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Treatment of Palm Oil Mill Effluent (POME) by Coagulation-Flocculation using different Natural and Chemical Coagulants: A Review

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Abstract: *Treatment of Palm Oil Mill Effluent (POME) requires a sound and efficient system to face the current challenge of wastewater disposal in Malaysia. To comply with the discharge standard regulation, environmental protection and economic viability, several treatment technologies have been used. However, treatment of POME by coagulation-flocculation within a short period of time without involving a vast area of land was found as the most suitable, popular and cost-effective solution to negative environmental impacts as a result of untreated POME discharged to the environment. However, most chemical coagulants used in the process contain too much salt that also have effect on human health. In other to reduce these negative effects, quantity of alum used in POME treatment would be reduced by partially replacing it with either a seafood (chitosan), herb (Moringa oleifera), geological material (zeolite) and another iron salt that tends to be less hazardous (ferric chloride).*

Keywords: *Coagulation, Chemical coagulants, Flocculation, Natural coagulants, Palm oil mill effluent.*

I. Introduction

Palm oil is a very important and essential commodity in Malaysia; it contributes immensely to the economy. Presently, Malaysia is currently one of the largest producers of palm oil exporting to over 150 countries around the world. Palm oil cultivation is currently around 4.48 million hectares and generates revenue of RM 65.2 billion. Thus it is estimated that for 1 tonne of crude palm oil produced, about 5-7.5 tonnes of water is required and more than 50% turn out as POME. Thus, the adverse environmental impact from palm oil effluent cannot be neglected [1].

POME is a thick brownish viscous liquid waste which is non-toxic but has unpleasant odour which contains soluble materials that may have a significant impact on the environment. The composition of POME are mainly water, oil, suspended solid, dissolved solid and sand. [2]. Palm oil mill effluent (POME) is a highly polluting wastewater with typically a biochemical oxygen demand of 25 g/l, a chemical oxygen demand of 50 g/l, oil and grease of 8 g/l, suspended solids of 20 g/l, and total solids of 40 g/l[3]. POME also contains macromolecules, such as polysaccharides, lipids, proteins, and a number of monocyclic and polymeric aromatic molecules [4]. The production of POME especially in Malaysia known to be one of the largest producers of palm oil recorded to have national production rate of 0.67 cubic meters per tonne of FFB processed by mill is a major challenge to researchers [5]. It has been estimated that POME contributes to about 30% of the total biochemical oxygen demand (BOD) load exerted on the Malaysian aquatic environment [6]. Therefore, POME cannot be discharged directly to the land, as it will adversely affect the soil and vegetation system. It is cannot also be discharged into the watercourses directly without treatment as the good quality of water bodies for aquatic lives will be depleted and distracted [7].

Palm oil mill effluent is a critical source of water pollution when released without treatment into local rivers and lakes. The effluent has to be thoroughly treated so that it can be tolerated by organisms present in the receiving system [8]. Several conventional treatment methods were reported to be used in treating POME which involved the use of aerobic, anaerobic and facultative ponds zero discharge technology, land application, adsorption, biological treatments, coagulation-flocculation, ultrafiltration as well as membrane technology [9]. However, coagulation-flocculation constitute the backbone process in most water and wastewater treatment plants. Their purpose is to improve the separation of particulate species in downstream processes such as sedimentation and filtration. Thus, palm oil mill effluent can be treated using natural and chemical coagulants as they can be used to reduce the pollutant strength of POME.

II. Materials And Method

2.1 Coagulation-Flocculation

Coagulation-flocculation is a chemical water treatment technique typically applied prior to sedimentation and filtration to enhance the ability of a treatment process to remove particles. Coagulation and flocculation processes are essential parts of water treatment, and the clarification of water using coagulants is practiced since ancient times [10]. Coagulation is a process used to neutralize charges and form a gelatinous mass to trap or bridge particles thus forming a mass large enough to settle or be trapped in the filter. Flocculation is gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from solution [11].

