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Utilization of Angsana Leaves (*Pterocarpus indicus Willd*) as a Natural Coagulant for Palm Oil Mill Effluent (POME) Treatment

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Abstract: This research aims to prepare natural coagulants from Angsana leaves (*Pterocarpus indicus willd*) for Palm Oil Mill Effluent (POME) treatment, especially reducing main variables such as TSS, COD, and pH. The amounts of 100 mesh Angsana powder (5, 10, 15, and 20 grams) were extracted using NaCl solvent with concentrations of 0.25 M and 0.5 M, respectively. The extract (200 mL) were added to 500 mL of POME and stirred (180 rpm) for 30 minutes. The concentrations of TSS, COD, and pH in POME were analyzed. Results showed that the coagulation-flocculation process using Angsana leaves powder was able to reduce COD by 55.79% at a coagulant dose of 5 g/L with 0.25 M NaCl solvent and TSS by 99.75% at a dose of 20 g/L with 0.25 M NaCl solvent. However, treatment using Angsana leaves extract was not able to reduce COD to the predetermined quality standard limits while the TSS value met the quality standard. Therefore, POME treatment still requires further processing.

Keywords: Angsana leaf; Natural coagulant; POME; *Pterocarpus indicus Willd*

Introduction

The palm-oil sector is a vital aspect of the economies of developing countries, particularly those located in Southeast Asia (Kahar et al., 2022). In 2020, the growth of oil palm plantations was recorded at 14,824.60 hectares. Meanwhile, the area of oil palm plantations in Indonesia in 2020 is 16,381,000 hectares (Kementerian Pertanian Republik Indonesia, 2020). Oil palm is one of the plantation crops that has an important role for the national economy, especially as a provider of employment, a source of income and foreign exchange for the country. Indonesia as the largest palm oil producing country in the world has enormous potential to market crude palm oil Crude Palm Oil (CPO) and other preparations at home and abroad. CPO itself is a raw material for the manufacturing industry of cooking oil, margarine, candles, soap, various kinds of body care products. The palm oil process is carried out through extraction in the palm oil industry (Awalludin et al., 2015; Chan et al., 2019; Nutongkaew et al., 2019; Prapaspongsa et al., 2017). Palm oil represents 17% of total agricultural revenues, making it the most important agricultural product of Indonesia. In 2016 palm oil represented 2.36% of Indonesia's GDP (Indonesia Investments, 2017; The World Bank, 2016). However, it also leads to an increase in waste volume and a bigger amount of liquid matter in waste, thereby reducing the advantages of the recovered palm oil (Chan et al., 2019; Dominic et al., 2022). These liquid wastes are otherwise known as palm oil mill effluent (POME) (Abdullah et al., 2020).

The production of CPO will produce a large amount of Palm Oil Mill Effluent (POME). POME will become an environmental pollution problem if not managed properly because its contains Biochemical

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Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), oil and fat that exceeds the threshold of environmental quality standards, all of which cause serious environmental issues (Sukiran et al., 2017). Every ton of fresh fruit bunches (FFB) processed into CPO will produce 23% Palm Oil Empty Bunches (POEB) waste, 6.5% shells, 13% fiber, and 50% liquid waste (Fitria et al., 2021).

Every additional CPO capacity produced will result in an increase in the amount of liquid waste produced so that good liquid waste treatment is needed. In addition, a study by Sadhukhan et al. (2018) estimates that using palm-oil waste to produce fine and platform chemicals, polymers and ingredients for food and pharmaceuticals, along with biofuel and bioenergy, could plausibly replace the use of fossil resources. POME has a water content of (95-96%), COD ranges from 40,000 to 80,000 mg/L, BOD ranges from 20,000 to 30,000 mg/L. Due to the acidic nature of the contaminant and very high level of biological oxygen demand (BOD), POME cannot be disposed without specific treatment due to the pollution threat to the environment (Hosseini et al., 2015).

Treating POME before disposal is one of the concerns and necessities for every palm oil manufacturer. POME treatment is a standard requirement that needs to be followed in order to persist in the manufacturing industry. Most of the POME treatments lead to biological handling due to its high lipids, nitrogenous compound, and protein and minerals content (Tan et al., 2019). There are three main methods that are commonly preferred by the palm oil manufacturer, which are anaerobic digestion, feedstock for biodiesel, and composting method. Some of the manufacturers convert the POME produced from their plant into biodiesel by dark fermentation process, whereas some use treated POME on land application of compost production to act as fertilizer of the palm oil trees (Garritano et al., 2018).

Processing of fresh fruit bunches until CPO and palm kernel is obtained through a fairly long process (Choong Lek et al., 2018). The wastewater produced from the CPO production process is in the heating and sterilization process, FFB is treated by steam sterilization with steam pressure of 2.5-3.0 kg/cm^2, temperature 135-1400 ^{0}C for 90-100 minutes. First, wastewater drain (condensate) is produced from each process using a sterilizer in this process (Cherie et al., 2018).

