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Potential Utilization of Oil Palm Mesocarp and Oil Palm Empty Fruit Bunch Fiber Powder as Natural Coagulant-Flocculant for POME Treatment

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Abstract

The palm oil industry is one of the agro-based industries that has a high contribution to the global economy, including Malaysia. However, there is a negative impact on the environment caused by palm oil production, which results in high waste pollution known as palm oil mill effluent (POME). A common practice for the palm oil industry regarding the POME treatment is using conventional coagulant and flocculant agents due to their effectiveness and affordable cost. However, high usage of agents in wastewater treatment can threaten human and environmental health, such as air and soil pollution, water pollution, and disease transmission. The palm oil industry also produces other waste such as oil palm mesocarp (OPM) and oil palm empty fruit bunch (OPEFB) which have the potential to be utilized due to their existence of a hydroxyl group in cellulose and lignin. Therefore, this study provides a novel approach by utilizing naturally occurring functional groups in OPM-OPEFB to facilitate pollutant removal in POME as sustainable natural coagulants-flocculants. The effective treatment of POME is critical for reducing its environmental footprint, given the high organic content and large quantities generated by the palm oil industry. This study demonstrates the ability of these biopolymers to achieve significant reductions in turbidity and suspended solids, aligning with the principles of green chemistry. The effectiveness of lignocellulose biomass in enhancing coagulation-flocculation, offering a sustainability alternative to conventional chemical coagulants. For the coagulation-flocculation treatment of POME, jar tests were performed to evaluate the effectiveness of the process. The parameters measured for the untreated and treated POME are pH, dissolved oxygen (DO), turbidity (TUR), biochemical oxygen demand (BOD), total suspended solids (TSS), and ammoniacal nitrogen (AN). Removal efficiencies of pH, TUR, BOD, TSS, and AN were 7.39%, 41.28%, 53.14%, 62.69%, and 30.56% respectively for OPM-OPEFB. Results obtained from characterization show that the coagulation–flocculation mechanism was ruled by the existence of a hydroxyl group and hydrogen bond in cellulose and lignin that increase the rate of absorption and bonding. OPM-OPEFB demonstrates the potential to lower the organic contaminants. Therefore, optimizing contact time and coagulant dosage may enhance the effectiveness of the removal of organic pollutant in the POME.

1. Introduction

The palm oil industry currently is one of the agro-based industries that have a high contribution to the global economy, including Malaysia [1]. With over 5.65 million hectares of oil palm biomass, Malaysia's palm oil industry plays an important part in the Malaysia economy and presently becomes the global second largest palm oil producer of commodity after their neighboring country, Indonesia [2]. Oil Palm biomass derived from the oil palm tree has gained considerable attention. Utilizing oil palm fiber for value-added products plays a vital role in promoting sustainability and minimizing waste in the palm oil industry. Oil palm mesocarp (OPM), oil palm trunk (OPT), oil palm empty fruit bunch (OPEFB), palm kernel shell (PKS), oil palm frond (OPF), and palm kernel cake (PKC) are among the biomass products produced by this industry. Based on dry weight, the total expected production of oil palm biomass in 2023 was 92.37 million tons [3]. OPEFB contributed 7.2 million tons, OPT contributed 9.83 million tons, OPF contributed 63.4 million tons, OPM contributed 7.57 million tons, and PKS contributed 4.47 million tons [3]. This waste product is a lignocellulosic biomass that contains not only cellulose (35%), lignin (44%), but a large amount of silica on the fiber surface [4]. While oil palm empty fruit bunches (OPEFB), which are abundant lignocellulosic waste produced by the palm oil industry, are being studied as a possible low-cost substrate for bioflocculant production [5]. OPEFB contains 40-50% cellulose, 20-30% hemicellulose, and 15-20% lignin, and is the largest quantity of waste material produced by palm oil production [6].

Despite the advancement in the palm oil industry being great for the economy, there is a negative impact on the environment caused by the production of by-product palm oil, which results in high waste pollution or known as palm oil mill effluent (POME). Characterized by its high organic load and chemical oxygen demand, this by-product contributes to greenhouse gas emissions from methane release, odor pollution, land contamination from improper disposal, water pollution from oxygen depletion and aquatic life toxicity, and major waste management challenges because of its high volume and treatment costs. The characteristic of POME is brownish due to the colloidal mixture, gives off an unpleasant smell, and usually shows temperatures from 80°C to 84°C [7]. The two main processes that use a large quantity of water around 5-7.5 tonnes only to produce 1 tonne of crude palm oil where 50% of the used water will generate the POME is oil palm fruit bunch (OPFB) sterilization and oil palm kernel shell (OPKS) separation [1], [8]. The processes discharge of POME has high pollution properties such as oil, grease, and thick solids. Thus, POME can become a threat to the environment [8]. Besides, an enormous number of compounds are also found in the POME such as nitrogen, phosphorus, potassium, and magnesium due to the presence of vital plants. These compounds or nutrients may cause eutrophication that can damage the aquatic environment [9].