According to [12], the term coagulation describes the effect produced when certain chemicals are added to raw water containing slowly settling or nonsettleable particles. The chemicals hydrolyse and neutralise the electrical charges on the colloidal particles, which begin to form agglomerations termed floc which will be removed by clarification and filtration. Coagulation process can alter the suspended particles so that they can adhere to each other. During coagulation, a positive metal ion is added to water to reduce the surface charge to the point where the particles are not repelled from each other. Chemicals (coagulant) are added to the water to bring the non-settling particles together into larger, heavier masses of solids called floc [13].

In wastewater treatment, coagulation and flocculation are employed to separate suspended solids from water. Although the terms coagulation and flocculation are often used interchangeably, or the single term "flocculation" is used to describe both; they are, in fact, two distinct processes. Finely dispersed solids (colloids) suspended in wastewaters are stabilized by negative electric charges on their surfaces, causing them to repel each other. Since this prevents these charged particles from colliding to form larger masses, called flocks, they do not settle. For removal of colloidal particles from suspension, chemical coagulation and flocculation are required. These processes, usually done in sequence, are a combination of physical and chemical procedures. Chemicals are mixed with wastewater to promote the aggregation of the suspended solids in to particles large enough to settle or be removed. Coagulation is the destabilization of colloids by neutralizing the forces that keep them apart. Cationic coagulants provide positive electric charges to reduce the negative charge (zeta potential) of the colloids. As a result, the particles collide to form larger particles (flocks). Rapid mixing is required to disperse the coagulant throughout the liquid [14].

Coagulants work by creating a chemical reaction and eliminating the negative charges that cause particles to repel each other. The coagulant-source water mixture is then slowly stirred in a process known as flocculation. This water churning induces particles to collide and clump together into larger and more easily removable clots, or “flocs”. The process requires chemical knowledge of source water characteristics to ensure that an effective coagulant mix is employed. Inappropriate coagulants make these treatment methods ineffective [15]**.** The efficiency of the coagulation-flocculation method depends on the raw wastewater characteristics, pH and temperature of the solution, the type and dosage of coagulants, and the intensity and duration of mixing [16]. The effectiveness of coagulation process depends on coagulant type, coagulant dosage, pH of the solution, the concentration and nature of the organic compounds present in the wastewater [17]. The best approach for determining the treat ability of a water source and determining the optimum parameters (more effective coagulant, required dose rates, pH, flocculation times, most effective coagulant aids) is by use of a jar tester. It is the quickest and most economical way to obtain good reliable data on the many variables which affect the coagulation and solid removal process [18].

The jar test process consists of three steps which is the first rapid mixing stage; aiming to obtain complete mixing of the coagulant with the wastewater to maximize the effectiveness of the destabilization of colloidal particles and to initiate coagulation. Second step is slow mixing; the suspension is slowly stirred to increase contact between coagulating particles and to facilitate the development of large flocs. After that, the third step settling stage; mixing is terminated and the flocs are allowed to settle [19].

2.2 Coagulation-Flocculation in POME Treatment

The biological treatment currently used in treating POME and effluent discharged still contains high organic loads [20]. Therefore, the pre-treatment of POME using coagulation and flocculation processes has become an important feature, in order to efficiently reduce the organic load prior to subsequent treatment processes. Aluminium sulphate (alum), an inorganic salt, is the most widely used coagulant in wastewater treatment, due to its proven performance, cost-effectiveness and availability [21]. Numerous researches have reported the success recoded in the treatment of oily mill effluents using coagulation, filtration and settling procedure [22]. A pilot plant study of POME treatment using a series of process such as coagulation, sedimentation, solvent extraction, membrane filtration and adsorption was also found to be very successful by [23].