Palm oil industry wastewater consisting of sludge, condensate water, factory washing water, hydroclone water, etc. from sterilization and clarification stations is flowed into fat pit for oil quotation. POME has a high concentration and is dark brown and often causes pollution (Hasanudin et al., 2017).

Table 1. POME Characteristics based on Research Results (Elvitriana et al., 2021)

Parameters	Unit	Range
pH		3.5 – 4.7
COD	mg/L	16,000 – 100,000
BOD	mg/L	10,000 – 44,000
Total Suspended Solid (TSS)	mg/L	5,000 – 54,000
Temperature	˚C	70 – 80

Table 1 shows that palm oil industry wastewater contains very high organic matter, namely BOD 20,000 – 30,000 mg/L and COD 40,000 – 60,000 mg/L, so that the level of pollution will be higher. Therefore, to reduce the content of pollution levels, degradation of organic matter is needed.

Total Suspended Solids (TSS) (4-5%), oils and fats (0.6-0.7%) and acidic pH (3.5-4). If discharged directly into water bodies, POME can cause pollution that can reduce water quality (Ilmannafian et al., 2020). If POME is discharged directly into the environment, sedimentation will occur and then decompose which causes turbidity and emits a sharp odor (Elvitriana et al., 2017; Ramadhan et al., 2020).

Palm oil industry waste consisting of sludge, condensate water, factory washing water, hydroclone water, etc. originating from boiling/sterilization and clarification stations is flowed into fat pits/sludge recovery tanks for oil quotation. POME has a high concentration and is dark brown and often causes pollution (Hasanudin et al., 2017). Given the high potential for pollution due to palm oil liquid waste, a pollution control strategy is needed by processing liquid waste before being discharged into the environment as an effort to nourish the environment. Processing is carried out so that liquid waste released into water bodies is in accordance with the quality standards of POME (Elvitriana et al., 2014; Ruhmawati et al., 2017).

Palm oil liquid waste can be processed by several processing processes, such as using physical, chemical or biological processes or a combination of these three processes. There have been many studies discussing the processing of POME to comply with quality standards. Some of the studies include the use of hyacinth plants (*Eichhornia crassipes*), cacti (*Cactaceae*) in the coagulation and flocculation processes.

One of alternatives to processing POME by coagulation-flocculation method using natural coagulants, in the form of the use of water hyacinth plants (*Eichhornia crassipes*). The results of the BOD analysis that have not met the quality standards are at 100% and 75% concentration treatment, (894.7 g/L and 304.15 mg/L, respectively), and meet the quality standard at 50% concentration treatment (77.03 mg/L). All COD analysis results have not met quality standards (at concentrations of 100%, 75%, and 50% are 4,320 mg/L, 1,120 mg/L and 440 mg/L, respectively). The results of TSS analysis that have not met the quality standards are at 100% wastewater concentrations (400 mg/L), and meet quality standards at concentrations of 75% and 50% (200 mg/L and 0 mg/L, respectively). All pH analysis results meet quality standards (successively at 100%, 75%, and 50% wastewater concentrations, namely 7, 8, and 9), (Ilmannafian et al., 2020).

The results of biocoagulant research from Opuntia cactus (*Cactaceae*) on okra extract with an optimal dose of Opuntia 8 g/L, a ratio of 1:2 okra extract to palm liquid waste, pH 9 and deposition time for 240 minutes gave the best results for processing palm liquid waste. The average percentage achieved was approximately 93.9% for COD and turbidity allowance, and 96.1% for TSS allowance. From this research, it can be concluded that Opuntia has great potential to be used as a source of biocoagulant for palm oil liquid waste treatment. The addition of okra as a bioflocculant seems to increase the percentage of COD, TSS, and turbidity allowance, but only slightly. Therefore, further research is needed to see if Opuntia can be developed for use as a coagulant (Vasanthi, 2019).

POME treatment using coagulation and flocculation is an effort to reduce the dissolved and suspended solids contained in liquid waste. But usually, this coagulation and flocculation process is not able to reduce pollutant levels to meet quality standards (Fatoni et al., 2020).

In this study, one alternative treatment has been evaluated for POME by coagulation-flocculation method using natural coagulants, namely Angsana leaves (*Pterocarpus indicus willd*). Angsana leaves are one of the plants that are used as natural coagulants because they have chemical compounds contained in this plant showing positive tests for phenols, flavonoites, saponins, triterpenoids, and tannins, so that they can work under the right coagulant conditions and optimal deposition, helping turbidity because they are able to adsorb palm oil waste (Sopian et al., 2021).

