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Conversion of Oil Palm Empty Fruit Bunch (OPEFB) and Mesocarp (OPM) Fibers into Liquid Natural Coagulants and Performance Evaluation for Palm Oil Mill Secondary Effluent (POMSE)

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Abstract

Palm oil mill secondary effluent (POMSE) can still contain a high level of organic pollution even after biological treatment making an additional polishing step necessary. This study focused on producing liquid bio-coagulants from oil palm empty fruit bunch (OPEFB) and oil palm mesocarp (OPM) fibers using sodium hydroxide exttraction and examining their chemical characteristics and treatment performance. The chemical functional groups of the extracted liquids were analysed using Fourier Transform infrared Spectroscopy (FTIR), while their effectiveness in treating POMSE was tested through jar test experiments at different dosages. At the optimum condition of 300 mL of coagulant per 200 mL of effluent the OPEFB-based liquid achieved a BOD_5 reduction of about 49 – 56 %, whereas the OPM-based liquid showed much lower removal which is below 10 %. The pH of the treated effluent remained close to 8. Although the treated effluent did not fully meet discharge standards the findings suggest that OPEFB-derived liquid has stronger potential as a polishing bio-coagulant and should be further improved through optimisation of the extraction process and dosage.

1. Introduction

The palm oil industry is one of the major agricultural sectors in Malaysia and contributes significantly to national economic development [1]. During the palm oil milling process, large volumes of wastewater and solid residues are generated particularly Palm Oil Mill Effluent (POME), Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers [2]. Palm Oil Mill Effluent (POME) is brownish wastewater produced during sterilization, digestion, oil extraction and clarification processes in palm oil mills [3]. It is characterized by high concentrations of organic matter, suspended solids, oil and grease resulting in elevated biochemical oxygen demand (BOD) and total suspended solids (TSS) [4]. If discharged without adequate treatment, POME can significantly degrade water quality and negatively affect aquatic ecosystems [4]. In most palm oil mills, Palm Oil

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Mill Effluent (POME) is commonly treated using biological treatment processes, particularly anaerobic and aerobic systems as they are effective in reducing organic load and are widely applied in the palm oil industry [5].

After biological treatment, the treated effluent is commonly referred to as Palm Oil Mill Secondary Effluent (POMSE). However, studies have reported that POMSE still contains residual organic matter and suspended solids indicating that further treatment is required before safe discharge into the environment [4]. Coagulation-flocculation is commonly applied as a polishing step to improve wastewater quality by reducing turbidity and suspended solids [6]. Conventional chemical coagulants such as alum are effective however, their application is associated with high operational cost and excessive sludge generation [6]. In addition, concerns have been raised regarding the environmental sustainability and sludge disposal issues related to chemical-based coagulants [7].

As a result, natural coagulants derived from plant-based and agricultural biomass have been increasingly explored due to their biodegradability and environmental compatibility [8]. Oil palm biomass such as Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers is abundant and rich in lignocellulosic constituents including cellulose, hemicellulose and lignin [8]. These materials contain functional groups such as hydroxyl and carboxyl groups which are important for coagulation and adsorption mechanisms [9].

Previous studies have shown that alkaline treatment can change the structure of lignocellulosic biomass by removing lignin and exposing cellulose and hemicellulose components. Treatment using sodium hydroxide (NaOH) increases the availability of functional groups that are able to interact with suspended particles in wastewater [10]. In addition, previous studies have reported that liquid natural coagulants extracted using alkaline treatment demonstrated good coagulation performance due to high polysaccharide content and the presence of active functional groups [11]. Previous studies have highlighted that the effectiveness of liquid bio-coagulants is closely related to the presence of soluble polysaccharides and active functional groups which can be identified through spectroscopic techniques such as Fourier Transform Infrared Spectroscopy (FTIR).

