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Integrating ammonium-based polymer with phytoremediation for phosphate and chemical oxygen demand reduction in palm oil mill effluent

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ABSTRACT

Environmental pollution caused by the palm oil industry is a severe problem. In palm oil production, liquid waste is obtained as palm oil mill effluent containing COD and phosphate, which can pollute aquatic ecosystems and soil. Phytoremediation technology with modification using ammonium-based polymer adsorbents effectively reduces palm oil mill effluent contaminants. This study aimed to test the effectiveness of phytoremediation and adsorption modification technology using ammonium-based polymer adsorbents to consider environmentally friendly and economical reducing pollutants in palm oil mill effluent. *Vetiveria zizanioides* plants were cultivated in floating treatment wetlands, and the planting media was varied using ammonium-based polymer to treat palm oil mill effluent with a volume of 3 L. The performance of the modified reactor in degrading COD and phosphate was examined by monitoring the floating treatment wetlands for 9 days and measuring the physiochemical parameters. Variations in ammonium-based polymer showed optimal performance using a lower ratio of 0.3. This combination of technologies removed COD by around 77.3% with an adsorption capacity of 558.4 mg/g and phosphate by around 59.5% with an adsorption capacity of 2.77 mg/g within nine days. These results could be elaborated on with tertiary treatment for future treatment to enhance removal according to the quality standards of the Ministry of Environment and Forestry in Indonesia.

Keywords: adsorption, ammonium polymer, chemical oxygen demand, palm oil mill effluent, phosphate, phytoremediation.

INTRODUCTION

Palm oil is Indonesia's largest plantation commodity, and the plantation area is growing very rapidly (Listiningrum et al., 2022). In 2015, the estimated CPO (crude palm oil) production was around 31 million tons, increasing to 46 million tons in 2020 and 47 million tons in 2023, with a productivity of 2.79 million tons/million hectares. In 2023, substantial production was supported by a rise in oil palm plantations, which cover 16.8 million hectares and comprise areas from smallholder plantations, government plantations, and private plantations (Ministry of Agriculture Indonesia, 2024). The development of the palm oil industry has had a positive impact on society because it provides job opportunities, but on the other hand, it has also had a severe negative impact caused by CPO production activities (Shahputra and Zen, 2018).

In the operational activities of industry, palm oil is only produced in 20% of fresh fruit bunches (FFB), and the remaining 80% is disposed of as waste (Kramanandita et al., 2014; Suksong et al., 2020). In general, 1 ton of fresh FFB produces around 0.5–0.75 tons of palm oil mill effluent (POME) and 0.2–0.3 tons of empty fruit bunches (EFB) (Abnisa et al., 2013; Irvan, 2018). POME is a brown liquid consisting of 95–96% water, 0.6–0.7% oil and 2–4% suspended solids with characteristics as in Table 1.

Various POME treatments have been implemented in industry, such as chemical treatment, membrane filtration, and aerobic and anaerobic, which are considered adequate in degrading pollutants in POME (Mohammad et al., 2021; Zainal et al., 2017). However, the weakness of the existing technology is that it is too expensive, has high energy consumption and is not environmentally friendly (Abdurahman et al., 2011; Liew et al., 2015; Wu et al., 2010). Phytoremediation is a green technology using plants and can be used as an alternative to POME processing. This technology is considered efficient, economical, simple, and aesthetic (Lakshmi et al., 2017; Nedjimi, 2021). A variety of plants have been tested that can be used to degrade POME pollutants, such as *salvinia molesta* (Ng and Chan, 2017), *eichhornia crassipes* (Tan et al., 2019), *chrysopogon zizanioides* (Darajeh et al., 2014), *ipomoea aquatica forsk* (Zulfahmi et al., 2021), *scirpus grossus* (Sa'At et al., 2022), *pennisetum purpureum* (Osman et al., 2020), etc. However, the drawback of the phytoremediation technology is that it is limited to several types of pollutants and requires long time in the pollutant degradation process.

Adsorption is the most common technique and is quite effective and economical in degrading pollutants in water and wastewater. The most commonly used adsorbent is activated carbon. However, many studies have been conducted over the past few years using various adsorbents for wastewater purification (Singh et al., 2018). One type of adsorbent developed is ammonium-based polymer, a cationic polymer applied for pollutant degradation in wastewater. The ammonium-based polymer operates as an anion exchanger, effectively reducing phosphate, nitrate, and nitrite ions in wastewater (Aini et al., 2023; Rahayu, Jamilatun, et al., 2023). This ammonium-based polymer has also been successfully applied to the stationary phase of capillary system chromatography for fast and short separation and detection of phenol and pyrocatechol levels (Rahayu et al., 2021).