In conventional wastewater treatment systems, coagulants such as aluminum chloride, ferrous sulphate, aluminum sulphate, ferric chloride and hydrated lime are the most widely used ones. This is because of their effectiveness, cheap, easy to handle and availability [24]. It has been reported by [25] that chemical coagulation can be used to enhance the reduction of POME organic load to an acceptable and economical level. Up to 60% removal of BOD and COD with 90% removal of SS, can be done with proper selection of chemical coagulant and its optimum dosage.Results obtained by [26] showed that, the pre-treatment process is able to remove the suspended solids in POME at optimum pH 6. 5 and 90% of turbidity removal. However, at higher temperature, the excellent result was showed at 50^{o}C which is 86% suspended solids removal at pH 6. From the analysis result by [13], it clearly demonstrates that various parameters used in the experiment contribute their effect to the coagulation process. The optimum condition for suspended solids removal using a jar test process were obtained at alum dosage of 4,000 mg/L at pH 4, mixing rate of 150 rpm and optimum mixing time of 1.5 hours.A study by [20] demonstrated that coagulation with aluminium sulphate and ferric chloride is an effective way to treat POME from aerated lagoon by reducing the turbidity. Coagulation using ferric chloride with polyacrylamide gave high turbidity reductions from 132.4 Nephelometric Turbidity Unit (NTU) to 2 NTU. Thus, ferric chloride at 100 mg/L, pH of 8 and with polyacrylamide (coagulant aid) dose of 100 mg/L, was used in treating POME from the aerated lagoon.

2.3 Natural Coagulants

Palm oil mill effluent can be treated using natural coagulants which can be obtained from plant parts such as seeds, roots and leaves. These natural ingredients of organic polymer are important because they contained acrylamide monomers that are not harmful to human. They are potential products to be commercialized in future due to their abundance and other valuable properties that are environmentally sound [27]. The main advantages of using natural plant based coagulants as water treatment material are apparent; they are cost-effective, unlikely to produce treated water with extreme pH and highly biodegradable [28]. Application of natural coagulant in POME wastewater using physical treatment from coagulation - flocculation process could present a new alternative of POME treatment. The use of chemical coagulant or flocculant such as alum (aluminium sulphate) or polyaluminium chloride (PAC) is not accurate choice in POME treatment. Alum and PAC have an aluminium content which has a number of disadvantages: a high concentration of aluminium in water may be associated with human health problems [29].

Inorganic coagulantsmay be toxic for aquatic life and produce a large volume of sludge. Besides, high cost of these chemicals, disposal of sludge with a high concentration of residual metal could be difficult. Thus, selections from natural, environmentally friendly coagulant and biodegradable flocculant are the better alternatives to be used in POME treatment[30]. Given the potential of natural coagulants to be an appropriate solution to produce potable water, remarkable number and variety of natural substances have been examined for their coagulation properties. To date, studies have shown that natural compounds from *moringa oleifera, Cactus latifaira* and *Prosopis jaliflora* are effective coagulants in wastewater treatment. In addition, using natural-derived compounds, considerable saving of chemicals will be achieved. Apart from that, natural products are readily biodegradable and environmentally safe to humans [31].

*Moringa oleifera*is among the most highly valued and cultivated plant all over the world, because of its medicinal and nutritional value. The specie belongs to the single-generic family called Moringaceae. The genus moringa has 14 species, which comprise shrubs and trees. The actual botanical name of the species is *moringa oleifera*(*moringa oleifera*Lam), [32].

*Moringa oleifera*seeds contain various properties that are useful in medicinal field for example antimicrobial properties and buffering capacity. These factors are useful contributors for remediation of wastewater by removing microbes, suspended matters and high turbidity in water. [33] Reported that *moringa oleifera*seeds coagulation activity has been testified at industrial scale for industrial wastewater treatment such as palm oil mill effluent (POME) and the advantages of the seeds for high effluent removal were highlighted. Seeds extract of *moringa oleifera*was found as an effective purifier for removing suspended materials such as solids, turbidity and other waste products [34].

Different methods of POME treatment have been reported. But, since *moringa oleifera* seed provides good results for water treatment and being a cheap resource that is useful in many applications; smart utilisation of this species will be beneficial to improve the industrial waste treatment. It would be a sustainable substitute to the conventional coagulants system and help to upgrade economic level of a country that possess the species abundantly [34].In recent years, chitosan and zeolitehave been applied as coagulants in water treatment [35].

Chitosan (*N*-acetyl-d-glucosamine) is a cellulose-like polyelectrolyte biopolymer which is derived from the deacetylation of chitin. Chitosan has been recommended as a suitable coagulant resource material because of its excellent properties such as biodegradability, biocompability, adsorption property, flocculating ability, polyelectrolisity and its possibilities of regeneration in number of applications[36]. It is a non-toxic, linear cationic polymer with high molecular weight, charge density and readily to be soluble in acidic solution [37]. Chitosan was used as coagulation agents in removal residual oil and suspended solids. The flocs produced by chitosan appear rapidly and grows very fast to form a larger size which can be easily sedimented [38].