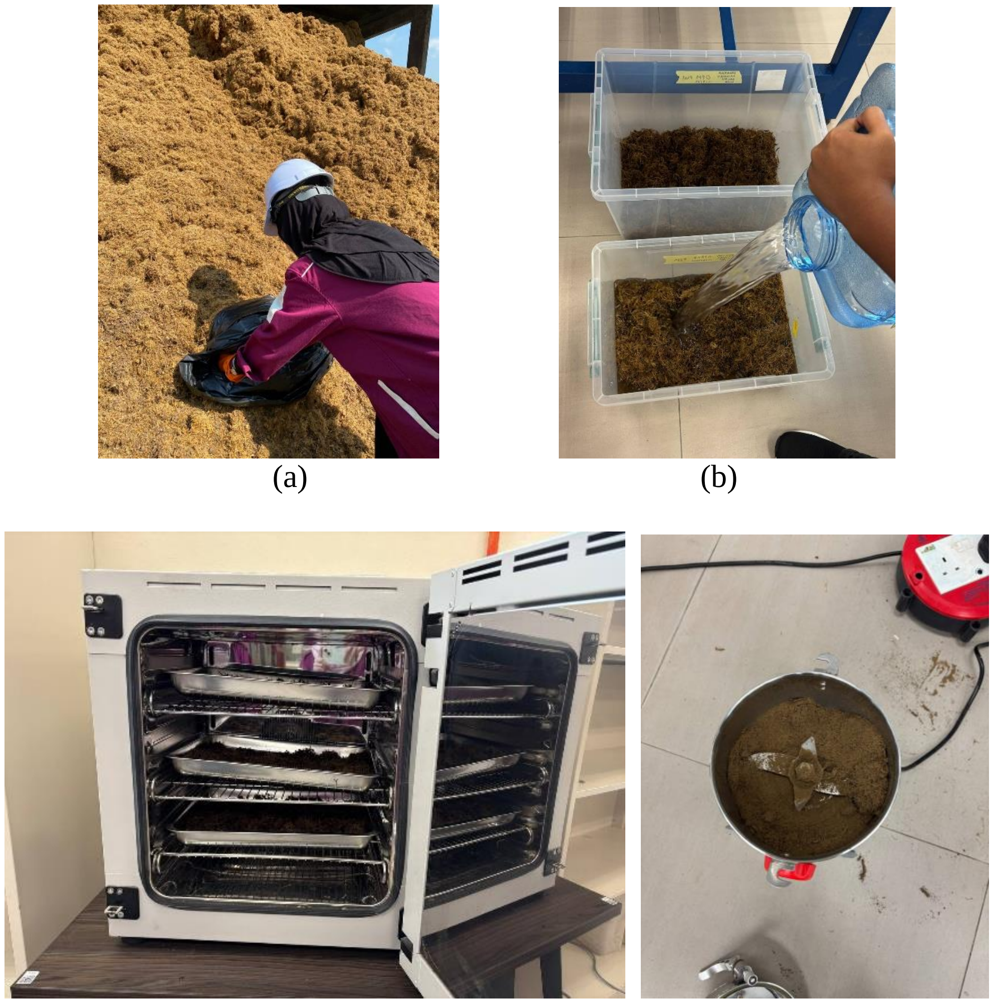
Therefore, FTIR analysis is important to verify the functional groups that contribute to coagulation and adsorption mechanisms in bio-coagulant systems [11]. Despite the abundance of oil palm biomass, studies focusing on the conversion of OPEFB and OPM fibers into liquid bio-coagulants and their application for the treatment of Palm Oil Mill Secondary Effluent (POMSE) remain limited. Existing studies mainly report the physicochemical characteristics and limitations of the current POMSE treatment indicating the need for alternative treatment approaches [4].

Therefore, this study aims to develop liquid bio-coagulants from Palm Oil Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers using an alkaline extraction method. The comparison between OPEFB and OPM is conducted because both are abundant oil palm residues with lignocellulosic composition, allowing the evaluation of how differences in biomass structure and composition influence the performance of the extracted liquid bio-coagulants for POMSE treatment. The extracted coagulants are characterized using Fourier Transform Infrared Spectroscopy (FTIR) to identify their functional groups. The treatment performance of the bio-coagulants is evaluated through jar test experiments on POMSE by analyzing pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and total suspended solids (TSS).

2. Materials and Methods

2.1 Preparations of Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM)

Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers were obtained from Kilang Sawit Bukit Pasir Sdn. Bhd., Johor, Malaysia. The fibers were washed thoroughly with distilled water to remove adhering dirt and residual oil. The cleaned fibers were then soaked in distilled water for 24 h at room temperature. After soaking, the fibers were oven-dried at 100 °C for 2 h. The dried materials were subsequently ground using a laboratory grinder and sieved to obtain a particle size of 150 μm following similar preparation methods reported for oil palm biomass [12]. The prepared OPEFB and OPM fiber samples were stored in airtight containers at room temperature prior to the extraction process. The preparation steps of OPEFB and OPM fibers are illustrated in Figure 1.