This study aimed to observe the performance of a combination of modified technologies using cationic polymers to degrade phosphate ions and COD from POME wastewater. This study conducted a series of mass effect tests of polymer used to understand the mechanisms involved in phosphate degradation and COD. To the best of authors' knowledge, this could be the first time that a modified phytoremediation technology with adsorption using advanced materials in the form of ammonium-base polymers for the degradation of phosphate ions and COD in POME has been implemented.

EXPERIMENTAL

Synthesis of ammonium-base polymer and characterization

The ammonium–based polymer was prepared based on previous research that the polymerization stage was carried out by preparing a mixed solution of 1.25 mL of META, 0.375 mL of EDMA, 1.75 mL of isopropyl alcohol, 0.35 mL of ethanol, 1.4 mL of PEG, and 2 mg AIBN (Rahayu et al., 2023). The homogenized solution was poured into a cylindrical tube, and then the polymerization was carried out at 70 °C for 12 hours in a water bath. The obtained polymer was rinsed with methanol to remove the remaining reaction and cooled. According to previous research, polymer characterization analysis was also carried out using FTIR, SEM, BET, and elemental analysis (Rahayu et al., 2023).

Modified phytoremediation system and setup

Ten FTWs (floating treatment wetlands) reactors with duplo system were prepared in modified plastic containers with dimensions of (L = 28 cm; W = 20 cm; H = 16 cm), with each treatment in the reactor consisting of 6 *vetiveria zizanioides* stems that had their roots and stems cut. Six–month–old plants purchased from nurseries had their stems cut to a distance of 15 cm from the roots before being cultivated. Modifications were made to the planting media. Plants were grown in plastic cups containing a mixture of soil, polymer and gravel with a detailed configuration as in Table 2 and Figure 1. At the bottom of the plastic cup, holes are made on the bottom and sides to facilitate contact between plant roots and wastewater. FTWs are placed at 28 ± 2°C with sufficient sunlight intensity. The plants were then acclimatized in 3 L of tap water and given hydroponic fertilizer (P_2O_5 2.0%, Fe 0.10%, Vitamin B1 0.10%, and NAA 0.04%). Acclimatization lasted for 21 days, then the water was replaced with POME. The POME used in this

Table 1. POME characteristics

Parameters	Unit	Average Raw POME Quality[1]	Discharge Standard Limit		
			Indonesia[2]	Malaysia[3]	Thailand[4]
Temperature	°C	80–90	NG		
pH	-	3–5	6–9	5–9	5–9
BOD	mg/L	10,250–43,750[a]	100[b]	100[a]	20[b]
COD	mg/L	15,000–100,000	350	NG	120
TSS	mg/L	5,000–54,000	250	400	50
Oil and Grease	mg/L	130–18,000	25	50	5
Nitrogen	mg/L	180–1,400[c]	50[c]	200[d]	200[d]
Phosphate	mg/L	91–131	NG	NG	NG
Potassium	mg/L	1281–1982	NG	NG	NG
Calcium	mg/L	276–405	NG	NG	NG
Magnesium	mg/L	254–344	NG	NG	NG
Iron	mg/L	254–344	NG	NG	NG

Note: [1](Kamyab et al., 2018; Soo et al., 2022) ; [2](Ministry of Environment and Forestry, 2014) ; [3](The Commissioner of Law Revision, 1982) ; [4]The Enhancement and Conservation of the National Environmental Quality Act B.E. 2535, 1992 in (Tan et al., 2022) ; [a]BOD_5 ; [b]BOD_3 ; [c]Total N ; [d]Total Kjeldahl N ; NG = not given.

Table 2. Experimental setup of FTWs

Reactor	Treatment	Mass ratio comparison		
		Soil	Polymer	Gravel
A	Control	-	-	-
B	Phytoremediation without polymer	0.6	-	0.4
C1	Phytoremediation with polymer	0.3	0.5	0.2
C2	Phytoremediation with polymer	0.3	0.4	0.2
C3	Phytoremediation with polymer	0.3	0.3	0.2

