

Clarifying Tropical Peat Water Using Chitosan–PAC: From Practical Dose Tuning to Solvent-Controlled Efficiency

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Tropical peat water is difficult to clarify because of its intense colour, colloidal content, and high concentration of oxidisable organic matter. This study evaluated polyaluminium chloride (PAC) and chitosan as single coagulants and as a combined coagulation system, with particular attention to PAC and chitosan dosage and the acid medium used for chitosan preparation. Jar tests were conducted using natural peat water. PAC and chitosan used individually produced their highest observed turbidity removals at 20 mg L⁻¹, reaching 96.93% and 97.46%, respectively. In the broad PAC–chitosan dose evaluation, 5 mg L⁻¹ PAC combined with 0.2 mg L⁻¹ chitosan produced 97.8% turbidity removal, whereas higher PAC dosages reduced treatment performance. In the low-dose solvent comparison, chitosan dissolved in 2% (v/v) acetic acid generally produced higher and more consistent turbidity removal than chitosan dissolved in 2% (v/v) HCl. The highest observed removals were 99.21% for the acetic-acid system at 1 mg L⁻¹ PAC and 98.01% for the HCl system at 5 mg L⁻¹ PAC. Oxidisable organic-matter removal was lower than turbidity removal, with a maximum of 33.23% at 5 mg L⁻¹ PAC and 0.2 mg L⁻¹ chitosan. These findings indicate that low PAC dosages combined with chitosan prepared in acetic acid provided the most favourable turbidity-removal performance among the tested conditions, while oxidisable organic matter remained more difficult to remove.

Keywords: Tropical peat water, PAC-chitosan system, turbidity removal, organic removal, solvent effect

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Peatland areas in Indonesia represent the largest tropical peat zones, covering approximately 21 million hectares distributed across various regions, particularly in Sumatra (43%), Kalimantan (32%), and Papua (25%) [1]. One of the distinguishing features of peat water is its high color intensity (reddish-brown), strong acidity (low pH), elevated concentration of organic compounds, and low turbidity [2]. The level of organic matter in peat water can be visually observed from its color, the darker the color, the higher the concentration of organic content [3]. A large proportion of South Kalimantan consists of peatlands, where high color and turbidity levels make peat water physically unsuitable as a source of clean water. Nevertheless, peat water can be treated into consumable clean water through proper treatment processes. This condition has prompted the development of innovative approaches in peat water treatment to ensure its feasibility as a safe water resource[4].

One of the widely applied peat water treatment methods is coagulation. Coagulation is a physicochemical process commonly used in conventional water treatment plants. Its performance

is significantly influenced by the characteristics of the raw water. Among the most frequently used coagulants for removing suspended particles and natural organic matter (NOM) is polyaluminium chloride (PAC). However, an excessive dose of PAC may lead to the presence of undesirable residual aluminium, which can cause post-treatment turbidity due to aluminium precipitation. Furthermore, aluminium residues may pose health hazards such as neurological damage such as Alzheimer's disease [5]. Hence, improving coagulation performance while simultaneously minimizing aluminium residue is a practical issue that needs serious consideration, particularly for raw water with low turbidity levels. For this reason, the development of efficient, non-toxic coagulant aids or organic coagulants is highly anticipated.

Chitosan (Chit), as a natural bio-flocculant derived from crustacean shells, has gained attention due to its renewability, biodegradability, and lack of secondary pollution [6]. The combined use of PAC and chitosan may improve coagulation performance because the two materials contribute through complementary mechanisms. PAC mainly promotes

charge neutralisation and floc formation through hydrolysed aluminium species, whereas chitosan contributes through adsorption and interparticle polymer bridging. Previous studies have reported that PAC–chitosan systems can form larger and more settleable flocs and provide higher turbidity removal than PAC alone. Jia and Wang reported that the addition of chitosan increased turbidity removal by 17.9% compared with PAC alone [7], while Zhang et al. associated the improved performance with charge neutralisation by polymeric aluminium species and interparticle bridging by chitosan [8]. The effectiveness of PAC–chitosan systems for NOM removal may nevertheless depend on the characteristics of the raw water and the organic compounds present [9].