(a) (b) (c) (d)

Figure 1 Preparation steps of Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers: (a) collection of fibers, (b) washing and soaking, (c) oven drying at 100 °C and (d) grinding.

2.2 Wastewater Sample (POMSE)

Palm Oil Mill Secondary Effluent (POMSE) was collected after biological treatment from Kilang Kelapa Sawit Bukit Pasir Sdn. Bhd, Johor, Malaysia. The effluent was stored in high-density polyethylene (HDPE) bottles and kept in a cold room at 4°C prior to use to minimize the biological activity. Pior to the coagulation-flocculation experiments, the initial characteristics of POMSE, including pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and total suspended solids (TSS) were determined to establish baseline water quality conditions.

2.3 Alkaline Extraction of Liquid Bio-Coagulants

Liquid bio-coagulant were extracted from the prepared OPEFB and OPM fibers using an alkaline extraction method adapted from previous studies [11]. A sodium hydroxide (NaOH) solution with a concentration of 2% (w/v) was prepared using distilled water. The extraction was carried out by mixing the fiber powder with NaOH solution at a solid-to-liquid ratio of 1:10 (w/v).

The mixture was heated at 120°C for 2h with continuous stirring to facilitate the extraction of active coagulating compounds from the fibers. After the extraction process, the mixture was allowed to cool to room temperature and then filtered to separate the solid residues from the liquid extract.

The obtained liquid extracts from OPEFB and OPM fibers were collected and stored in airtight containers at 4°C prior to further characterization and coagulation-flocculation experiments. The alkaline extraction procedure of liquid bio-coagulants from OPEFB and OPM fibers is illustrated in Figure 2.

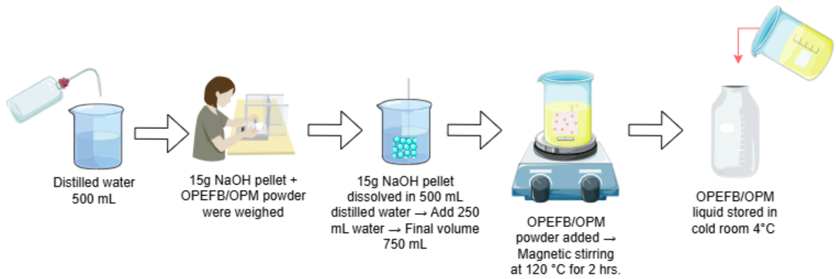


Figure 2 Schematic diagram of the alkaline extraction process of OPEFB and OPM fibers

2.4 Characterisation of Liquid Bio-Coagulants (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) analysis was carried out to identify the functional groups present in the extracted liquid bio-coagulants derived from OPEFB and OPM fibers. The FTIR analysis was performed using an FTIR spectrometer in the wavenumber range of 4000-400 cm^{-1}, as this range is commonly applied for lignocellulosic materials and enables the identification of key functional groups such as hydroxyl (O-H), carbonyl (C=O) and ether (C-O-C) groups associated with cellulose, hemicellulose and lignin. The spectra obtained were analysed to determine the presence of characteristic functional groups such as hydroxyl (-OH), carboxyl (-COOH), carbonyl (C=O) and ether (C-O-C) groups. These functional groups are commonly associated with lignocellulosic materials and are important for coagulation and adsorption mechanisms. The FTIR results were used to support the coagulation performance of the extracted liquid bio-coagulants.

2.5 Characterisation Coagulation-Flocculation (Jar Test) Procedure

Coagulation-flocculation experiments were carried out using standard jar test procedures to evaluate the performance of the extracted liquid bio-coagulant on Palm Oil Mill Secondary Effluent (POMSE). For each test, 200 mL of POMSE were transferred into 500 mL beakers. Liquid bio-coagulants derived from OPEFB and OPM fibers were added at different dosages, while untreated POMSE was used as the control sample.

The samples were first subjected to rapid mixing at 200 rpm for 1 min to ensure uniform dispersion of the bio-coagulant, followed by slow mixing at 80 rpm for 30 min to promote floc formation. After mixing, the samples were allowed to settle for 30 min. This procedure was adapted from previous studies on bio-coagulant application for palm oil mill effluent treatment, which employs similar coagulation-flocculation mechanisms [13]. The supernatant then carefully collected for subsequent water quality analysis. The optimum dosage of the liquid bio-coagulants was determined based on the removal efficiency of selected water quality parameters. The coagulation-flocculation procedure is illustrated in Figure 3.