Angsana is a tree with a height of 10-40 m, trunk diameter 2m, twig length 1-2 m. Morphological characteristics of Angsana include alternating leaves 5-13 leaves, elongated, ovoid shape, blunt, tapered and shiny. Trees that sometimes become giant, up to 40 m high. Stems often tuberous or grooved; Usually with papa root (banir). The dense canopy is a dome, with branches that duck down close to the ground. Brownish-gray bark, broken down or similar to fine scales, secretes reddish lymph when injured (Ingeswari, 2019). Based on the previous description, this research focussing on the utilization of Angsana Leaves (*Pterocarpus indicus willd*) as a Natural Coagulant for POME Treatment.

Method

Materials

Glass jars/containers for sample filling, Hanna digital pH meters, sample bottles, plastic jerry cans containing 10 liters, filter paper, ovens, desiccators, analytical balances, funnels, erlenmeyer, beakers, measuring cups, label paper, stirring rods (magnetic stirrer), drip pipettes, stop watches, blenders, sieves 100 mesh.

The POME used in this research was obtained from primary pounds of Palm Oil Mill in Aceh Province. Angsana leaves (*Pterocarpus indicus Willd*) as a coagulant material was taken from the campus yard of Serambi Mekkah University. All regeans, such as NaCl 0.25 and 0.5M, sulfuric acid 0.1 gr, aluminum sulfate 0.1 gr, NaOH and KOH 0.1 gr were obtained commercially from WACO LTD.

Metode Research

Research was carried out using qualitative descriptive research with pure experimental methods. Table 2 describes three variables of research for the implementation plan during the study. Preliminary tests were carried out to obtain the optimum pH of coagulation for waste reduction with a pH range of 2-7, then the wastewater (POME) was adjusted to this optimum pH to make easier treatment using the natural coagulant from Angsana leaves.

Table 2. Variables of Research

Sampel	Fixed Variabel	Variables
Coagulants Natural leaf Angsana	Rapid stirring followed by slow stirring	Types of coagulant solvents (aquadest + NaCl 0,25 M and 0,5 M).
	Time deposition 1 hour	Coagulant dose (5000 - 20.000 mg/L).
Coagulant chemistry (PAAC)	Size sieve 100 mesh	pH dose (2-8). Types of natural coagulants and chemical (PAC).

Preparation of Angsana Leaves as Coagulant

The preparation of coagulants from Angsana leaves was modified from the former research (Sethu et al., 2019). Angsana leaves (*Pterocarpus indicus Willd*) were taken from the tree, cleaned, and dried in an oven at 105 ^{o}C for 30 minutes to homogenize and reduce the water content until constant followed by blending into powder which has a particle size of 100 mesh. A total of 3 grams of powder was suspended in 1 L of different solvents such as distilled water and 25.5 NaCl. Each active component of the coagulant was extracted by stirring the suspension using a magnetic stirrer, then filtered using filter paper until an extract is obtained. The extract was stored at 4 °C before used.

POME Treatment

The amounts of 100 mesh Angsana powder (5, 10, 15, and 20 grams) were extracted using NaCl solvent with concentrations of 0.25 M and 0.5 M, respectively. The extract (200 mL) were added to 500 mL of POME and stirred (180 rpm) for 30 minutes. Then, concentrations of TSS, COD, and pH in POME were analyzed.

Sample Analysis

Fourier Transform Infrared Spectroscopy (FTIR) was used to identify chemical bonds and functional groups in a molecule by producing an infrared absorption spectrum. This test was carried out at the Chemical Engineering Laboratory, Syiah Kuala University, Banda Aceh. Key parameters analysis such as pH, COD, and TSS was carried out using the standard methods SNI 6989.11:2019, SNI 6989.2:2019, and SNI 6989.3.2019, respectively.

Results and Discussion

POME samples were taken from one of the primary ponds of palm oil mills located in Aceh Province using the grab sampling method of 20 L of waste water, then put into 2 plastic jerry cans with a capacity of 10 L each. The waste is then filtered and tested for initial quality. The initial waste analysis results are shown in Table 3.

The organic material and nutrient content in POME has organic material that has not been properly degraded and when it is disposed of into receiving water bodies it will result in a decrease in water and environmental quality. So that POME can be disposed of into the environment or water bodies, a processing process is needed which aims to reduce the BOD, COD, and oil content, increase the pH, increase the nutrient content and degrade organic matter (dissolved and suspended material). Alternative processing that can be done includes using Angsana leaf extraction as a natural coagulant.