Previous studies have demonstrated the use of PAC and chitosan as coagulants for river water treatment [10] and reported the influence of acetic acid and hydrochloric acid on the performance of chitosan as a single coagulant for peat water treatment [11]. However, the effect of the acid medium used for chitosan preparation in a PAC–chitosan co-coagulation system for tropical peat water has received limited evaluation. This study therefore evaluates chitosan dissolved in acetic acid and HCl, both as a single coagulant and as a coagulant aid with PAC, based on turbidity and oxidisable organic-matter removal. The results are expected to support the development of more effective coagulation strategies for organic-rich peat water while reducing the required PAC dosage.

EXPERIMENTAL

Chemicals and Materials

All chemicals used in this study were of analytical reagent grade and were used without further purification. Polyaluminium chloride (PAC) was employed as the primary inorganic coagulant, while chitosan powder (degree of deacetylation approximately 75–85%) served as a bio-based coagulant aid. The chitosan was dissolved in either acetic acid (CH_3COOH , 98%) or hydrochloric acid (HCl, 37%) to prepare 2% (v/v) acid solutions for evaluating solvent effects. Potassium permanganate (KMnO_4), sulfuric acid (H_2SO_4), and oxalic acid ($\text{H}_2\text{C}_2\text{O}_4$) were used for the determination of the permanganate index, representing the oxidizable organic content of the water sample. Distilled water was used for all dilutions and solution preparations throughout the experiments.

All reagents were obtained from Merck (Germany). The raw peat-water samples were collected from a drainage channel near SMA Banua Gambut, located in Banjar District, South Kalimantan, Indonesia, an area characterized by acidic peat soil and dark-colored surface water. The samples were stored in sealed polyethylene containers and maintained

at 4 °C prior to use to prevent microbial alteration of organic matter.

Apparatus

Standard glassware was used throughout the study. Major instruments included a VELP Scientifica JLT-6 Jar Tester (6 paddles), Lutron TU-2016 Turbidimeter, Ohaus PA224 Analytical Balance, and a magnetic stirrer for chitosan dissolution.

Sampling and Study Location

Peat-water samples were collected from the drainage channel in front of SMA Banua Gambut, Banjar District, South Kalimantan (Indonesia). Sampling was carried out in clean polyethylene containers, transported to the laboratory within 3 hours, and stored at 4 °C before analysis. All laboratory experiments were conducted between June and October 2023 in the Inorganic Chemistry Laboratory (FMIPA) for reagent preparation and in the Environmental Engineering Laboratory (Faculty of Engineering, ULM) for coagulation–flocculation, turbidity, and organic-content analysis.

Preparation of Coagulant and Co-Coagulant Solutions

PAC was used as the primary coagulant. A 1000 mg L^{-1} PAC stock solution was prepared by dissolving 1.0 g of PAC in distilled water and diluting the solution to a final volume of 1.0 L. Appropriate aliquots of the stock solution were added to the peat-water samples to obtain the required final PAC dosages in the jar-test experiments.

Chitosan was used as a natural coagulant aid. Separate chitosan stock solutions were prepared using 2% (v/v) acetic acid (Chit-AA) and 2% (v/v) hydrochloric acid (Chit-HCl). For each preparation, 1.0 g of chitosan was added to the corresponding acid solution and diluted to a final volume of 100 mL. The mixture was stirred magnetically until a homogeneous solution was obtained, producing a 1% (w/v) chitosan stock solution. Appropriate aliquots or dilutions were subsequently used to obtain the required final chitosan dosages. All solutions were used within one week of preparation.

Coagulation-Flocculation Procedure

All coagulation–flocculation experiments were conducted using 500 mL of peat-water sample placed in 1 L beakers on a six-unit jar-test apparatus. Individual-coagulant tests were initially performed to evaluate the dose-response behaviour of PAC and chitosan. PAC and chitosan were separately applied at final dosages of 5, 10, 20, 50, and 100 mg L^{-1} . The combined PAC–chitosan system was then evaluated

using PAC dosages of 5, 10, 20, 50, and 100 mg L⁻¹ and chitosan dosages of 0.2, 0.4, 0.6, 0.8, and 1.0 mg L⁻¹.