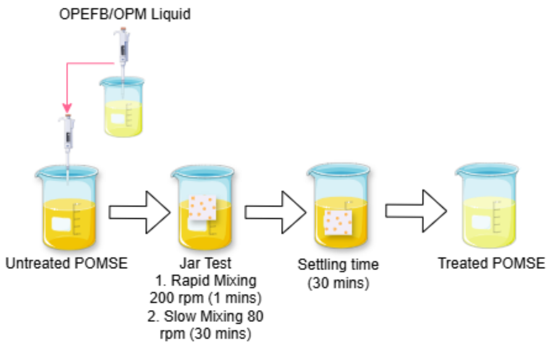


Figure 3 Schematic diagram of the coagulation-flocculation (jar test) procedure

2.6 Water Quality Analysis

The treatment performance of the liquid bio-coagulant was evaluated by analysing selected water quality parameters of POMSE before and after the coagulation-flocculation process. The parameters analysed included pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and total suspended solids (TSS).
pH and dissolved oxygen were measured using a calibrated benchtop meter, while turbidity was determined using a turbidity meter. Biochemical oxygen demand (BOD_5) was analysed using the standard five-day incubation method at 20°C. Total suspended solids (TSS) were determined usning standard gravimetric method involving filtration and oven-drying. All measurements were carried out following standard wastewater analysis procedures.

3. Result and Discussion

3.1 FTIR Characterisation of Liquid OPEFB and OPM Bio-Coagulants

FTIR analysis was performed to identify the functional groups present in liquid bio-coagulants extracted from Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers. The FTIR spectra provide insight into the chemical characteristics of the extracts and their potential coagulation mechanisms.

As shown in Figure 4, both liquid OPEFB and OPM exhibited a broad absorption band in the range of 3,200–3,600 cm^{-1}, which is typically associated with O-H stretching vibrations indicating the presence of hydroxyl groups. Adsorption peaks observed at 2,800–2,950 cm^{-1} can be attributed to C-H stretching vibrations. Peaks around 1,600–1,650 cm^{-1} suggest the presence of carbonyl-related groups while bands in the 1,000–1,200 cm^{-1} region are commonly linked to C-O stretching vibrations in polysaccharide structures. These functional groups are relevant to coagulation and adsorption mechanisms as they can support particle interaction and floc formation [11 , 14].

Overall, the FTIR results confirm that both liquid OPEFB and OPM bio-coagulants contain active functional groups suitable for coagulation and adsorption processes. The similarity in functional groups suggests that performance differences are influenced by extract composition rather than the absence of reactive chemical groups.

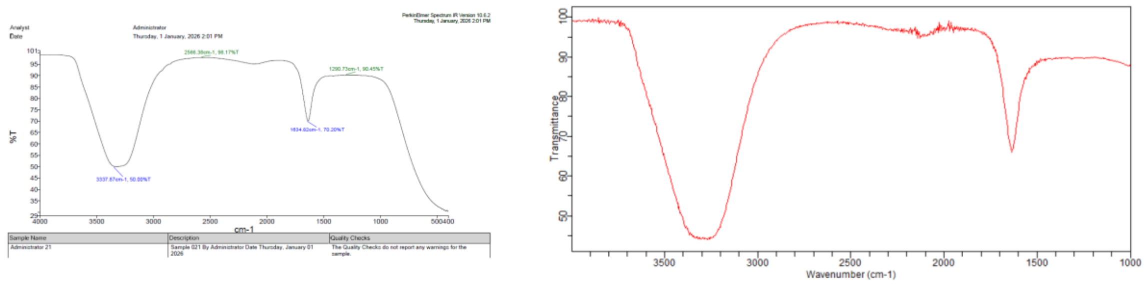


Figure 4 FTIR spectra of a liquid bio-coagulants extracted from (a) Oil Palm Empty Fruit Bunch (OPEFB) and (b) Oil Palm Mesocarp (OPM)

3.2 Effect of Bio-Coagulant Dosage on POMSE Treatment

The effect of bio-coagulant dosage on the treatment performance of POMSE was evaluated using OPEFB and OPM extracts at different dosages. The results showed that the removal efficiency of selected water quality parameters generally increased with increasing bio-coagulant dosage up to an optimum level, after which no significant improvement was observed.