[39] Carried out a comparative study between the use of chitosan powder and chitosan flake with respect to their adsorption equilibrium, isotherm, thermodynamic and kinetic on their residue oil removal efficiency from POME. Series of experiments were carried out using different conditions and parameters. The control variables were weight dosage, initial concentration, sedimentation time, mixing time, mixing rate, pH and temperature. The best removal of residue oil was accomplished using 0.5g/l of powdered chitosan with sedimentation time of 30min, mixing time of 30min, mixing rate of 100rpm, pH 4.0 - 5.0 and at a temperature in the range of 50-70°C. The removal percentages obtained were very satisfactory i.e. 99%. FT-IR and SEM micrographs of chitosan powder and flake before and after adsorption were presented to prove that the residue oil had been adsorbed by chitosan. Chitosan powder showed a better capacity of residue oil removal compared to chitosan flake. The research attested that chitosan, biopolymer is a potential alternative to coagulate and adsorb residue oil from POME.

[40] Chose activated carbon, chitosan, and bentonite clay as adsorbents to identify the best residual oil remover from POME. Chitosan showed the best removal compared to the other adsorbents for all the parameters studied. Chitosan could successfully remove 99% of residual oil and minimize the suspended solid content to a value of 25 mg/l from POME at a dosage of 0.5 g and employing a mixing time of 30 min, a mixing rate of 100 rpm, sedimentation for 30 min and a pH value of ranging from 4.0 to 5.0. For activated carbon and bentonite clay, the optimum dosages were 8.0 g and 10.0 g/l, respectively, 30 min of mixing time at 150 rpm, 80 and 60 min of settling time, respectively, and pH of 4.0–5.0 to obtain the same percentage of removal as performed by chitosan.

[41] explored the potential and effectiveness of applying chitosan-magnetite nanocomposite particles as a primary coagulant and flocculent, in comparison with chitosan for pre-treatment of palm oil mill effluent (POME). A series of batch coagulation processes with chitosan-magnetite nanocomposite particles and chitosan under different conditions, i.e. dosage and pH were conducted, in order to determine their optimum conditions. Chitosan-magnetite particles showed better parameter reductions with much lower dosage consumption, compared to chitosan, even at the original pH of POME, i.e. 4.5. At pH 6, the optimum chitosan-magnetite dosage of 250 mg/L was able to reduce turbidity, TSS and COD levels by 98.8%, 97.6% and 62.5% respectively. At this pH, the coagulation of POME by chitosan-magnetite was brought by the combination of charge neutralization and polymer bridging mechanism. On the other hand, chitosan seems to require much higher dosage, i.e. 370 mg/L to achieve the best turbidity, TSS and COD reductions, which were 97.7%, 91.7% and 42.70%, respectively. It is interesting to note that both chitosan-magnetite nanocomposite and chitosan performed exceptionally well to coagulate and remove the suspended solid and residue oil from POME. Therefore, coagulation with either chitosan-magnetite or chitosan could be regarded as effective and environmentally friendly pre-treatment technique for palm oil mill effluent with less or no hazardous residual waste.

Zeolites are microporous crystalline aluminosilicates. Aluminium, silicon, and oxygen are arranged in a regular structure of [SiO4]- and [AlO4]-tetrahedral units that form a framework with small pores (also called tunnels, channels or cavities) of about 0.1– 2 nm diameter running through the material [42]. Zeolites are naturally occurring hydrated aluminosilicate minerals. They belong to the class of minerals known as “tectosilicates.” Most common natural zeolites are formed by alteration of glass-rich volcanic rocks (tuff) with fresh water in playa lakes or by seawater [43]. The structures of zeolites consist of three-dimensional frameworks of SiO4 and AlO4 tetrahedra. The aluminum ion is small enough to occupy the position in the center of the tetrahedron of four oxygen atoms, and the isomorphous replacement of Si4+ by Al3+ produces a negative charge in the lattice. The net negative charge is balanced by the exchangeable cation (sodium, potassium, or calcium). These cations are exchangeable with certain cations in solutions such as lead, cadmium, zinc, and manganese [44].