The effect of the acid medium used to prepare chitosan was evaluated by comparing chitosan dissolved in 2% (v/v) acetic acid (Chit-AA) with chitosan dissolved in 2% (v/v) hydrochloric acid (Chit-HCl). In the individual-coagulant tests, Chit-AA and Chit-HCl were evaluated at dosages of 1, 5, 10, 50, and 100 mg L⁻¹. In the combined treatments, PAC was applied at 1, 5, and 10 mg L⁻¹, while Chit-AA or Chit-HCl was added at 0.2, 0.4, 0.6, 0.8, and 1.0 mg L⁻¹.

For the combined treatments, PAC and chitosan were added simultaneously at the beginning of the rapid-mixing stage. The samples were rapidly mixed at 200 rpm for 1 min, followed by slow mixing at 40 rpm for 15 min to promote floc formation. The suspensions were then allowed to settle undisturbed for 30 min. After sedimentation, the supernatant was carefully withdrawn from a sampling point approximately 4 cm below the water surface using a syringe, without disturbing the settled flocs. The collected supernatant was immediately analysed for turbidity and oxidisable organic matter, expressed as the permanganate index.

Analytical Methods

Turbidity and permanganate index were measured before and after the coagulation–flocculation treatment. Turbidity was determined using a Lutron TU-2016 Turbidimeter and expressed in nephelometric turbidity units (NTU). The efficiency of turbidity removal was calculated using the following formula [12]:

$$\text{Turbidity removal efficiency (\%)} = \frac{T_o - T_t}{T_o} \times 100 \%$$

Where T_o is the initial turbidity of the untreated peat water, and T_t is the turbidity after coagulation–flocculation treatment.

The permanganate index, expressed as KMnO₄ consumption and used as an operational indicator of oxidisable organic matter in peat water, was determined according to SNI 06-6989.22-2004 [13]. A 100 mL water sample was transferred into an Erlenmeyer flask and acidified with 5 mL of 8 N sulfuric acid. The sample was then treated with 10 mL of 0.01 N KMnO₄ and heated for 10 min. After heating, 10 mL of 0.01 N oxalic acid was added, and the remaining oxalic acid was titrated with 0.01 N KMnO₄ until a persistent pale-pink colour was obtained. The permanganate index in mg L⁻¹ KMnO₄ was calculated using:

$$\text{Permanganate index (mg L}^{-1} \text{ KMnO}_4\text{)}$$

$$= \frac{[(10 + a)b - (10c)] \times 31.6 \times 1000}{d} \times f$$

where a is the volume of KMnO₄ used in the final titration (mL), b is the normality of KMnO₄, c is the normality of oxalic acid, d is the sample volume (mL) and f is the dilution factor.

A decrease in the permanganate index after treatment was interpreted as the removal of oxidisable organic matter. Accordingly, the organic-matter removal efficiency was calculated from the reduction in the permanganate index using:

$$\begin{aligned} \text{Oxidisable organic matter removal efficiency (\%)} \\ = \frac{PI_o - PI_t}{PI_o} \times 100 \% \end{aligned}$$

where PI_o is the initial permanganate-index of untreated peat water, and PI_t is the permanganate index after coagulation–flocculation treatment.

Data Processing

The observed turbidity and permanganate-index values were converted into removal percentages and evaluated descriptively across the tested PAC and chitosan dosages. The performance of PAC alone, chitosan alone, and the combined PAC–chitosan system was compared based on the observed treatment responses. The influence of the acid medium used for chitosan preparation was assessed by comparing the removal profiles obtained using chitosan dissolved in 2% (v/v) acetic acid and 2% (v/v) hydrochloric acid at corresponding PAC and chitosan dosages.