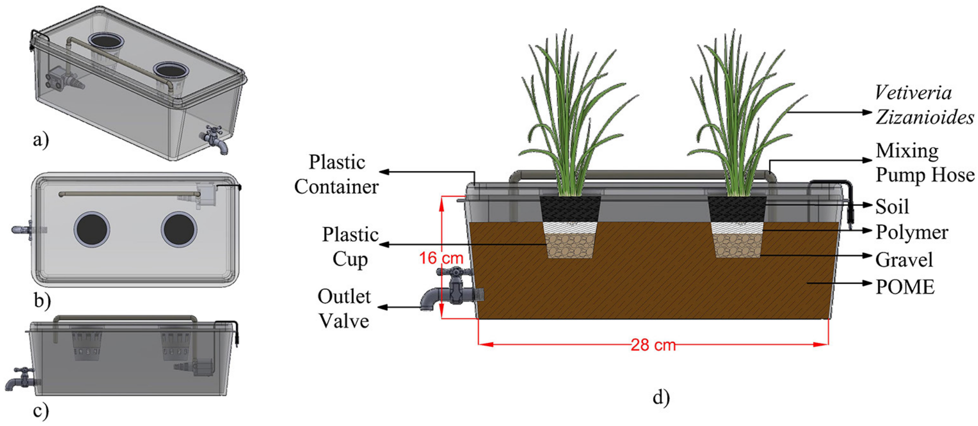

Figure 1. Reactor configuration at: (a) 3D view, (b) top view, (c) side view, (d) experimental setup

study was diluted ten times using demineralized water, with initial COD 421.05 mg/L, phosphate 1.6 mg/L, pH 6.62, and TDS 912 mg/L. Furthermore, FTWs were run for 9 days while maintaining wastewater quality for pH, TDS, and temperature parameters. Physicochemical parameters were analyzed following the Indonesian National Standards for Water and Wastewater, which refer to the Standard Methods for Examination of Water and Wastewater, American Public Health Association (Environmental and Forestry Instrument Standardization Agency, 2023).

Analysis removal of COD and phosphate

The adsorption step occurs in the polymer part according to the varying amount of polymer. Adsorption isotherm balance was carried out to determine the maximum adsorption capacity (*qe*) for COD and PO_4^3. To calculate adsorption capacity, Equation 1 is employed, while Equation 2 calculates adsorption efficiency. The adsorption efficiency (*RE*) and capacity (*qe*) values at equilibrium are expressed in (mg/g) and (%), respectively:

$$q_e = \frac{(C_0 - C_e) \times V}{W} \quad (1)$$

$$RE = \frac{(C_0 - C_e) \times 100\%}{C_0} \quad (2)$$

where: *W* – the weight of adsorbent (gram), *V* – the volume of solution (Liter), *Co* – initial concentration of the adsorbate solution (mg/L) and *Ce* – equilibrium concentration (mg/L).

RESULT AND DISCUSSION

Physical parameter

The performance of physical parameters during the treatment process is shown in Table 3. Physical concentrations fluctuated during the treatment process in each reactor.

TDS, temperature, and pH levels between C1, C2 and C3 (Phytoremediation combined with adsorbent) as well as FTW control in reactors A and B did not show significant differences ($p > 0.05$). During the initial treatment, palm oil mill effluent has a pH close to neutral, around 6.62, then changes to a pH of around 8 (low alkaline) at the end of treatment. According to Watharkar et al. (2015) consumption of organic compounds by plants and bacteria in the root zone can cause changes in pH and the release of ions through various mechanisms. Then, all FTW reactors showed high TDS levels and small TDS reductions. The reduction levels did not differ significantly during 9 days of treatment. The high TDS levels in palm oil mill effluent were caused by the fresh fruit bunch extraction process, which carried organic content, such as ions and oil compounds into the palm oil mill effluent.

Effect amount of polymer

Effect of polymer ratio on COD removal

Determining the optimum conditions in combining phytoremediation and adsorption systems involves several factors, one of which is the mass of the polymer used. On the basis of the results, Figure 2 illustrates the reactor performance in degrading COD contained in POME. The removal efficiency of COD pollutants fluctuated in all FTWs reactors. Reactors showed significant differences, especially in reactor A (control without plant) and other FTWs. Reactor A showed a decrease in COD concentration (removal 6.1%), which may be caused by the influence of living organisms and the remaining surface oxygen in the wastewater. This case is the same as the study conducted by Bala et al. (2014). The reduction of pollutants in POME can occur due to microorganisms in the POME itself, such as *Bacillus cereus, Micrococcus luteus* and *Stenotrophomonas maltophilia*.