According to Razak et al. [8], an effective treatment process is necessary for POME to drop the prominent level of pollutant, and the conventional treatment that is applied by most palm oil factories in Malaysia is the ponding system. This is proven by studies from Kai et al. [2] that state around 85% of the palm oil factories implement conventional ponding treatment that consists of acidification, and anaerobic and aerobic processes. The ponding method is commonly practiced because of its affordable cost and uncomplicated operation. However, it needs a long hydraulic retention time (HRT) and a large size of treatment areas to be efficient [9]. The conventional ponding method must be followed up with advanced technologies for effective removal of the BOD, COD, turbidity, and ammonia from wastewater. Coagulation-flocculation process is one of the advanced wastewater treatments that is widely practiced due to its simple operation, low cost, and comparatively more effective [10]. Coagulation is a chemical process that requires a coagulant agent with opposite-charged particles to neutralize the colloidal particles under rapid mixing. Then followed by flocculation, which is the process of creating heavier and settleable flocs under mild stirring or using a flocculant agent [11]. Despite their effectiveness, the widespread use of traditional coagulants and flocculants in wastewater treatment can be hazardous to both human health and the environment if leftover chemicals are present in the treated water. These residues may result in bone disorders, neurotoxicity, and cognitive decline. Additionally, irritation of the skin, eyes, and respiratory system can result from exposure to hazardous byproducts [5].

Natural coagulants and flocculants can be extracted from various sources of living things such as microorganisms, animals, and plants that are organic, biodegradable, and have high effectiveness in water/wastewater treatment [12]. The presence of polysaccharides, protein polymers, and functional groups such as hydroxyl and carboxyl groups are significant properties of these materials that allow them to be implemented as natural coagulants-flocculants. Polysaccharides, protein polymers, and certain functional groups such as hydroxyl and carboxyl group can increase adsorption, polymer bridging, and charge neutralization processes [13]. OPM fiber is produced by extracting oil from the seeds of the palm fruit [14]. Adsorption occurs when natural polymers provide a surface that absorbs colloidal particles, causing them to floc into larger particles that settle more easily. Polymer bridging occurs when colloidal particles attach to a segment of a long-chain polymer. This interaction allows the free part of the polymer chain to form both a loop and a tail. As the free tail connects to another colloidal particle, these molecules increase in size. It is essential to use the correct dosage of coagulants to ensure that there is sufficient surface area for this process to take place. Charge neutralization occurs because colloidal particles are typically negatively charged, causing them to repel one another and prevent aggregation. By adding cationic coagulants, which introduce carboxylate and H^+ ions, the zeta potential of the suspension is neutralized. This process allows large flocs to form. If the coagulants have a high charge density, a lower dosage is required for effective treatment. The significant occurrence of silica bodies on the surface of OPEFB fiber powder, coupled with the presence of hydroxyl functional groups (-OH) in both OPM and OPEFB fiber powder, primarily serves to augment the coagulation and flocculation processes. Therefore, this study aims to investigate the effectiveness of OPM and OPEFB as natural coagulant-flocculant for POME treatment to enhance the POME quality for discharge purposes. The utilization of OPM and OPEFB is expected to reduce waste production in the palm oil industry and corresponds to the enhancement of POME discharge quality.