RESULTS AND DISCUSSION

Raw Peat-Water Characteristics

The untreated peat water collected from Banjar District, South Kalimantan, was dark brown, as commonly observed for water affected by the presence of humic and fulvic acids leached from decomposing peat soils [14, 15]. Representative visual changes during the PAC–chitosan coagulation–flocculation process are shown in **Figure 1**. Before sedimentation, the treated peat water remained yellowish and contained dispersed flocs (**Figure 1a**). After sedimentation, a clearer supernatant and visible floc deposits were observed at the bottom of the beakers (**Figure 1b**). These photographs provide qualitative evidence of floc formation and settling, while treatment performance was quantified using turbidity and permanganate-index measurements.

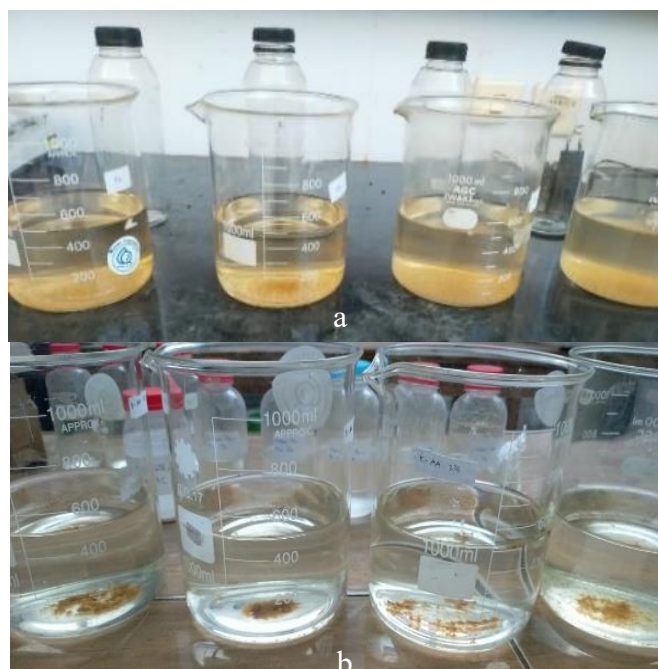


Figure 1. Representative visual appearance of peat water (a) peat water during coagulation–flocculation and (b) after PAC–chitosan coagulation–flocculation followed by sedimentation. The treated water showed a clearer supernatant and visible floc deposition at the bottom of the beaker.

The initial turbidity of the raw water (13.36–16.56 NTU) exceeded the Indonesian drinking-water limit of 5 NTU [16]. These values fall within the moderate turbidity range typically observed in peat-draining waters in Indonesia and Malaysia, where suspended colloids are stabilised by negatively charged organic macromolecules [15]. The oxidisable organic matter content, expressed as permanganate index (492–647 mg L⁻¹ KMnO₄), was extremely high and far above the national standard of 10 mg L⁻¹. Such elevated organic loads are characteristic of tropical peat waters, which are dominated by humic substances originating from peat decomposition processes [17, 18].

Baseline Coagulation with PAC

The effects of PAC dosage on turbidity and oxidisable organic matter removal are presented in **Table 1**. Turbidity removal increased from 84.13% at 5 mg L⁻¹ to 96.93% at 20 mg L⁻¹, which was the highest removal obtained among the PAC dosages tested. This increase may be associated with improved destabilisation of negatively charged colloidal particles as the PAC dosage increased. Miranda et al. [19] reported that monomeric and polymeric aluminium species can neutralise the negative surface charge of colloidal particles and promote floc formation. The improvement observed between 5 and 20 mg L⁻¹ is therefore consistent with charge neutralisation as one of the coagulation mechanisms.

Table 1. Coagulation performance of PAC in peat water treatment based on turbidity and organic matter removal.

PAC dose (mg L ⁻¹)	Initial Turbidity = 13.36		Initial Permanganate index = 647 mg L ⁻¹ KMnO ₄	
	Turbidity (NTU)	Turbidity removal efficiency (%)	Permanganate index (mg L ⁻¹ KMnO ₄)	Oxidisable Organic-matter removal efficiency (%)
5	2.12	84.13	477	26
10	1.77	86.75	497	23
20	0.41	96.93	502	22
50	2.58	80.69	482	26
100	17.60	–31.74	472	27

At PAC dosages above 20 mg L⁻¹, turbidity removal decreased to 80.69% at 50 mg L⁻¹ and became

negative at 100 mg L⁻¹. The negative removal value indicates that the final turbidity was higher than that of the untreated water. Similar responses have been reported under PAC-overdosed conditions [20–22]. Excess coagulant may saturate particle surfaces and promote charge reversal, thereby reducing particle aggregation and allowing previously destabilised particles to remain suspended. The result at 100 mg L⁻¹ therefore suggests possible particle restabilisation or floc disruption, although surface-charge measurements would be required to confirm the mechanism.