Zeolite has a negative charge neutralizationion mineral that can be neutralized by alkali metal, itis microporous that consist of cationic elements (K, Na, Ca, Mg) and H2O as it is possible to release the water and ion exchange. The other benefits are as an adsorbent of cations that contaminate theenvironment (Pb, Al, Fe, Mn, Zn and Cu). The zeolite reduced the environmental contamination [45]. Clay minerals, such as bentonite and zeolite, are some of the potential alternatives, as they have large specific surface areas with a net negative charge, which can be electrically compensated for by inorganic and organic cations from the environment [46].

The adsorption capacity of natural zeolite for the removal of heavy metal ions, zinc Zn(II), manganese Mn(II) and iron Fe(III), found in palm oil mill effluent was investigated by [47]. The effects of contact time, agitation speed, pH, and sorbent dosage on the sorption of heavy metals were evaluated. Desorption potential of zeolite was also investigated. The sorption was fast with equilibrium reached within 180 min which was followed by a gradual decline in the rate of adsorption. The maximum sorption capacities of 64.601, 53.644 and 52.446% for Fe, Zn and Mn respectively were obtained for natural zeolite. The optimal adsorption occurred at a pH of 7. It was observed that the adsorption capacity had a correlation with the mass of sorbent and based on the results, 25.0 g of zeolite was considered as the optimum dosage. Equilibrium data followed the Langmuir isotherm model while the kinetic data were well described by the pseudo-second-order model. Maximum desorption was attained by HCl with 69.638, 58.575 and 61.516% of the initial adsorbed amount for Fe, Zn and Mn, respectively. More than 50% of Zn (II) and Mn(II) and about 60% of Fe(III) could be removed in the experiments. By considering the fast adsorption–desorption properties and the reusability of natural zeolite, it is suggested that natural zeolite is a relatively low-cost naturally occurring material for the removal of metal ions from POME.

2.4 Chemical Coagulants

Chemical Coagulation is a process which involves coming together of colloidal particles so as to change into large sized particles which ultimately settle as a precipitate or float on the surface. It is an important unit process in water treatment for the removal of turbidity and is generally brought about by the addition of electrolytes. When an electrolyte is added to a colloidal solution, the particles of the sol take up the ions which are oppositely charged and thus get neutralized. The neutral particles then start accumulating to form particles of a larger size which settle down. Its application in water treatment is followed by sedimentation and filtration [48].

Inorganic Coagulants usually offer the lowest price and are quite effective in removing most suspended solids. They produce large volumes of floc which can entrap bacteria as they settle [49]. Each of the coagulant affects the destabilization degree of the colloid particles differently. They are effective in removing wide range of impurities from water, including colloidal particles and as well as dissolved organic substances. The higher the valance of the counter-ion, the more its destabilizing effect and lesser dose needed for coagulation. The formation of the hydrolytic products formed from metal salt coagulants occurred in a very short time and they are readily absorbed onto the colloid particles and then cause destabilization of their electrical charge. Apart of that, uniform pH of the wastewater during the coagulation process is essential for the enhancement of hydrolytic reaction [50].Aluminium sulphate (alum), an inorganic salt, is the most widely used coagulant in wastewater treatment, because they are more effective at lower temperatures, a broader pH range and forms positive charged Al species that adsorb to negatively charge natural particles resulting in charge neutralization. Destabilizing oil droplets and destroying emulsions via addition of alum and PAC; polyelectrolytes have been shown to be effective as a pre-treatment coagulant to separate oil and grease [51]. The merit of using iron coagulants over aluminium is the production of tougher and denser floes. Besides, they can operate at broader pH range and less sensitive to over dosage [52]. The addition of ferric chloride resulted in fine grey-brown flocs which tend to form large amorphous aggregates. Above the poorly settling floc, the translucent supernatant was very dark brown in color [25].