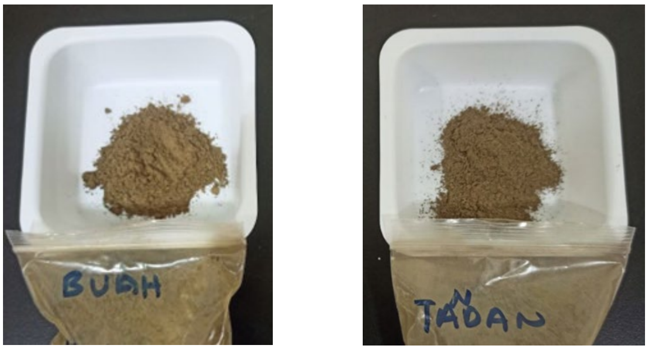
2. Materials and Methods

2.1 POME Collection and Parameters

POME were obtained from Kilang Kelapa Sawit Bukit Pasir Sdn Bhd as a wastewater sample for the experiment. POME have been preserved using APHA standard method for examination of water and wastewater. The sample was placed in the UTHM Environmental laboratory cool room at temperature of 4°C and stored in high-density polyethylene (HDPE) and glass bottles. This is intended to maintain the quality of the samples and prevent decomposition by bacteria [15]. The initial parameters such as pH value, dissolved oxygen (DO), turbidity (TUR), biochemical oxygen demand (BOD), total suspended solids (TSS), and ammoniacal nitrogen (AN) of untreated POME were measured and recorded. Then, the POME will go through the biocoagulant/bioflocculant treatment. Both initial and final parameters also were compared with the standard discharged of POME stated by Environment Quality Act 1974 from DOE Malaysia.

2.2 OPM and OPEFB Fiber Powder Preparation

OPM and OPEFB fiber were obtained from Kilang Kelapa Sawit Bukit Pasir Sdn Bhd. OPM and OPEFB fiber were prewashed and soaked separated by distilled water for 24 hours. The fibers were then rinsed with hot water at 60°C in order to eliminate contaminations from the fibers. Next, the fibers were then dried in an oven at a temperature of 100°C for 2 hours. After fully drying, the fibers are shredded and cut using scissors into smaller pieces. The size of the fibers was made smaller into powder by using a grinder. Finally, the fiber powder was sieved to get a size of 150-300 µm using sieve analysis. Fig. 1 depicts the prepared powder fibers.



(a) **(b)**

Fig. 1 *Fiber powder (a) OPM; (b) OPEFB*

2.3 Characterization of Fiber Powder (OPM and OPEFB)

2.3.1 Scanning Electron Microscopy (SEM)

Morphological properties or structures of OPM and OPEFB were scanned and obtained using EM-30 Benchtop SEM by COXEM from South Korea. At first, both OPM and OPEFB sieved that have turned into powder were placed in oven at temperature of 110˚C for 24 hours. Then, the samples involve meticulous process to ensure optimal imaging quality and accurate analysis. The purpose of SEM test was to indicate their porous and wax surface structure image that can increase rate of absorption and trapping POME pollutant particles which may explain the coagulation and flocculation mechanisms in OPM and OPEFB fiber powder [2].

2.3.2 Fourier Transform Infrared (FTIR) Spectroscopy

The presence of functional groups and chemical compounds in OPM and OPEFB that responsible for the coagulation and flocculation processes were determined using an Agilent Technologies Cary 630 FTIR by Agilent Technologies from California, United States. in the range of 400-4000 cm^{-1}. After the samples scanned by the Cary 630 FTIR, data were transferred into computer and results obtained showed their spectrum within the range with all peaks contain all possible functional groups especially methyl, hydroxyl and carbonyl group that are functional as absorption and hydrogen bond. This may assist the coagulation and flocculation mechanisms in OPM and OPEFB [2].

2.4 Coagulation-Flocculation Test

To conduct the POME treatment coagulation-flocculation method, jar tests were carried out at UTHM Environmental laboratory using Jar Test Flocculator VELP JLT6 from Italy. The flocculator has 6 revolving impeller shafts that enable six samples to run at the exact same time. However, for this experiment, only 1 rotating impeller shaft was used due to 1 sample only. A 1 L beaker was filled with approximately 500mL of untreated POME wastewater sample. For natural coagulant-flocculant, the total of 5 g/L OPM fiber powder and 5 g/L OPEFB fiber powder was weighed using a weighing balance, becoming the mixture of OPM and OPEFB (OPM-OPEFB). The mixture of OPM-OPEFB is chosen due to OPM containing natural fatty acids, biopolymers, and polysaccharides that aid in destabilizing colloidal particles by reducing the repulsive forces between them. Meanwhile, OPEFB fibers, rich in cellulose, hemicellulose, and lignin, provide a high surface area that enhances particle aggregation and adsorption. The combination ensures that OPM neutralizes charges, while OPEFB provides structural support for floc formation, leading to faster sedimentation and improved pollutant removal. After adding both fiber powder, a total of 10 g/ L into the beaker that was filled with the untreated POME, the samples were blended by stirring for 5 minutes at 200 rpm, then followed by 30 minutes at 50 rpm. The solutions were then left for 3 hours to monitor the flocculation and sedimentation processes. Then the solution is filtered into another 500 ml beaker and labelled as treated POME to separate the treated POME solution from the remaining OPM-OPEFB fiber powder [1]. This guarantees that solid fiber residues won't interfere with the assessment of treatment effectiveness, which includes turbidity reduction and pollutant elimination, and only includes the dissolved and suspended contaminants that are still in the liquid phase. Additionally, filtration aids in the precise analysis of parameters such as BOD, COD, and TSS, offering a transparent evaluation of the coagulation-flocculation capabilities of OPM-OPEFB as natural coagulant-flocculants. The experiment was illustrated and described in Fig. 2.