Characteristics of POME

Table 3 shows the characteristics of POME used in this study. Table 3 shows that the pH level of POME meets the requirements for waste water quality standards with a pH level of 6.8. Where the quality standard was set at pH 6.0–9.0 (Regulation of the Minister of Environment of the Republic of Indonesia No. 5/2014). Likewise, the BOD level shows that the value meets the quality standard of 90.36 mg/L (BOD quality standard 100 mg/L). However, the COD and TSS content in wastewater was found to be above the quality standards with values of 1,917.28 mg/L and 648 mg/L respectively. This wastewater is not suitable for discharge directly into waters because the COD and TSS parameter levels exceed the quality standard limits or do not comply with the quality standards as regulated in the Minister of Environment Regulation on Waste Water Quality Standards No. 5/2014 and the Minister of Health Regulation No. 32/2017. Therefore, POME needs to be treated before being discharged into waters.

Table 3. Characteristics of POME

Parameters	Method	Results	Standard
pH	6989.11:2019	6.8	6.0 – 9.0
COD (mg/L)	SNI 6989.73:2019	1,917.28	350
BOD (mg/L)	SNI 6989.72:2009	90.36	100
TSS (mg/L)	SNI 6989.3:2019	648	250

The Effect of Solvents on POME Treatment

Ten liters of POME were treated using the coagulation-flocculation using natural coagulant from 50 grams of Angsana leaf extract. The coagulation process with fast stirring was carried out at a speed of 180 rpm for 5 minutes followed by a flocculation process with slow stirring at a speed of 80 rpm for 10 minutes. After the coagulation-flocculation process, the mixture was deposited for 30 minutes and continued with analysis of the levels of pH, COD, BOD and TSS parameters. Characteristics of POME after the coagulation-flocculation process shown in Table 4.

Table 4 Characteristics of POME After the Coagulation-Flocculation Process

Parameters	NaCl 0.25 M				Standard
	5 g	10 g	15 g	20 g	
pH	2	2	2	2	6.0 – 9.0
COD (mg/L)	847.5	1,233.4	1,376,5	1,459.4	350
TSS (mg/L)	6.74	4.84	3,80	1.64	250

Initial pH:6.8; COD:1,917.28mg/L; TSS:648mg/L

The effect of different solvents in extracting Angsana leaves at different doses on coagulation analysis. Angsana leaves act as primary coagulants at the maximum pH of POME, which is pH 2. From the POME treatment table with 0.25M Angsana leaf extraction at a dose of 5 grams achieved a decrease in COD of 55.79% Image and the highest turbidity removal of 99.75% at the optimal dose of 20,000 mg/L. While the extraction of 0.5 M Angsana leaf coagulant at a dose of 5 grams reached a decrease in COD of 46.54% with the highest turbidity reduction of 99.48% at the optimal dose of 20,000 mg/L. The optimal dosage for Angsana leaf coagulant since there is no significant increase in turbidity removal with the addition of further coagulants.

pH

Table 4 shows that the initial pH value before treatment on magnetic stirrer hotplate stirring is neutral (6.8) and after treatment of magnetic stirrer hotplate stirring and sedimentation, the pH value is still the same, which is 6.8. However, when added 8.5 g/L coagulant Angsana leaf, when coagulant interacts with wastewater, the pH remains in the range of 6-9, which is 6.8 with a stirring speed of 180 rpm for 5 minutes, slow stirring of 80 rpm for 10 minutes and the suspension is allowed to stand for 60 minutes. The optimum pH is set at range 2 using HCl 1M. After being processed with the coagulation-flocculation process using Angsana leaf extract there is an increase. The pH parameter value before treatment was 6.8 and after treatmen rised to 6.0. The increase in the pH parameter value was caused by the binding process of hydrogen ions (H^+) by Angsana leaf extract from the coagulation-flocculation process, so that the level of acidity decreases.

COD

Results showed that there was a difference in COD values after treatment caused by the content of chemical compounds contained in decomposed wastewater. POME contains mineral materials and organic matter mainly consists of nitrogen, ammonia, nitrate and nitrite materials. The amount of organic matter in wastewater increases the pollution load, high COD has an impact on oxygen deficit in the water, so ecosystems and aquatic plants can be damaged. High COD values indicate that water is polluted (Dewa et al., 2017). COD levels after the 0.25 M coagulation-flocculation process decreased with the highest percentage at K1 dose of 5 grams with a percentage of 55.79% as seen in Figure 1.