On the other hand, reactor B showed a decrease in COD concentration (39.2% removal), which was caused by the degradation process carried out by *Vetiveria zizanioides*. The results of this study are comparable to the research conducted by Darajeh et al. (2017), which studied the COD degradation ability in POME with low concentrations for 4 weeks; they reported that the ability of *Vetiveria zizanioides* COD in the first week was around 20–30%. The comparison

Table 3. Physical parameters of POME with various treatments

Parameter	pH	TDS (mg/L)	Temperature (°C)
A	8.11[a] ± 0.38	826[a] ± 0.10	27,91[d] ± 0.19
B	8.71[a] ± 0.22	853[d] ± 0.15	26,23[c] ± 0.22
C1	8.84[a] ± 0.35	867[e] ± 0.11	26,97[ab] ± 0.31
C2	8.50[a] ± 0.28	851[c] ± 0.19	25,90[b] ± 0.20
C3	8.31[a] ± 0.31	845[b] ± 0.16	26,64[a] ± 0.20

Note: The values are mean of physical sampling for 9 days treatment. The values in symbol ± indicate standard error. Comparison between treatments were analyzed with one way ANOVA at 5% level of significance. Means in the same column followed by the same letter are not significantly different.

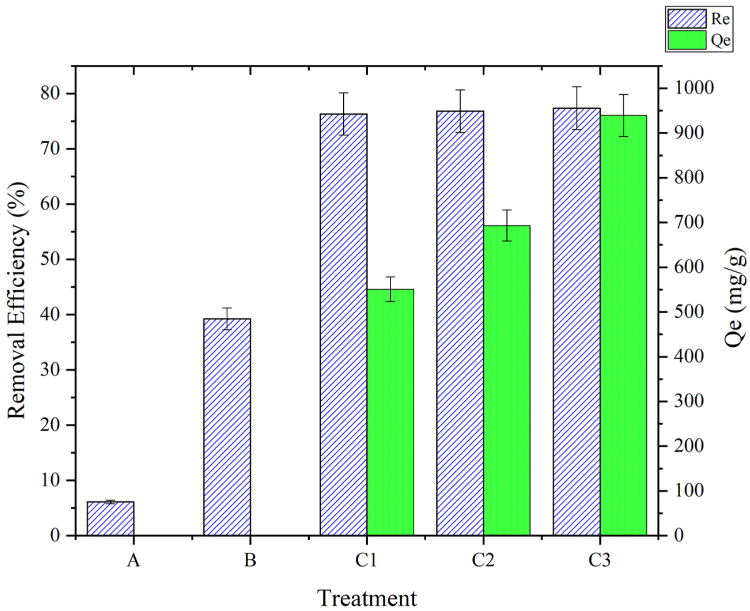

Figure 2. The effect amount of polymer on COD removal efficiency and adsorption capacity.
The different treatments were A (control POME only), B (control POME and plant), C1 (POME, plant and polymer, polymer ratio: 0.5), C2 (POME, plant and polymer, polymer ratio: 0.4), C3 (POME, plant and polymer, polymer ratio: 0.3), Qe means adsorption capacity

results with other studies showed that the range of COD reduction was between 30% to 80%, for various macrophytes and retention times used. Then, Tan et al. (2019) studied POME treatment using *Eichhornia crassipes* with various POME concentrations for 21 days; they reported a COD reduction of around 25%. Therefore, Ujang et al. (2018) studied POME treatment using *Napier Grass* for 21 days; they reported a COD reduction of about 72%.

Furthermore, the modified reactor showed that the mass of the polymer used affected the

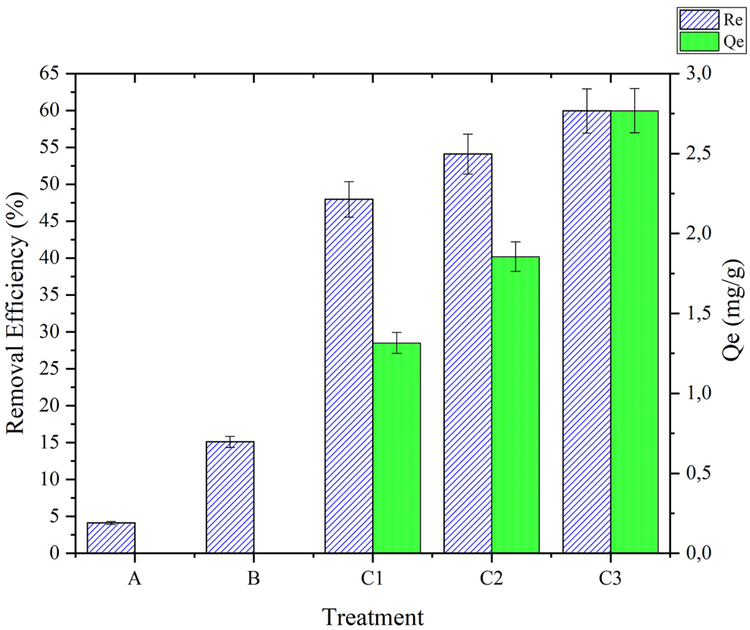

Figure 3. The effect amount of polymer on phosphate removal efficiency and adsorption capacity.
The different treatments were A (control POME only), B (control POME and plant), C1 (POME, plant and polymer, polymer ratio: 0.5), C2 (POME, plant and polymer, polymer ratio: 0.4), C3 (POME, plant and polymer, polymer ratio: 0.3), Qe means adsorption capacity