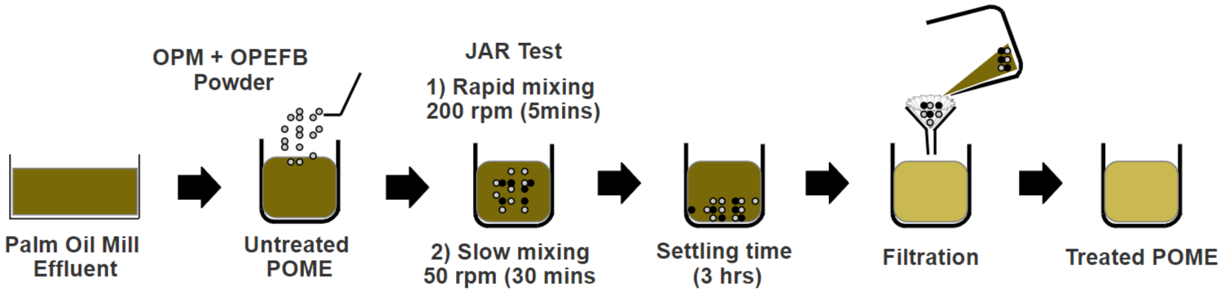


Fig. 2 *Schematic diagram of coagulation-flocculation jar test*

2.5 Data Analysis

The removal percentages of biochemical oxygen demand (BOD), total suspended solid (TSS), turbidity (TUR) and ammoniacal nitrogen (AN) were measured using Eq. 1 [1] to examine the performance of a powder fibre coagulant (a mixture of OPM-OPEFB).

$$\text{Removal (\%)} = \frac{\text{Influent pollutant} - \text{Effluent pollutant}}{Initial\ POME} x100 \tag{1}$$

3. Result and Discussion

3.1 Initial POME Parameters

The initial parameters of collected POME from the factory are shown in Table 1 with a comparison to standard discharge limits for POME [16]. Based on Table 1, only one parameter of AN and pH comply with the Environment Quality Act 1974 (EQA 1974 - Act 127), while BOD and TSS are over the limit set by DOE. High pollution properties in discharged POME such as oil, grease, thick solids [8], and an enormous number of compounds (nitrogen, phosphorus, potassium, and magnesium) increase the amount of TSS and thus lead to high demand of oxygen consumed by microorganisms for the solid decomposition process [9]. POME is levelled as acidic due to the amount of BOD and SS that can achieve up to a range of 25,000 mg/L and 50,000 mg/L [8]. POME becomes acidic due to the microbial breakdown of organic waste caused by high BOD, which results in the production of organic acids such as butyric and acetic acid. In the meantime, pH levels are further lowered by the breakdown of suspended solids (SS), which releases more acidic substances and volatile fatty acids (VFAs). Therefore, POME can become a threat to the environment if it is discharged without proper treatment [8].