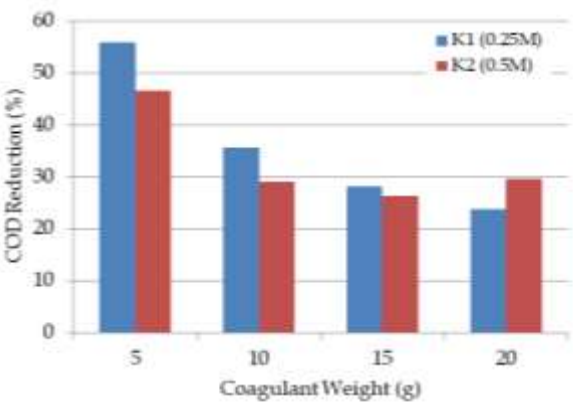

Figure 1. Reduction of COD in POME at various doses of NaCl and coagulant

The graph shows that the COD content of POME liquid waste has not met the requirements of wastewater quality standards, namely quality standards referring to the Regulation of the Minister of Environment of the Republic of Indonesia No. 5/2014 with a determined concentration of 350 mg/L. If the COD calculation results in waste samples exceed the threshold and do not meet quality standards, the impact will be on the ecosystem can be disrupted, and the creation of environmental imbalances. A high COD value indicates that more oxygen is used to break down inorganic compounds in the liquid, in other words the waste cannot be discharged into the environment without lowering its COD levels first.

In POME, there is an excess of COD levels above the quality standard threshold set by the government. in this case the author conducted a study using Angsana leaf extraction to determine the effectiveness in reducing COD levels. Where the extraction of Angsana leaves is gradually crushed into waste as much as 1 L. The method used in this process is the coagulation-flocculation method using Angsana leaf extract. The lowest yield from the use of Angsana leaf extraction at K1 with a dose of 20 grams was 23.88%. The decrease was very significant using a variable solvent NaCL 0.25 M at a dose of 5 g with a result of 847.55 mg/L. The percentage value of the decrease in the COD parameter is 55.79%. While at doses of 10, 15 and 20 grams are at a percentage below 50%. While in the variable solvent 0.5 M coagulant Angsana leaves for the best dose at a dose of 5 g amounted to 1,024.90 mg/L with a percentage value of 46.54%. Where at doses of 10, 15 and 20 grams are at a percentage below 30%. The decrease in COD parameter levels in POME is caused because Angsana leaf extract contains active substances that can help reduce the repulsive force between colloidal particles in water, so that COD parameter levels in POME decrease.

Total Suspended Solids (TSS)

TSS causes turbidity in water from insoluble solids and cannot settle directly. TSS consists of particles whose size and weight are smaller than sediments, e.g. clay, certain organic matter, cells of microorganisms, etc. The decrease in the total value of TSS or the increase in the percentage of reduction is caused by colloidal and suspension particles that have a stable electric charge after being added with coagulants and through the stirring process will become unstable and then combine with each other and form large floc and settle to the bottom (Suryanti et al., 2019). Figure 2 shows that TSS content in POME after treating Angsana leaf extract decreased that met the quality standards as required in the Regulation of the Minister of Environment of the Republic of Indonesia No. 5/2014 with a concentration set by the TSS quality standard of 250 mg/L.

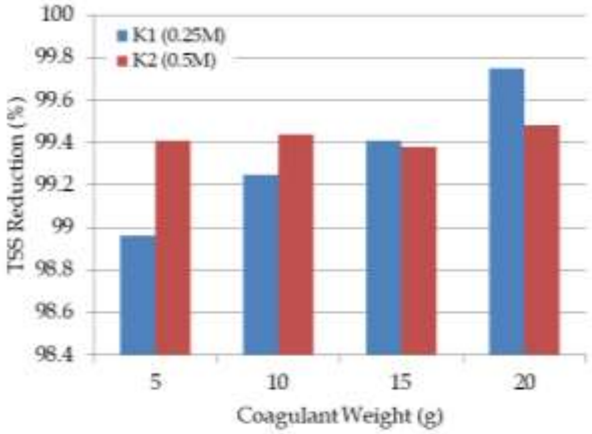

Figure 2. Reduction of TSS in POME at various doses of NaCl and coagulant

The results showed that the best TSS value in extraction of K1 0.25 M with the highest coagulant dose of 20,000 mg/l reached 99.75%, while with extraction of K2 0.5 M at a dose of 20,000 mg/l it reached 99.48%. TSS levels showed a decrease with different variations of Angsana leaf extraction in the 0.25M treatment for 60 minutes with the highest percentage of 99.75% at a dose of 20 grams. The lowest reduction percentage was obtained in 0.25M coagulant treatment for 60 minutes with a percentage of 98.96% at a dose of 5 grams. Furthermore, Figure 3 shows Ithe comparison of reduction of TSS and COD by coagulant from Angsana leaf extract.