Evaluation of the performance of coagulation process by the percentage reduction efficiency of COD, BOD and TSS of POME using six different doses of aluminium sulphate (alum): 90, 180, 270, 360, 450 and 540 mg combined with four different mixing ratios of (water: POME): 0.5:1.0, 0.75:1.0, 1.0:1.0 and 1.25:1.0 was carried out.[53]Reported that, at a mixing ratio of 0.5:1.0, the coagulant showed the highest increase on TSS percentage removal from 89.7% to 92.3%. But at 1.25:1.0 mixing ratio, the addition of coagulant which exceeded the optimum dosage (275.5 mg), lead to a continuous decrease in TSS removal efficiency from 90.6 to 82.9 %. The reduction occurred probably because of restabilization due to excessive coagulant addition.

[54]Investigated the settling rate of POME with 0-20 g/L alum by measuring the drop in the level of the clarified liquid interface with time. He observed that most of the settling occurred within the first 5-7 hours. In the first 3-4 hours, settling was fastest and the rates were constant. The best settling was at 11 g/L of alum, whereby the lowest solids volume of 30% of the original volume was obtained. The settling rate at 11 g/L alum was nearly 3 times faster than raw POME, with the lowest suspended solids and COD in the clarified liquor. It is evident that alum could effectively reduce the suspended solids in POME but not its COD or BOD.The use of alum, polyaluminium chloride (PAC), $FeCI_3$ and $FeSO_4$ in addition with an anionic polymer were studied by [25] using modified jar test method where their efficiencies were gauged on the basis of the BOD, COD and SS removal. Results showed that optimization of coagulation-flocculation processes on settleable solid-free POME was generally reached at between 150-200 ppm of $FeSO_4$.and $FeCI_3$, and 300-350 ppm of alum and PAC. The optimum coagulant dosages were found to be dependent on the strength of the wastewater. Suspended solid removal efficiency of the $FeCI_3$ coagulant at a dosage of 200 ppm was found to be 70%.

[55]Studied four different types of coagulant combinations (Type A, B, C and D) comprising of aluminium sulphate, ferric chloride, ferric sulphate and ammonium sulphate with commercial polymer SR316 as flocculent for use in the pre-treatment of POME. The combination of Type A and Type B (aluminium sulphate as the main coagulant) coagulants with SR316 do not show better removal of COD if compared to Type C and Type D whereby ferric salts act as the main coagulant. Turbidity removal efficiency of 97% was achieved using coagulant Type C1 with Aluminium sulphate (1% w/w), Ferric chloride (5% w/w), and Ammonium sulphate (1% w/w). Alternatively, coagulant Type C2 with 10% w/w of ferric chloride, 1% w/w of aluminium sulphate and 1% w/w of ammonium sulphate was found at 62% of the COD removal.

III. Analysis

Analysis of POME discharged or released onto any soil, inland waters or Malaysian waters shall be carried out in accordance with any of the methods contained in the publications as specified in the Environmental Quality Act 1974 which was later amended to Environmental Quality (Industrial Effluent) Regulations 2009 based on the results obtained from the laboratory scale experiments. POME composition varies widely among different palm oil extraction and processing companies. Hence, this variation makes a through characterization of POME mandatory for each processing company before appropriate treatment schemes can be adopted. The Malaysian Department of Environment (DOE), through [56] has set standard parameter limits for the quality of POME discharged into watercourse that must be obeyed by respective palm oil mill industries as shown in Table 1.