degradation of pollutants in wastewater. Reactor C3 (polymer ratio 0.3) showed the highest COD removal efficiency of 77.4% with an adsorption capacity of 939.6 mg/g) and this is the optimum condition for variations in the polymer ratio. This shows that the presence of plants and polymers as adsorbents can improve the performance of the reactor in degrading pollutants. In general, increasing the mass of the adsorbent will increase the number of active groups in absorbing pollutants (Bhuvaneshwari et al., 2011). This is because the more significant the mass of adsorbent used, the greater the surface area available, so there are more active sites on the polymer that can bind pollutant ions (Mahvi et al., 2023). However, this research is not linear; based on the study conducted by (Gorzin and Abadi, 2018; Safri et al., 2022), the use of adsorbents that are too high will, on the contrary, reduce adsorption performance and reduce the adsorption balance.

The polymer ratio greatly affects the reactor performance in COD and phosphate reduction, because the greater the amount of polymer, the less the adsorption capacity. Table 4 shows the BET analysis carried out using two types of experimental replicates for each.

According to the BET analysis, the use of excessive adsorbent can close the pores of the adsorbent, thereby reducing the effective surface area of the adsorbent and also making it difficult for adsorbate molecules to access and diffuse into the pores of the adsorbent. Fewer adsorbate molecules can be bound with less surface area, thus reducing the overall adsorption capacity.

Effect of polymer ratio on phosphate removal

Then, the ability of phosphate degradation can be seen in Figure 3. Phosphate degradation in reactor A is around 4%. This degradation is caused by aerobic microorganisms that utilize the remaining surface oxygen content in wastewater. Phosphate decomposition by microorganisms is lesser compared to processing using plants (Wang et al., 2012). Phosphate removal in reactor B was around 15.1%, which was caused by plant activity in carrying out the phytodegradation mechanism; this mechanism is used for several organic materials that can pass through the protective barrier of the rhizosphere zone in the roots (Dorafshan et al., 2023). The results of phosphate degradation in this study are in line with the research conducted by (Mahmoudpour et al., 2021), which studied the potential of *Vetiveria zizanioides* in degrading pollutants in synthetic wastewater for one month; they reported a decrease in phosphate on the tenth day of around 15% under phytoremediation conditions without using aeration.

The phosphate degradation in the modified reactor shows that the optimum phosphate degradation is at the lowest polymer ratio, 0.3 in the C3 reactor. The phosphate degradation mechanism is carried out by *Vetiveria zizanioides* and the polymer as an adsorbent. Phosphate degradation in the C3 reactor is around 59.9%, with an adsorption capacity of 2.77 mg/g. This result is linear with the research of Aini et al. (2023), who studied phosphate degradation in aqueous solutions using only polymers; they found that phosphate degradation could reach 67%. The results are slightly different, because the adsorbent used was a modification of cacao with grafted functional monomers directly containing quaternary ammonium for phosphate absorption in an aqueous solution with an N content of 3.86%.

In contrast, this study used POME with a reasonably high matrix that affected the removal percentage. The result of the N content based on elemental analysis was 1.22%. This also indicates that the study is quite linear when viewed from the contribution of ammonium polymer, which is comparable to the phosphate degradation ability of the tested samples. Additionally, the uneven condition of POME impacts the distribution of contaminants, which serve as a nutrient source for plants, resulting in suboptimal nutrient absorption by plant roots (Baiyin et al. 2021). In addition, it also affects the contact between the contaminant

Table 4. BET analysis

Parameter	Treatment		
	C1	C2	C3
Surface area (m^2/g)	11.46 ± 6.168	29.84 ± 21.831	34.91 ± 11.929
Pore volume (cc/g)	0.03 ± 0.017	0.08 ± 0.064	0.12 ± 0.063
Pore size (nm)	2.19 ± 0.001	1.94 ± 0.001	2.07 ± 0.126

Note: each value is the mean of two replicates. The values in the symbol ± indicate standard error.

and the adsorbent, leading to adsorption efficiency (Sarkar et al., 2021).

Effect of detention time

Effect of detention time on COD removal

The effect of residence time can be seen in Figures 4 and 5. It can be observed that the amount of chemical oxygen demand that is degraded increases along with residence time in each reactor (Figure 4 and Table 3). The performance of COD pollutant degradation in reactor A is not very significant. From the first day to the ninth day, unstable degradation occurs. Until the ninth day, only a removal efficiency of around 6.1% was obtained. While in reactor B, there was continuous COD removal until the ninth day, a COD removal efficiency of around 39.2% was obtained.