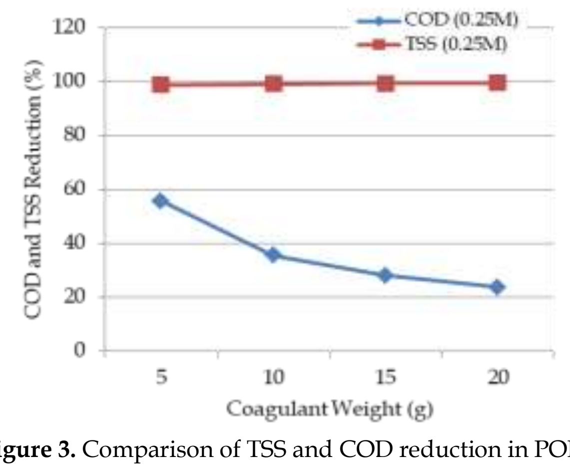

Figure 3. Comparison of TSS and COD reduction in POME after flocculation-coagulation process

FTIR Test

Results FTIR is infrared spectroscopy where the Fourier transform method is used to obtain infrared spectra in all wave numbers simultaneously. Then the structure was characterized by FTIR spectrophotometric measurements. Testing with FTIR spectrophotometry aims to analyze the functional groups contained in the extracted Angsana leaves. Fourier Transform Infrared Spectrophotometer (FTIR) The following figure shows the spectrum of the extracted Angsana leaves. The results of coagulant functional group of Angsana leaves by FTIR spectroscopy can be seen in Figure 4 and Figure 5.

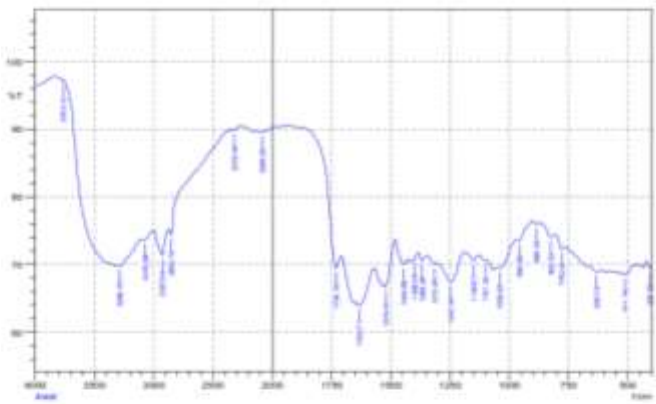

Figure 4. FTIR spectral analysis of Angsana leaf coagulant before contact with POME

Figure 4 shows FTIR spectroscopy with extraction of Angsana leaves before contact with POME, the most significant absorption peak is seen in the peak spectrum 3847.99 with an intensity of 91.383. Several peaks (absorption peaks) that appear in the FTIR spectrum of Angsana leaf extraction indicate that Angsana leaf coagulant has several types of bonds (functional groups). The results of identifying the type of functional group related to the FTIR spectral band are read at a certain wave number. Figure 5 shows FTIR spectral analysis of Angsana leaf coagulant after contact with POME.

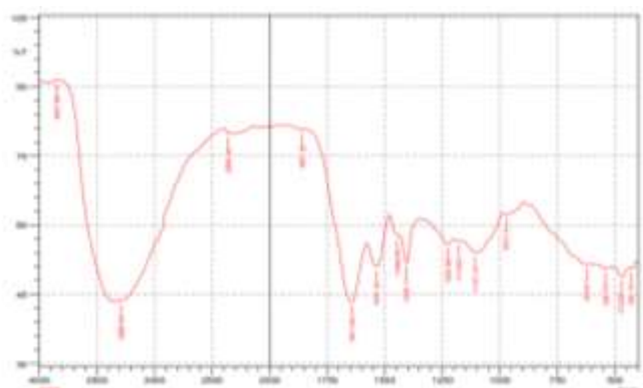

Figure 5. FTIR spectral analysis of Angsana leaf coagulant after contact with POME

Conclusion

This research results concluded that the coagulation-flocculation process using Angsana leaf powder was able to reduce COD by 55.79% at a coagulant dose of 5 g/L with 0.25 M NaCl solvent and TSS by 99.75% at a dose of 20 g/L with 0.25 M NaCl solvent. However, treatment using Angsana leaf extract was not able to reduce COD to the predetermined quality standard limits while the TSS value met the quality standard. Therefore, POME treatment still requires further processing.

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Author Contributions
Conceptualization: Elvitriana, M. Nazar, M. Nizar, Data curation: V. Viena, Funding acquisition: Suhendrayatna, Methodology: V. Viena, Visualization: Elvitriana, M. Nazar, M. Nizar, V. Viena, Suhendrayatna. Writing–original draft: M. Nazar, Suhendrayatna, Writing–review & editing: Elvitriana, Muhammad Nazar, Suhendrayatna.

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Conflicts of Interest
The authors declare no conflict of interest.