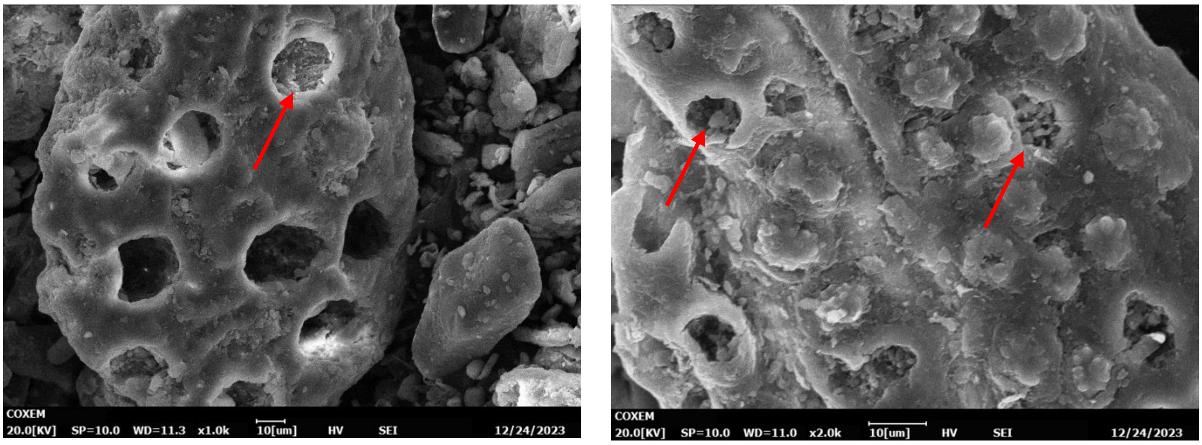
Table 1 *Initial POME parameters*

Parameters	Initial reading for POME	Standard Discharge for POME [16]
pH	8.80	5.5-9
Dissolved oxygen, mg/L	2.81	-
Turbidity, NTU	38.08	-
Biochemical oxygen demand, mg/L	183.79	50
Total suspended solid mg/L	1040	100
Ammoniacal nitrogen, mg/L	19.88	20

3.2 SEM Analysis

Fig. 3(a) shows the images obtained for the OPM fiber powder surface structure. The presence of porous structures on the surface of OPM fiber powder as shown in Figure 3 improves the roughness of the surface, which benefits fiber matrix bonding [17]. This increases the potential bond between the OPM particles and pollutant particles in POME for the coagulation process. Capability of absorption and trapping particles may also occur because of the porous structure due to capillary action [18]. This porous characteristic also can be seen on the OPEFB surface as shown in Fig. 3(b).

OPEFB fiber powder acts more as a role of flocculation due to uneven surface morphology and the presence of cellulose, hemicellulose, lignin, and non-cellulosic components [3]. The uneven surface present on the surface of OPM and OPEFB fiber enhances coagulation performance by strengthening the adsorption bridging effect, thereby improving its ability to trap and remove pollutants [3].