Table 1: Industrial Effluent or Mixed Effluent of Standards A and B

	Parameter	Unit	Standard A	Standard B
	(1)	(2)	(3)	(4)
i	Temperature	°C	40	40
ii	pH Value	-	6.0-9.0	5.5-9.0
iii	BOD_5 at 20°C	mg/L	20	50
iv	Suspended Solids	mg/L	50	100
v	Mercury	mg/L	0.005	0.05
vi	Cadmium	mg/L	0.01	0.02
vii	Chromium, Hexavalent	mg/L	0.05	0.05
viii	Chromium, Trivalent	mg/L	0.20	1.0
ix	Arsenic	mg/L	0.05	0.10
x	Cyanide	mg/L	0.05	0.10
xi	Lead	mg/L	0.10	0.5
xii	Copper	mg/L	0.20	1.0
xiii	Manganese	mg/L	0.20	1.0
xiv	Nickel	mg/L	0.20	1.0
xv	Tin	mg/L	0.20	1.0
xvi	Zinc	mg/L	2.0	2.0
xvii	Boron	mg/L	1.0	4.0
xviii	Iron (Fe)	mg/L	1.0	5.0
xix	Silver	mg/L	0.1	1.0
xx	Aluminium	mg/L	10	15
xxi	Selenium	mg/L	0.02	0.5
xxii	Barium	mg/L	1.0	2.0
xxiii	Fluoride	mg/L	2.0	5.0
xxiv	Formaldehyde	mg/L	1.0	2.0
xxv	Phenol	mg/L	0.001	1.0
xxvi	Free Chlorine	mg/L	1.0	2.0
xxvii	Sulphide	mg/L	0.50	0.50
xxviii	Oil and Grease	mg/L	1.0	10
xxix	Ammoniacal nitrogen	mg/L	10	20
xxx	Colour ADMI*		100	200

* ADMI – American Dye Manufacturers Institute

IV. Hypothesis

Addition of biodegradable coagulants as *moringa oleifera* and chitosan to a chemical coagulant (alum) would reduce the rate of hazardous sludge produced together with high percentage removal of residue oil from POME. 25% by weight of edible oil could be extracted from *moringa oleifera*seeds as a by-product, making this coagulant more economical in the treatment of POME. Combinations of chitosan and alum would show an increment in efficiency, remove most of the colloidal and suspended form of organic matter in POME and yield turbidity removal at original pH of 4.5. The synergistic effect of cationic character of both the chitosan amino group in the pre-treatment process for POME brings about enhanced performance for effective agglomeration, adsorption and coagulation-flocculation [21].

[57]Reported that coagulation with clay minerals followed by sedimentation can clean up effluent when the flocs formed are dense enough. Clay minerals used as coagulant aids decreased effluent COD value from 24.3g/L to 3.84 g/L at maximum clay concentration [58]. Alum performs better when combined with a clay mineral for heavy concentration oil and grease removal [59]. Hence, [60]concluded that, using clay mineral as a coagulant, the flocculation process becomes more efficient, cost effective, increased turbidity, colour and heavy metals removal from wastewater. Improvement in water clarity and filtration system was also observed. The adsorption process would show a substantial reduction in COD, turbidity, colour, total suspended solids, oil

and grease, NH_3-N, Fe, Pb, Cu, Mn, Cd and Zn which indicates that the performance of zeolite as an adsorbent is promising. Higher adsorption capacity is expected when the combination of zeolite and alum is used.

The combination of $FeCl_3$ as an iron salt that functions as both a coagulant and a flocculent with alum is expected to produce higher effluent removal because of the significant difference in the relative solubility and pH range of $FeCl_3$. A study by [61] proved that $Fecl_3$ is an effective coagulant in high turbidity removal. It has been reported by [58] that $FeCl_3$ produces better results when combined with other coagulants and a mixture of alum and $FeCl_3$ removed all the colloidal SS at a dose of 200 ppm from a study conducted by [62].

Supplementing an anionic polymer, provide a positive result of coagulation-flocculation process, which leads to maximum effluent removal. The addition of coagulant-aid chemical helps for high effluent removal and this will be a favourable approach for optimization of natural coagulants.

V. Conclusion

Palm oil mill effluent (POME) just like most other wastewaters cannot be discharged directly to the land, as it will adversely affect the soil and vegetation system. It is cannot also be discharged into the watercourses directly without treatment as the good quality of water bodies for aquatic lives will be depleted and distracted. Therefore, coagulation–flocculation process as a basic and essential treatment technique in water and wastewater treatment facilities would be most appropriate for the treatment of POME. Chemical coagulants such as Alum (aluminium sulphate) and Ferric chloride are commonly used as coagulants in the treatment of POME. However, the application of coagulation-flocculation process using natural coagulants such as chitosan, zeolite and *moringa oleifera* was found to be a new alternative for POME treatment as several research efforts have been devoted to improving its efficiency.

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