References

Abdullah, S., Mansor, A. A., Napi, N. N. L. M., Mansor, W. N. W., Ahmed, A. N., Ismail, M., & Ramly, Z. T. A. (2020). Air quality status during 2020 Malaysia Movement Control Order (MCO) due to 2019 novel coronavirus (2019-nCoV) pandemic. *Science of The Total Environment*, *729*, 139022. https://doi.org/10.1016/j.scitotenv.2020.139022

Awalludin, M. F., Sulaiman, O., Hashim, R., & Nadhari, W. N. A. W. (2015). An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews*, *50*, 1469–1484. https://doi.org/10.1016/j.rser.2015.05.085

Chan, Y. H., Cheah, K. W., How, B. S., Loy, A. C. M., Shahbaz, M., Singh, H. K. G., Yusuf, N. R., Shuhaili, A. F. A., Yusup, S., Ghani, W. A. W. A. K., Rambli, J., Kansha, Y., Lam, H. L., Hong, B. H., & Ngan, S. L. (2019). An overview of biomass thermochemical conversion technologies in Malaysia. *Science of The Total Environment*, *680*, 105–123. https://doi.org/10.1016/j.scitotenv.2019.04.211

Cherie, D., Makky, M., & Bahar, R. (2018). *Rekayasa Teknologi Long Range Detection Berbasis Machine Vision untuk Penentuan Umur Panen Optimum Tandan Buah Segar Kelapa Sawit secara Nondestructive berbasis Gimbal dan Android. Lembaga Riset/Perguruan Tinggi. Universitas Andalas*. Padang : LPPM Universitas Andalas.

Choong Lek, B. L., Peter, A. P., Qi Chong, K. H., Ragu, P., Sethu, V., Selvarajoo, A., & Arumugasamy, S. K. (2018). Treatment of palm oil mill effluent (POME) using chickpea (Cicer arietinum) as a natural coagulant and flocculant: Evaluation, process optimization and characterization of chickpea powder. *Journal of Environmental Chemical Engineering*, *6*(5), 6243–6255. https://doi.org/10.1016/j.jece.2018.09.038

Dewa, R., & Idrus, S. (2017). Identifikasi Cemaran Limbah Cair Industri Tahu di Kota Ambon. *Majalah BIAM*, *13*(2), 11. https://doi.org/10.29360/mb.v13i2.3544

Dominic, D., & Baidurah, S. (2022). Recent Developments in Biological Processing Technology for Palm Oil Mill Effluent Treatment—A Review. *Biology*, *11*(4), 525. https://doi.org/10.3390/biology11040525

Elvitriana, E., Munir, E., Delvian, D., & Wahyuningsih, H. (2021). Organic Substances Reduction in Palm Oil Mill Effluent (POME) After Cultivation with Locally Isolated Microalgae. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *80*(2), 98–105. https://doi.org/10.37934/arfmts.80.2.98105

Elvitriana, Munir, E., & Wahyuningsih, H. (2017). Degradasi Zat Organik Pada Limbah Cair Industri Kelapa Sawit Oleh Mikroalga Hijau. *Jurnal Serambi Engineering*, *01*(2), 109–113. https://doi.org/10.32672/jse.v1i2.497%0A

Elvitriana, Viena, V., & Muktamar, K. (2014). Green Microalgae Growth in Palm Oil Mill Effluent with Nutrient Addition of Urea. *Proceedings of International Conference on Natural and Environmental Science (ICONES)*, 180–184. Retrieved from https://jurnal.unsyiah.ac.id/ICONES/article/view/7046

Fatoni, I., Subiantoro, R., & Maryanti, M. (2020). Pengaruh Penggunaan Berbagai Koagulan Kimia Pada Limbah Cair Kelapa Sawit (Elaeis guineensis Jacq.) Terhadap Penurunan Beban Pencemar. *Jurnal Kesehatan Lingkungan: Jurnal Dan Aplikasi Teknik Kesehatan Lingkungan*, *17*(2), 63–72. https://doi.org/10.31964/jkl.v17i2.216

Fitria, A. N., Gunawan, V. S., & Mardiah, M. (2021). Study of the Utilization of Palm Oil Industry Liquid Waste. *Konversi*, *10*(1), 31– 40. https://doi.org/10.20527/k.v10i1.10146

Garritano, A. N., Faber, M. de O., De Sá, L. R. V., & Ferreira-Leitão, V. S. (2018). Palm oil mill effluent (POME) as raw material for biohydrogen and methane production via dark fermentation. *Renewable and Sustainable Energy Reviews*, *92*, 676–684. https://doi.org/10.1016/j.rser.2018.04.031

Hasanudin, U., & Haryanto, A. (2017). Karakteristik Pengolahan Limbah Cair Pabrik Minyak Kelapa Sawit Dalam Bioreaktor Cigar Semi Kontinu Characteristic of Palm Oil Mill Waste Water Treatment Using Semicontinue Anaerobic Cigar Bioreactor. *Teknik Pertanian Lampung*, *6*(2), 81–88. Retrieved from https://jurnal.fp.unila.ac.id/index.php/JTP/article/view/1705