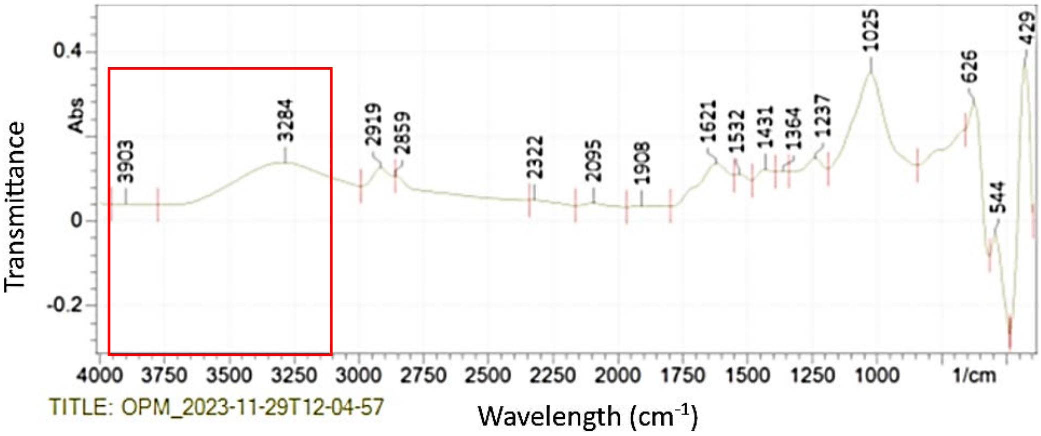
(a) **(b)**

Fig. 3 *SEM micrographs (a) OPM (b) OPEFB*

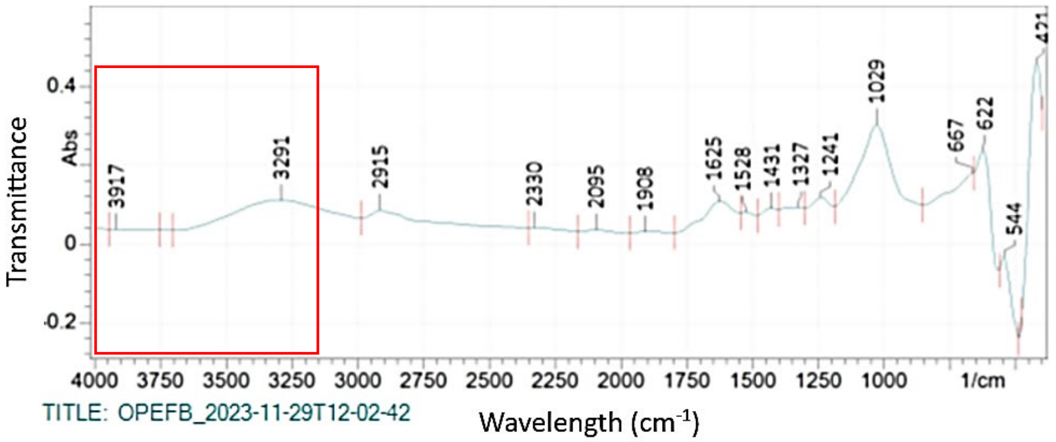
3.3 FTIR Analysis

The characteristic features of the FTIR spectrum for OPM and OPEFB fibers at wavelengths between 400 cm^{-1} and 4000 cm^{-1} are shown in Fig. 4. The hydroxyl (-OH) functional group was predominantly identified in both fiber samples. Based on Fig. 4, each peak on the graph for both samples were analyzed to determine the corresponding functional groups present. The hydroxyl (-OH) group, primarily associated with cellulose, hemicellulose, and lignin, was detected in the 3200–4000 cm^{-1} range for both OPM and OPEFB. These hydroxyl groups enhance hydrogen bonding, facilitating the aggregation of suspended solids in POME. OPM and OPEFB are valuable abundant sources of lignocellulosic biomass generated by the palm oil industry [5], [4]. In general, natural elements of lignocellulosic fiber are cellulose, hemicellulose, lignin, and ash [19]. The hydrophilic nature of oil palm fibers is closely related to their cellulose and lignin content, as these compounds contain hydroxyl groups that influence water absorption [17].

The higher hydroxyl compound for OPM was detected at peaks of 3903 cm^{-1} and 3284 cm^{-1}, while for OPEFB, the higher hydroxyl compound was found at 3291 and 3917 cm^{-1}. This absorption of the hydroxyl group may assist in the coagulation-flocculation process. The coagulation and flocculation process occurs through hydrogen bonding interactions between the hydroxyl groups of polysaccharides and the functional groups present in impurities [1]. Methyl (C-H) stretch, Alkyl was found at all peaks for both OPM and OPEFB fiber powder within the range 2800 cm^{-1} and 3200 cm^{-1}. The C-H stretch is a higher energy vibration that occurs at a higher frequency in the IR spectrum. Based on these findings, OPM and OPEFB fibers exhibit characteristics that align with natural flocculants, particularly due to their hydroxyl, carbonyl, and ether functional groups. These functional groups can interact with suspended solids through hydrogen bonding, electrostatic interactions, and bridging mechanisms, potentially enhancing the coagulation and flocculation efficiency in POME treatment.



(a)



(b)

Fig. 4 *FTIR Spectra of (a) OPM; (b) OPEFB*

3.4 Coagulation-Flocculation Langmuir of OPM-OPEFB

Fig. 5 illustrates the coagulation-flocculation mechanism that occurs between the pollutant particles in 500 mL POME and particles of 5 g/L OPM and 5 g/L OPEFB fiber powder. OPM-OPEFB powder acts as natural coagulant-flocculant to absorb and trap pollutant particles of POME followed by creation of settleable floc. Existence of hydroxyl group and hydrogen bond in cellulose and lignin increase the rate of absorption and bonding that assist in this mechanism [17], [1]. The porous and wax structure of the fibers powder also contributes to the effectiveness of this coagulation-flocculation mechanism [20].

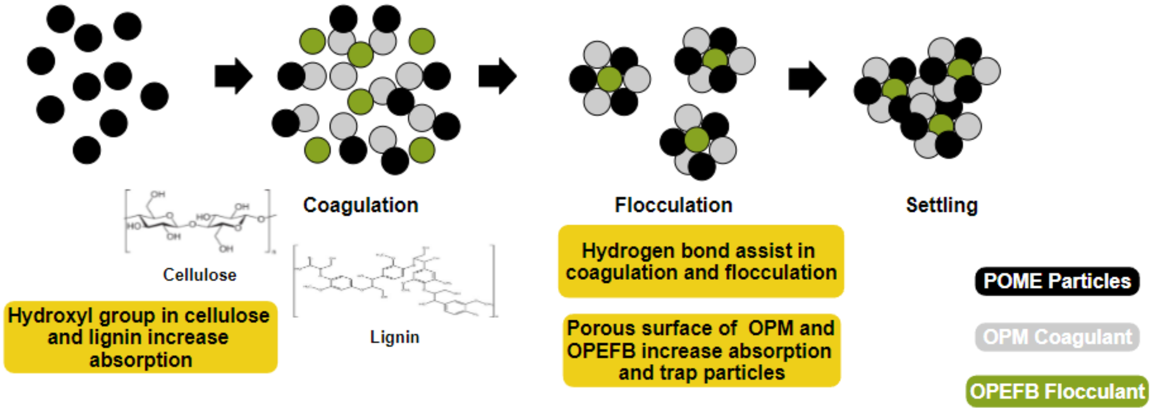


Fig. 5 *Schematic diagram of the coagulation-flocculation mechanism of POME + OPM + OPEFB*