In contrast, the removal efficiency of oxidisable organic matter varied only slightly across the tested PAC dosages, ranging from 22% to 27%. Increasing the PAC dosage therefore did not produce a corresponding improvement in oxidisable organic matter removal. PAC may preferentially remove particulate and colloidal matter, whereas some dissolved organic compounds in peat water may remain in the treated water because they are less readily incorporated into the coagulated flocs [15]. PAC produced the highest turbidity removal at 20 mg L⁻¹, while the removal of oxidisable organic matter remained within a narrow range across the tested dosages.

Coagulation with Chitosan

The performance of chitosan as a single coagulant is summarised in Table 2. Even at the lowest dosage of 5 mg L⁻¹, chitosan showed strong coagulation activity for peat water, achieving 88.92% turbidity removal. The removal efficiency increased to 95.58% at 10 mg L⁻¹ and reached the highest value of 97.46% at 20 mg L⁻¹, but then decreased to 89.82% and

70.51% at 50 and 100 mg L⁻¹, respectively. At suitable dosages, the protonated –NH₃⁺ groups of chitosan can neutralise the negative charge of suspended particles, while its long polymeric chains promote interparticle bridging and floc formation. However, excessive chitosan may oversaturate the particle surfaces, producing steric hindrance and repulsive interactions that reduce effective bridging and may lead to floc restabilisation and breakage [23][24]. This mechanism explains why chitosan produced high turbidity removal at 5–20 mg L⁻¹ but showed lower performance at 50–100 mg L⁻¹. At corresponding dosages, chitosan generally produced higher turbidity removal than PAC alone, which may be attributed to the combined effects of charge neutralisation and polymer bridging.

Oxidisable organic-matter removal efficiency ranged from 2.32% to 28.59%. At chitosan dosages of 5–20 mg L⁻¹, the removal efficiency ranged from 20.09% to 28.59%, with the highest value obtained at 20 mg L⁻¹. The amine groups of chitosan can form hydrogen bonds and electrostatic interactions with organic acids such as humic and fulvic substances, facilitating their incorporation into the formed flocs [25]. However, the removal efficiency decreased sharply to 3.09% and 2.32% at chitosan dosages of 50 and 100 mg L⁻¹, respectively. This decline may be associated with excessive polymer coverage, which reduces effective particle bridging and limits the removal of dissolved organic matter.

These results show that chitosan was effective for turbidity removal at dosages of 5–20 mg L⁻¹. The removal of organic matter was also highest at 20 mg L⁻¹ but decreased substantially at higher chitosan dosages.

Table 2. Coagulation performance of chitosan in peat water treatment based on turbidity and organic matter removal.

Chitosan dose (mgL ⁻¹)	Initial Turbidity = 13.36		Initial Permanganate index = 647 mg L ⁻¹ KMnO ₄	
	Turbidity (NTU)	Turbidity removal efficiency (%)	Permanganate index (mg L ⁻¹ KMnO ₄)	Oxidisable Organic matter removal efficiency (%)
5	1.48	88.92	507	21.64
10	0.59	95.58	517	20.09
20	0.34	97.46	462	28.59
50	1.36	89.82	627	3.09
100	3.94	70.51	632	2.32

Table 3. Final turbidity of peat water after coagulation–flocculation using various combinations of PAC (5–100 mg L⁻¹) and chitosan (0.2–1.0 mg L⁻¹).