Meanwhile, in reactors C1, C2, and C3, the optimum condition was found in reactor C3, which used the lowest polymer ratio, 0.3. In reactor C3, COD removal efficiency was very significant from the first to the ninth day compared to reactors A and B. The mechanism of COD removal in phytoremediation technology is due to the relationship between macrophytes and microorganisms in the rhizosphere. Macrophytes provide growth media and an aerobic environment for the roots, and microorganisms degrade organic pollutants, such as COD.

Then, continuous COD degradation was obtained from the modified reactor's first to the ninth day. Until the ninth day, the optimum COD degradation results were obtained in the C3 reactor with a removal efficiency of 77.4%. These results indicate combining phytoremediation and adsorption is better than using phytoremediation alone. The results of this study are in line with Siswoyo et al. (2019), who studied the removal of COD in laundry waste using a combination of phytoremediation and adsorption using *Pistia stratiotes* and *Eichhornia crassipes* plants as well as adsorbents taken from the sludge of drinking water treatment plants. The study showed that detention time significantly influenced the pollutant degradation process until day 15, showing a COD reduction result of 77.5%.

Effect of detention time on phosphate removal

Figure 5 and Table 5 show that each reactor has a fluctuating reduction and detention time. In reactor A, a significant decrease in phosphate occurred from the first to the third day, but from day 5 to day 9, the phosphate content increased.

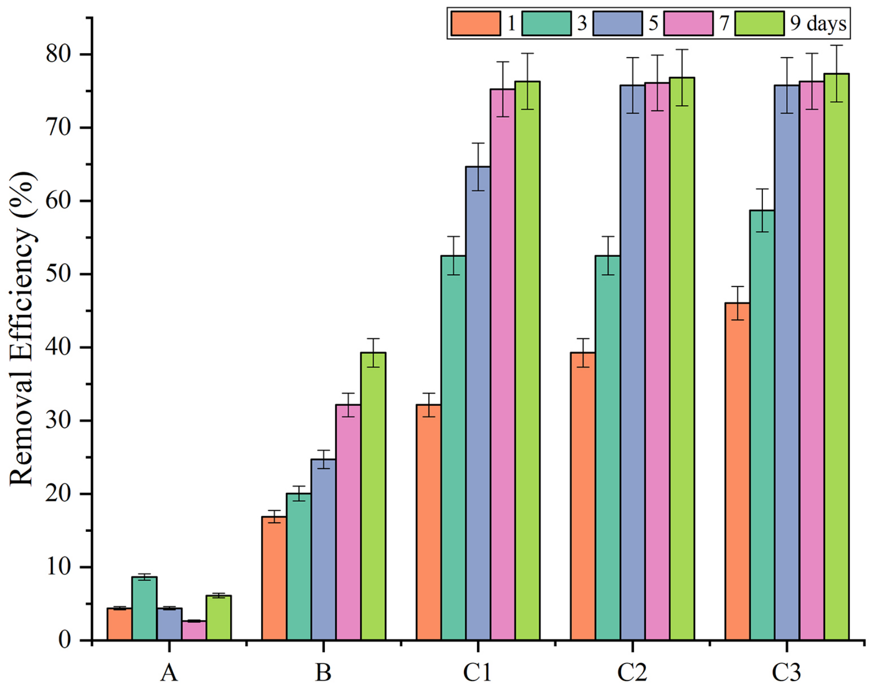

Figure 4. The effect of detention time on COD removal efficiency. The different treatments were A (control POME only), B (control POME and plant), C1 (POME, plant and polymer, polymer ratio: 0.5), C2 (POME, plant and polymer, polymer ratio: 0.4), C3 (POME, plant and polymer, polymer ratio: 0.3)