3.5 Evaluation of OPM-OPEFB Performance

To evaluate the performance of OPM-OPEFB fiber powder as a natural coagulant-flocculant for the POME treatment, the obtained results after treatment were compared to the initial parameters value of POME from a factory. Besides, the results achieved were also compared to the standard discharge limits for POME [16]. The comparison parameter values are shown in Table 2. All the parameter values indicated positive change after treatment by OPM-OPEFB and complied with the standard discharge of POME by DOE especially for pH, and AN. There was an increase in the value of DO to 4.93 mg/L, near to the value of 5 mg/L which shows good oxygen content for aquatic life [21]. For turbidity, even the original colour of the POME does not change, but it shows there was a percentage of pollutant removal as the value of turbidity decreased after treatment.

Table 2 *Comparison parameters before and after treatment*

Parameters	Average Reading		Standard Discharge for POME [16]
	Before Treatment	After Treatment	
pH	8.80	8.15	5.5-9
Dissolved oxygen, mg/L	2.81	4.93	-
Turbidity, NTU	38.08	22.63	-
Biochemical oxygen demand, mg/L	183.79	86.13	50
Total suspended solid mg/L	1040	388	100
Ammoniacal nitrogen, mg/L	19.88	13.84	20

3.6 Percentage Removal

The results of using OPM-OPEFB fiber powder as natural coagulant-flocculant in this study are also compared to other research that used different types of natural material as coagulant-flocculant in POME treatment. The same method of treatment was used by all the research references, which are jar tests but with different dosages, stirring speeds, settling times, and pH values during treatment. The comparison was in percentage removal as shown in Table 3. The percentages were calculated using Eq. 1 for each parameter. DO parameter was not calculated for the percentage removal because, compared to other parameters, DO was the one that showed a positive change in trend of increase. Therefore, it cannot be calculated using Eq. 1. Then, for the pH parameter, most of the previous researches usually neutralize the pH using additional chemicals to optimize the effectiveness of fiber used before treatment. Due to that, it cannot be concluded that the pH value was neutralized by the natural fiber treatment. However, for this study, the pH parameter was concluded as the treatment of OPM-OPEFB fiber powder fully reduced without using additional chemicals.

The comparison illustrates the efficiency of OPM-OPEFB compared to other natural coagulants for different wastewater parameters in POME treatment. The data reveals that while OPM-OPEFB shows promising coagulation-flocculation potential, its performance varies across different pollutants. Turbidity removal of OPM-OPEFB achieved 41.28%, which is significantly lower than 98% removal by pomegranate seeds [11]. This indicates that while OPM-OPEFB has some ability to destabilize colloidal particles, it may require higher dosages, pH adjustments, or additional flocculants to enhance its efficiency. The limited charge neutralization capacity of OPM-OPEFB could be a contributing factor to the lower performance compared to pomegranate seeds, which are known for their high tannin content and strong coagulation properties. In terms of BOD removal, OPM-OPEFB demonstrated 53.14% efficiency, which is moderately close to the 65.67% removal achieved by tannin-based coagulants [11]. This suggests that OPM-OPEFB is effective at reducing organic pollutants, possibly due to its adsorption capacity and bio-polymer content. However, its performance could be improved by optimizing the contact time, coagulant dose, or combining it with another bio-coagulant to enhance organic matter removal.

TSS removal of OPM-OPEFB achieved 62.69%, showing relatively high efficiency but still lower than 83.40% observed in the fenugreek-aloe vera mixture [2]. The effectiveness of OPM-OPEFB in removing TSS is likely due to its fiber-rich composition, which enhances floc formation and sedimentation. However, its lower performance compared to fenugreek-aloe vera suggests that additional modifications, such as increasing the fiber concentration or using a dual-coagulant system, may be required to enhance its performance. Regarding Ammoniacal Nitrogen (NH_3-N) removal, OPM-OPEFB achieved 30.38%, but there was no comparison reference provided. The lower efficiency in NH_3-N removal suggests that OPM-OPEFB lacks strong adsorption or ion-exchange capabilities for ammonia-related compounds. To improve this, incorporating biochar, activated carbon, or zeolite into the treatment process could enhance nitrogen removal.

