothesis means that the null hypothesis is discredited. This is greatly due to the characteristic difference between the coagulants used for the treatment. F values for all samples were > 1. This indicates that there is a significant change in the mean values when different concentrations were used.

4. Conclusion

Fresh POME was characterized and the feasibility of using both chemical (Aluminium sulphate and Ferric chloride) and natural coagulants (Chitosan, *Moringa oleifera* and Zeolite) in the removal of COD, TSS, oil & grease, turbidity, colour, and NH_3-N were studied. The study emphasized on determining the optimal doses of coagulant for the various coagulants used. Findings revealed that alum has the highest dose requirement having obtained 4000 mg/L as its optimum. *Moringa oleifera* had 2000 mg/L, chitosan 400 mg/L while both zeolite and $FeCl_3$ at 1000 mg/L. Zeolite is the best in terms of sludge reduction with the least sludge quantity of 11.25% accompanied by alum with 12.50%. However, chitosan said to be very good in TSS and turbidity removal is least in sludge volume reduction with a percentage volume of 32.50%. Data processing with the use of OriginPro tool has proven that there is a statically significant difference for all coagulant since $p < 0.05$ and $F > 1$.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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