Chitosan dosage mg L ⁻¹	Initial turbidity = 16.56 NTU				
	Final turbidity after PAC-chitosan treatment (NTU)				
	PAC 5 mg L ⁻¹	PAC 10 mg L ⁻¹	PAC 20 mg L ⁻¹	PAC 50 mg L ⁻¹	PAC 100 mg L ⁻¹
0.2	0.37	0.53	1.53	4.52	9.15
0.4	2.77	1.51	2.95	7.01	8.33
0.6	2.21	2.89	3.93	5.41	8.43
0.8	1.80	2.83	4.60	10.28	17.44
1.0	1.17	2.48	4.94	14.78	18.67

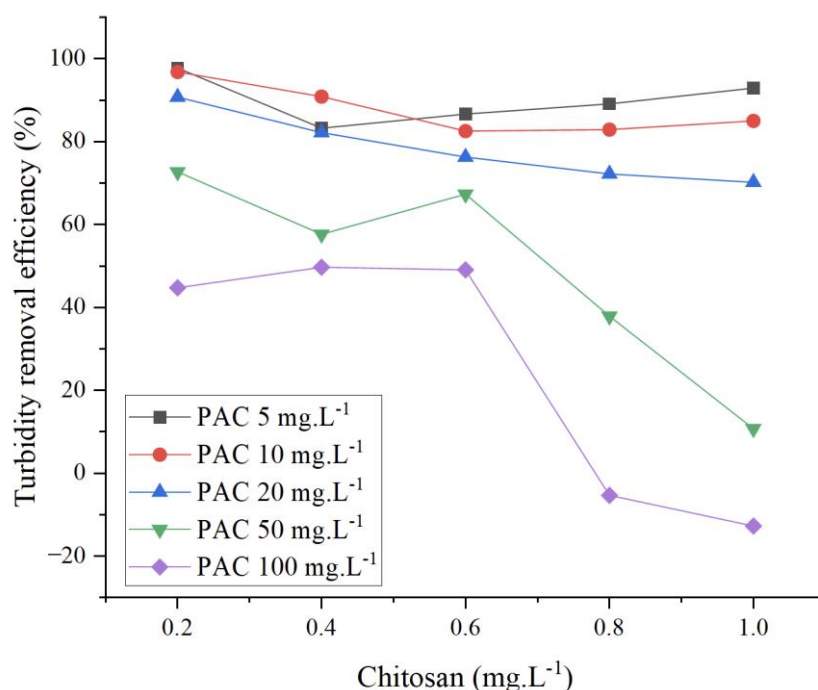


Figure 2. Effect of chitosan dosage (0.2–1.0 mg L⁻¹) on the turbidity removal efficiency of peat water at PAC dosages of 5 (black), 10 (red), 20 (blue), 50 (green), and 100 (purple) mg L⁻¹. Removal efficiency was calculated relative to the initial turbidity of 16.56 NTU.

Combined PAC-Chitosan System (Co-Coagulation Performance)

The combined use of PAC (5–100 mg L⁻¹) and chitosan (0.2–1.0 mg L⁻¹) is summarised in **Table 3**, while the corresponding turbidity removal efficiencies calculated from these data are shown in **Figure 2**. With an initial turbidity of 16.56 NTU, the system showed better performance at the lower PAC dosages. At 5–10 mg L⁻¹ PAC, the addition of chitosan produced final turbidity values ranging from 0.37 to 2.89 NTU, corresponding to removal efficiencies of 82.5–97.8%. The best performance was achieved

using 5 mg L⁻¹ PAC and 0.2 mg L⁻¹ chitosan, which reduced the turbidity to 0.37 NTU and resulted in 97.8% removal. When the PAC dosage was increased to 20 mg L⁻¹, the final turbidity increased to 1.53–4.94 NTU, corresponding to removal efficiencies of approximately 70.2–90.8%. At 50–100 mg L⁻¹ PAC, the final turbidity increased sharply to 4.52–18.67 NTU, and the removal efficiency decreased accordingly. Negative removal efficiencies were observed at 100 mg L⁻¹ PAC combined with 0.8–1.0 mg L⁻¹ chitosan, indicating that the treated water had a higher turbidity than the untreated water. These results show that

increasing the PAC dosage beyond the effective range reduced the performance of the PAC–chitosan system.