Hosseini, S. E., & Abdul Wahid, M. (2015). Pollutant in palm oil production process. *Journal of the Air & Waste Management Association*, *65*(7), 773–781. https://doi.org/10.1080/10962247.2013.873092

Ilmannafian, A. G., Lestari, E., & Khairunisa, F. (2020). Pengolahan Limbah Cair Pabrik Kelapa Sawit dengan Metode Filtrasi dan Fitoremediasi Menggunakan Tanaman Eceng Gondok (Eichhornia Crassipes). *Jurnal Teknologi Lingkungan*, *21*(2), 244–253. https://doi.org/10.29122/jtl.v21i2.4012

Indonesia Investments. (2017). *Economic Growth Indonesia 2016*. Retrieved from https://www.indonesia-investments.com/news/todays-headlines/economic-growth-indonesia-gdp-at-5.02-in-2016-not-good-not-bad/item7587?

Kahar, P., Rachmadona, N., Pangestu, R., Palar, R., Triyono Nugroho Adi, D., Betha Juanssilfero, A., Yopi, Manurung, I., Hama, S., & Ogino, C. (2022). An integrated biorefinery strategy for the utilization of palm-oil wastes. *Bioresource Technology*, *344*, 126266. https://doi.org/10.1016/j.biortech.2021.126266

Kementerian Pertanian Republik Indonesia. (2020). *Rencana Strategis Kementerian Pertanian 2020-2024*.

Nutongkaew, P., Waewsak, J., Riansut, W., Kongruang, C., & Gagnon, Y. (2019). The potential of palm oil production as a pathway to energy security in Thailand. *Sustainable Energy Technologies and Assessments*, *35*, 189–203. https://doi.org/10.1016/j.seta.2019.07.002

Prapaspongsa, T., Musikavong, C., & Gheewala, S. H. (2017). Life cycle assessment of palm biodiesel production in Thailand: Impacts from modelling choices, co-product utilisation, improvement technologies, and land use change. *Journal of Cleaner Production*, *153*, 435–447. https://doi.org/10.1016/j.jclepro.2017.03.130

Ramadhan, M. B. A., Wardana, & Kahar, A. (2020). Pengaruh pH Terhadap COD, BOD Dan VFA Pada Pengolahan Limbah Cair Pabrik Kelapa Sawit Dalam Bioreaktor Anaerobik. *Prosiding Seminar Nasional Kimia Berwawasan Lingkungan*, 69–74. Retrieved from http://jurnal.kimia.fmipa.unmul.ac.id/index.php/prosiding/article/view/992

Ruhmawati, T., Sukandar, D., Karmini, M., & Roni S., T. (2017). Penurunan Kadar Total Suspended Solid (TSS) Air Limbah Pabrik Tahu Dengan Metode Fitoremediasi. *Jurnal Permukiman*, *12*(1), 25. https://doi.org/10.31815/jp.2017.12.25-32

Sadhukhan, J., Martinez-Hernandez, E., Murphy, R. J., Ng, D. K. S., Hassim, M. H., Siew Ng, K., Yoke Kin, W., Jaye, I. F. M., Leung Pah Hang, M. Y., & Andiappan, V. (2018). Role of bioenergy, biorefinery and bioeconomy in sustainable development: Strategic pathways for Malaysia. *Renewable and Sustainable Energy Reviews*, *81*, 1966–1987. https://doi.org/10.1016/j.rser.2017.06.007

Sukiran, M. A., Abnisa, F., Wan Daud, W. M. A., Abu Bakar, N., & Loh, S. K. (2017). A review of torrefaction of oil palm solid wastes for biofuel production. *Energy Conversion and Management*, *149*, 101–120. https://doi.org/10.1016/j.enconman.2017.07.011

Suryanti, T., Ayu Ambarwati, D., Udyani, K., & Purwaningsih, D. Y. (2019). Penurunan Kadar BOD dan COD Pada Limbah Cair Industri Batik Dengan Metode Gabungan Koagulasi Dan Adsorpsi. *Seminar Nasional Sains Dan Teknologi Terapan VII - Institut Teknologi Adhi Tama Surabaya*, *I*(1), 113–118. Retrieved from http://ejurnal.itats.ac.id/sntekpan/article/view/662

Tan, Y. D., & Lim, J. S. (2019). Feasibility of palm oil mill effluent elimination towards sustainable Malaysian palm oil industry. *Renewable and Sustainable Energy Reviews*, *111*, 507–522. https://doi.org/10.1016/j.rser.2019.05.043

The World Bank. (2016). *Indonesian Demographics Data*. Retrieved from http://databank.worldbank.org/data/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=IDN

Vasanthi, S. (2019). *Opuntia cactus sebagai bio-koagulan baru untuk pengolahan Limbah Pabrik Kelapa Sawit (LCPKS)*.