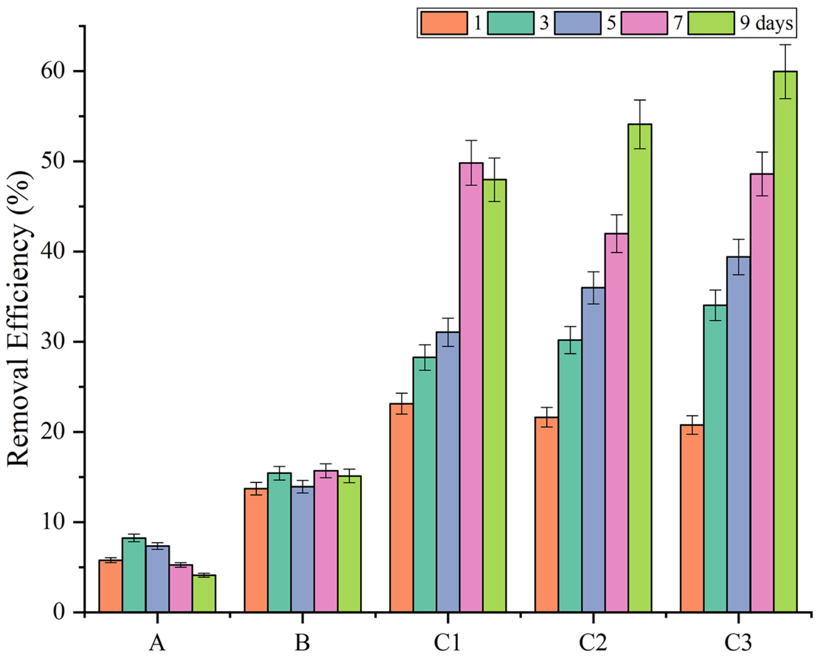

Figure 5. The effect of detention time on phosphate removal efficiency. The different treatments were A (control POME only), B (control POME and plant), C1 (POME, plant and polymer, polymer ratio: 0.5), C2 (POME, plant and polymer, polymer ratio: 0.4), C3 (POME, plant and polymer, polymer ratio: 0.3)

Table 5. Pollutant adsorption capacity with various treatments

Detention time (Days)	COD adsorption capacity (mg/g)			Phosphate adsorption capacity (mg/g)		
	C1	C2	C3	C1	C2	C3
1	232.0	354.1	559.0	0.63	0.74	0.96
3	378.9	473.7	712.9	0.78	1.04	1.57
5	466.5	683.6	920.2	0.85	1.23	1.82
7	543.0	686.5	926.7	1.37	1.44	2.24
9	550.7	693.2	939.6	1.32	1.86	2.77

On the 9th day, only 4.1% of phosphate was successfully removed. The degradation process is influenced by microorganisms that consume the residual surface oxygen found in wastewater. These microbes use some phosphates for their metabolic processes, decreasing the phosphate concentration in the waste. However, when the remaining surface oxygen has run out, the processing conditions will change to anaerobic, which will certainly also affect the biological performance of these microorganisms in reducing phosphate. After the population of microorganisms reaches its peak and begins to decline due to changes in environmental conditions, the decomposition process of dead organisms can release phosphate back into the wastewater. This causes an increase in dissolved phosphate levels again (Azni et al., 2022; Zhang et al., 2023). Then, in reactor B, there was no significant phosphate degradation from day 1 to day 9. Until day 9, only phosphate degradation of 15.1% was obtained. This decrease is certainly due to the ability of *vetiveria zizanioides* to degrade various pollutants, including phosphate. Then, compared to the modified reactor, the highest phosphate removal was in reactor C3, around 59.9%. This proves that combining phytoremediation and adsorption in a detention time of 9 days can reduce phosphate better than phytoremediation alone. This parallels the study by Türker and Baran (2018), which examined the degradation of boron pollutants in drinking water through a combination of phytoremediation with Lemna Gibba plants and chitosan-based adsorbents. The study showed a reduction in boron that could reach 50% up to a detention time of 4 days. The detention time is very influential and essential for plant roots to absorb pollutants as nutrients. It also allows microorganisms in the rhizosphere area to participate in degradation. An increase in detention time will initially increase the contact time with the polymer as an adsorbent, enabling the adsorbent to absorb more pollutants (Hadiyanto et al., 2014).

Detention time in the context of combined phytoremediation and adsorption refers to the length of time a pollutant or substrate is in contact with the system. Both phytoremediation and adsorption are greatly influenced by the length of this contact time in degrading pollutants. The longer the retention time, the more pollutants can be absorbed by plant roots and translocated to other parts of the plant. Then, the more adsorbate molecules can attach to the surface of the adsorbent. However, it should be remembered that there is an optimal detention time in the phytoremediation and adsorption processes, which achieves good plant growth conditions and maximum adsorption equilibrium.

Characterization of polymers

Fourier transform infrared spectroscopy (FTIR) has been conducted to determine the functional groups contained in the polymer before and after waste treatment application. The FTIR results for the polymer used before and after POME treatment can be seen in Figure 6. Figure 6 shows several peaks found in the ammonium polymer before and after the adsorption process. The first peak is located at wave number 1148 cm^{-1}, followed by waves number 1241 cm^{-1}, 1642 cm^{-1} in the third peak, 2960 cm^{-1} in the fourth peak, and 3357 cm^{-1} in the fifth peak. The peaks in this graph that appear before POME processing are not very prominent or pointed. The C-O adsorption area (stretched) is the adsorption area at wave number 1025–1150 cm^{-1}. The C-N adsorption area (amine) is identified by the adsorption area at wave number 1020–1250 cm^{-1}.