For both liquid OPEFB and OPM bio-coagulants, an optimum dosage of 300 mL added to 200 mL of POMSE was identified. This dosage resulted in the highest removal efficiency and the formation of well-defined and stable floc. Dosages below this level provided insufficient charge neutralization and particle interaction, while higher dosages did not lead to further improvement and may have caused overdosing effects due to excess coagulant in the system. Therefore, 300 mL was selected as the optimum dosage as it represents the balance between effective coagulation performance and the avoidance of overdosing effects. At the optimum dosage 300 mL, turbidity decreased from 50.3 NTU to 44.3 NTU for liquid OPEFB and 47.9 NTU for liquid OPM corresponding to turbidity removals pf 11.9% and 4.8% respectively. All treated turbidity values were below the Department of Environment (DOE) guideline value of 50 NTU, indicating compliance with the standard. Liquid OPEFB demonstrated better turbidity reduction compared to liquid OPM at the same dosage.

For biochemical oxygen demand (BOD_5) the untreated POMSE recorded values in the range of 7.13 – 7.60 mg / L. After treatment with liquid OPEFB BOD_5 decreased to 3.38 – 3.60 mg / L corresponding to a removal efficiency of approximately 49 – 56 %. In contrast, liquid OPM showed little improvement with BOD_5 values remaining between 7.50 – 8.00 mg / L. Although liquid OPEFB significantly reduced BOD_5 the final values were still slightly higher than the DOE discharge limit of 3 mg / L indicating the further treatment is required.

The pH of the POMSE remained unchanged at pH 8 before and after treatment using both bio-coagulants. This shows that liquid OPEFB and OPM did not significantly affect the acidity or alkalinity of the effluent. All pH value were within the acceptable DOE range of 6 – 9.

For total suspended solids (TSS), the untreated POMSE recorded 154.1 mg / L. After treatment with liquid OPEFB, TSS slightly decreased to 152.1 mg / L corresponding to a removal of 1.30 %. Treatment using liquid OPM resulted in a TSS value of 154.4 mg/L indicating a small increase and a negative removal efficiency of -0.19%. In both cases, the final TSS value were well above the DOE limit of 50 mg/L showing that TSS removal was limited.

Overall, liquid OPEFB showed better treatment performance than liquid OPM at the optimum dosage especially for turbidity and BOD_5 reduction. However, the limited removal of TSS and the inability to fully meet all DOE discharge standards indicate that liquid OPEFB and OPM bio-coagulants are more suitable as a supplementary or polishing treatments rather than standalone solution for POMSE treatment. The changes in turbidity, pH, BOD_5 and TSS before and after treatment at the optimum dosage are summarised in Table 1.

Table 1 ***Comparison parameters before and after treatment***

Parameter	Initial Reading	Treated POMSE (OPEFB)	Treated POMSE (OPM)	Removal (%) OPEFB	Removal (%) OPM	Standard	Unit
Turbidity	50.3	44.3	47.9	11.9	4.8	50	NTU
pH	8	8	8	-	-	6 – 9	-
Biochemical Oxygen Demand (BOD)	7.13 – 7.60	3.38 – 3.60	7.50 – 8.00	49 – 56	-	3	mg/l
Total Suspended Solid (TSS)	154.1	152.1	154.4	1.30	-0.19	50	mg/l

3.2.1 Effect of Bio-Coagulant Dosage on BOD_5 Removal

The reduction in and BOD_5 observed for liquid OPEFB can be attributed o the presence of active functional groups in bio-coagulant such as hydroxyl (-OH) and carbonyl (C=O) groups which were identified through FTIR analysis. These functional groups enhance the interaction between the bio-coagulant and biodegradable organic matter present in POMSE through adsorption, charge neutralization and inter-particle bridging mechanisms. A s a result, part of dissolved and suspend organic matter was destabilized and remove together with the formed flocs leading to a reduction in BOD_5. Similar findings have been reported in previous studies on oil palm biomass-based bio-coagulants where the presence of lignocellulosic functional groups contributed to the partial removal of organic load in POME and POMSE treatment [14 , 11 , 15].

Despite the observed improvement, the treated POMSE using both bio-coagulants did not fully meet the Department of Environment (DOE) discharge standards for BOD_5. This indicates that while liquid OPEFB is effective in improving effluent quality, it is more suitable for use as an additional treatment step rather than as the main treatment process.

3.2.2 Effect of Liquid Bio-Coagulants on Turbidity and TSS Removal

The effect of liquid OPEFB and OPM bio-coagulants on turbidity and total suspended solids (TSS) of POMSE was evaluated at the optimum dosage of 300 mL. The results showed that both bio-coagulants contributed to a reduction in turbidity; however, the overall removal efficiencies were relatively low.