The difference between the application of OPM-OPEFB fiber powder compared to other previous studies (Table 3) may be due to the optimization condition for jar test that affects the performance of coagulation-flocculation by each natural material. For example, high dosages for corn and potato starches and also for fenugreek-aloe vera with each 17 and 24.13 g/L increase the function of each material in their treatment. Other than that, a factor of pH also plays an important role in increasing the effectiveness of the natural material performance in POME treatment as we can see, most of the previous studies would neutralize the pH between 4 and 8 not too acidic or too alkali, a preferred condition for process of coagulation-flocculation by each natural material [1].

Table 3 *Percentage removal after treatment by OPM-OPEFB*

Parameters	Percentage Removal, %	Comparison References, %	
Turbidity, NTU	41.28	98.00 (Pomegranate seeds)	[10]
Biochemical oxygen demand, mg/L	53.14	65.67 (Tannin)	[11]
Total suspended solid mg/L	62.69	83.40 (Fenugreek – aloe vera)	[2]
Ammoniacal nitrogen, mg/L	30.38	-	

4. Conclusion

This study evaluated the water quality parameters of POME, which are pH, turbidity, DO, BOD, TSS, and ammoniacal nitrogen removal efficiency of POME samples using OPM-OPEFB fibers powder as natural coagulant/flocculant. This natural alternative was conducted as a replacement for conventional chemical treatment at the factory to ensure safety and environmental friendliness without using any chemicals. Due to that, the initial pH under alkaline conditions was maintained during treatment without undergoing neutralization that required the addition of sulphuric acid (H_2SO_4). Other operation conditions of jar test are dosage: 500 mL POME, 5 g/L OPM, and 5 g/L OPEFB fiber powder, stirring speed: 200 rpm for first 5 minutes followed by 50 rpm for 30 minutes, and settling time: 3 hours.

Characterization analyses by SEM indicated that the potential coagulation/flocculation mechanism is due to the pores on the surface of both fibers capable of trapping contaminant particles. Besides, analysis of FTIR also showed that the major peak of both fibers contains a high hydroxyl group. This functional group existed in cellulose and lignin, which have properties of hydrophilic, which is strong in absorption. The evaluation of the OPM-OPEFB fiber powder performance was shown by percentage removal by calculation of initial and final parameters. The OPM-OPEFB mixture demonstrated moderate efficiency, achieving 41.28% turbidity reduction, 53.14% BOD removal, 62.69% TSS removal, and 30.38% NH_3-N removal. While these results indicate that OPM-OPEFB has potential as a natural coagulant, it is less efficient than conventional and other natural coagulants such as pomegranate seeds, tannins, and fenugreek-aloe vera. The promising removal efficiency of TSS and BOD suggests that OPM-OPEFB is effective in reducing suspended particles and organic pollutants, making it suitable for primary wastewater treatment applications. The lower turbidity and ammoniacal nitrogen removal efficiencies indicate that OPM-OPEFB lacks sufficient charge neutralization and ammonia adsorption capacity. This suggests the need for further modifications, such as blending with other coagulants or optimizing the treatment process. All the final parameters after treatment using OPM-OPEFB fiber powder show a positive value of removal. Future research endeavors might optimize the operational parameters of treatment to enhance the efficacy of OPM-OPEFB in POME treatment. This could involve actions such as conducting response surface methodology or artificial neural network analysis to determine the optimal dosage, pH, mixing speed, and contact time for maximum efficiency. Additionally, upcoming researchers may explore the surface modification and functionalization of OPM-OPEFB to enhance its adsorption properties by using chemical or thermal treatment. Overall, while OPM-OPEFB exhibits moderate efficiency in coagulation-flocculation however, its low cost, sustainability, and biodegradability make it a viable option, especially if improvements such as process optimization, dosage refinement, and coagulant blending are explored.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhamad Aiman Mohd Atarabusyi, Nor Maizzaty Abdullah, Najeeha Mohd Apandi;* ***data collection:*** *Muhamad Aiman Mohd Atarabusyi, Nor Maizzaty Abdullah, Muhammad Faiz Haikal Ali;* ***analysis and interpretation of results:*** *Muhamad Aiman Mohd Atarabusyi, Nor Maizzaty Abdullah, Siti Nor Hidayah Arifin;* ***draft manuscript preparation:*** *Muhamad Aiman Mohd Atarabusyi, Nor Maizzaty Abdullah, Siti Nor Hidayah Arifin. All authors reviewed the results and approved the final version of the manuscript.*

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