Moreover, the N-H absorption region (amine) is indicated by the absorption area at wave number 1580–1650 cm^{-1}. The functional monomer that was utilized contributes to this amine group. The absorption region denotes the C-H absorption area (stretching) at wave number 2853–2962 cm^{-1}. The O-H group absorption area is then indicated by the absorption area at wave number 3000–3600 cm^{-1} (Rahayu et al., 2021; Silverstein et al., 2005). The peaks produced in the FTIR analysis showed a significant difference in the sharpness of the peaks in the polymer groups before and after treatment. All functional groups in the ammonium polymer, especially those related to the amine group itself, are used as strong anion exchangers. This indicates that the ammonium polymer is effectively used to adsorb pollutant ions contained in POME.

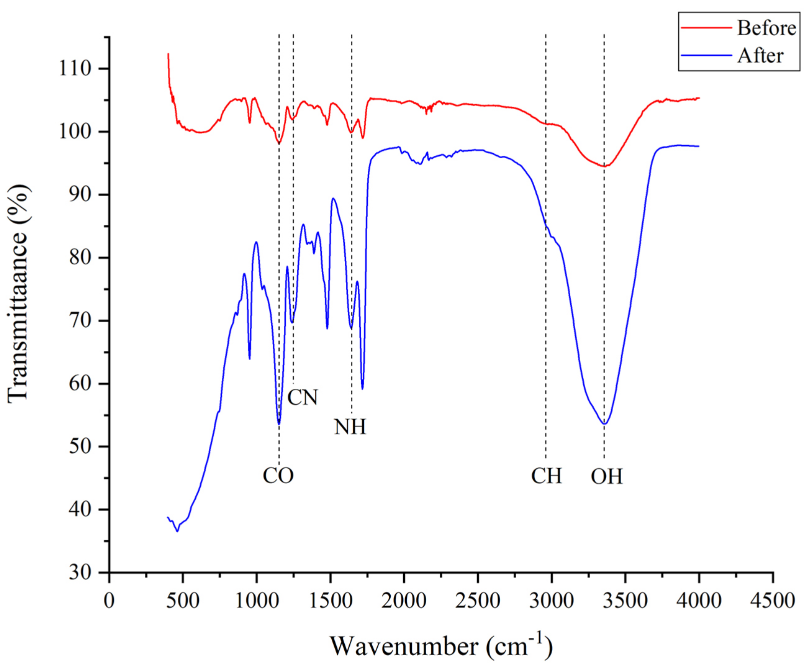

Figure 6. Fourier transform infrared (FTIR) of polymer before and after treatment (C3)

Table 6. The percentage of weight of H, C, N in ammonium polymer (C3)

Treatment	Unit	Component		
		H	C	N
Before	% wt	7.5738	43.0472	2.8715
After		2.4999	14.0224	1.2228

Furthermore, elemental analysis was used to measure the weight percentage of C, H, and N in the ammonium polymer before and after processing, as seen in Table 6. The weight percentage of the C component in ammonium polymer after treatment is smaller than before POME wastewater treatment.

This is because some organic contaminants containing carbon may be adsorbed on the surface of the adsorbent and bind to the carbon in the adsorbent. After treatment, these contaminants may be released or removed, reducing the carbon content of the original adsorbent. Then, the weight percentage of the N and H components in ammonium polymer after treatment is more significant than before the POME treatment. This indicates that ammonium polymer containing nitrogen and hydrogen acts as a strong anion exchanger as a NH_4^+. Furthermore, this strong anion exchanger has the potential to react with negative sites of pollutant ions in POME, one of which is known to be phosphate (PO_4^{3-}).

CONCLUSIONS

This study successfully investigated the relationship between floating treatment wetlands (FTWs) and adsorption using ammonium-based polymers to treat high contaminants in POME. Floating treatment wetlands using *Vetiveria zizanioides* modified with ammonium polymer with a 0.3 ratio in the reactor reduced COD and phosphate by 77.3% and 59.9%, respectively. Elemental analysis showed 1.2228% of the polymer weight for N content in the reactor and 34.91 ± 11.929 m^2/g for the surface area of polymers in the optimum reactor. POME can be processed into an environmentally friendly and economical waste treatment system by combining phytoremediation with the adsorbents from ammonium-base polymers. Therefore, further research on the parallelization system between FTW and adsorption needs to be conducted to determine the system's effectiveness, which will be implemented later.

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