Liquid OPEFB achieved a turbidity reduction of approximately 11.9%, while liquid OPM resulted in a lower removal of about 4.8%. The modest turbidity reduction suggests that the coagulation process was only partially effective in removing suspended particles. This can be attributed to the presence of hydroxyl (-OH) functional groups in the liquid bio-coagulants which promote adsorption and particle bridging as identified through FTIR analysis. These interactions enhance floc formation and settling leading to a reduction in turbidity. However, the effect is limited for fine and stable particles. Similar observations have been reported in previous studies on palm-based bio-coagulants where hydroxyl – rich lignocellulosic materials contributed to partial turbidity removal rather than complete clarification [14, 15].

The limited TSS removal may due to the presence of very fine and stable suspended solids in POMSE which are difficult to destabilize and settle during using natural bio-coagulants alone. Similar limitations of natural coagulants in TSS removal have been reported in previous studies where additional treatment steps were required to achieve significant suspended solids reduction [15].

Overall, the results demonstrate that while liquid OPEFB and OPM bio-coagulants can slightly improve turbidity, their effectiveness in reducing TSS remains limited. These findings further support the suitability of the bio-coagulants as an additional treatment step rather than a primary treatment method for POMSE.

3.2.3 Effect of Liquid Bio-Coagulants on pH and Dissolved Oxygen (DO)

The changes in pH and dissolved oxygen (DO) of POMSE after treatment with liquid OPEFB and OPM bio-coagulants were evaluated at the optimum dosage of 300 mL. The results showed that the pH of the treated effluent remained relatively stable after the coagulation–flocculation process.

For both liquid OPEFB and OPM treatments, the pH values remained around pH 8, indicating that the application of the bio-coagulants did not cause significant changes to the effluent acidity or alkalinity. This suggests that the use of liquid OPEFB and OPM bio-coagulants does not require additional pH adjustment, which is advantageous for practical wastewater treatment applications.

Dissolved oxygen (DO) levels showed a slight decrease after treatment for both bio-coagulants. This reduction is expected due to the consumption of oxygen during the BOD_5 incubation process rather than the direct effect of the coagulation–flocculation treatment. The observed DO values remained within an acceptable range and did not indicate adverse impacts on effluent quality.

Overall, the stable pH and slight changes in DO suggest that the application of liquid OPEFB and OPM bio-coagulants has minimal impact on the physicochemical characteristics of POMSE, further supporting their suitability as an additional treatment step.

4 Conclusion

This study evaluated the potential of liquid bio-coagulants derived from Oil Palm Empty Fruit Bunch (OPEFB) and Oil Palm Mesocarp (OPM) fibers for the treatment of Palm Oil Mill Secondary Effluent (POMSE). The effectiveness of the bio-coagulants was assessed based on pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), and total suspended solids (TSS). FTIR analysis confirmed the presence of key functional groups such as hydroxyl (–OH), carbon–hydrogen (C–H), and carbonyl (C=O) in both liquid OPEFB and OPM extracts, indicating their lignocellulosic nature and suitability for coagulation mechanisms involving adsorption and particle bridging.

At the optimum dosage of 300 mL, liquid OPEFB demonstrated better treatment performance compared to liquid OPM. Liquid OPEFB achieved moderate reduction in BOD_5, with removal efficiencies of approximately 49–56%, while only limited improvement was observed for liquid OPM. Turbidity reduction was also modest, with removal efficiencies of 11.9% for OPEFB and 4.8% for OPM. The pH of the treated effluent remained stable at around pH 8, indicating that the application of the bio-coagulants did not significantly alter the acidity or alkalinity of POMSE.

Dissolved oxygen levels showed only slight reductions after incubation, which is expected during BOD_5 testing. Despite the observed improvements, the treated effluent did not fully comply with the Department of Environment (DOE) discharge limits for BOD_5 and TSS. Therefore, while liquid OPEFB and OPM bio-coagulants are environmentally friendly and capable of improving certain water quality parameters, they are more suitable as additional or polishing treatment steps rather than as standalone treatment solutions for POMSE. The findings also indicate that the concentration of liquid bio-coagulants applied in this study may not be sufficient to achieve full compliance with all Department of Environment (DOE) discharge standards particularly for BOD_5 and TSS. Therefore, further studies are recommended to optimize the bio-coagulant concentration and dosage levels to enhance treatment efficiency. Future work may also focus on evaluating the effect of higher bio-coagulant concentrations and different application conditions to improve pollutant removal performance.

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