The high turbidity removal obtained at low PAC dosage agrees with previous studies showing that chitosan can improve PAC coagulation performance when used as a coagulant aid. A CTS/PAC system applied to low-temperature and low-turbidity source water achieved 86.32% turbidity removal, which was 17.9% higher than that obtained using PAC alone [7]. Another optimised PAC–chitosan system achieved 99.85% turbidity removal, indicating that high removal can be obtained while limiting the amount of inorganic coagulant used [26]. Although the water characteristics and operating conditions differed from those of the present study, these findings support the use of chitosan to enhance PAC coagulation at relatively low PAC dosages.

Mechanistically, the performance of the PAC–chitosan system can be explained by the combined roles of aluminium species and polymer bridging. Aluminium species in PAC are commonly classified as Al_a , Al_b , and Al_c , representing predominantly monomeric, polymeric and colloidal or precipitated aluminium species, respectively [27, 28]. At suitable PAC dosages, Al_b , which includes polymeric aluminium species such as Al_{13} , may neutralise the negative charge of humic substances and reduce electrostatic repulsion. This mechanism is supported by the zeta-potential observations reported by Jia and Wang, which indicated that PAC primarily acts through charge neutralisation [7]. Meanwhile, Al_c and chitosan may contribute to interparticle bridging, producing larger and more settleable flocs, as reported by Zhang et al [8]. However, when PAC is overdosed, the excessive presence of Al_a and Al_b species can reverse the surface charge of particles, causing restabilisation [29]. Excessive chitosan may likewise increase steric repulsion and disrupt bridging, which

explains the decline in coagulation performance at high doses.

Oxidisable organic-matter removal efficiency showed a narrower response than turbidity removal. The final permanganate-index values are presented in **Table 4**, while the corresponding removal efficiencies calculated from these data are shown in **Figure 3**. Starting from an initial permanganate index of $492 \text{ mg L}^{-1} \text{ KMnO}_4$, the final values after PAC–chitosan treatment ranged from 397 to $422 \text{ mg L}^{-1} \text{ KMnO}_4$, corresponding to removal efficiencies of 14.23–19.31%. The highest observed removal of 19.31% was obtained at several treatment combinations, including 5 mg L^{-1} PAC with 1.0 mg L^{-1} chitosan, 20 and 50 mg L^{-1} PAC with 0.8 mg L^{-1} chitosan, and 100 mg L^{-1} PAC with 0.2 or 0.8 mg L^{-1} chitosan. Increasing either the PAC or chitosan dosage did not produce a consistent improvement in permanganate-index removal. This observation is consistent with Nti et al. [22], who reported that excessive PAC saturates particle surfaces and inhibits flocculation.

De-Paz-Arroyo et al. [29] demonstrated that chitosan can interact directly with $-\text{COOH}$ and $-\text{OH}$ groups of natural organic matter and bind simultaneously with aluminium species, forming larger, more compact flocs. This mechanism may explain the contribution of chitosan dosage to organic-matter removal in the combined system. The observed performance of the PAC–chitosan system can be described through three main mechanisms: (i) charge neutralization by polymeric aluminium species (Al_b), (ii) sweep flocculation by $\text{Al}(\text{OH})_3$ precipitates (Al_c) and (iii) polymer bridging by chitosan. The system performed best at low PAC dosages, whereas excessive PAC or chitosan reduced the coagulation performance and may have promoted particle restabilisation. In contrast, permanganate-index removal remained low across the tested PAC chitosan combinations, ranging only from 14.23% to 19.31%.

Table 4. Organic matter concentration (permanganate index) of peat water after coagulation–flocculation using various combinations of PAC ($5\text{--}100 \text{ mg L}^{-1}$) and chitosan ($0.2\text{--}1.0 \text{ mg L}^{-1}$).

Chitosan dosage (mg L^{-1})	Initial permanganate index = $492 \text{ mg L}^{-1} \text{ KMnO}_4$				
	Final permanganate index after PAC–chitosan treatment ($\text{mg L}^{-1} \text{ KMnO}_4$)				
	PAC 5 mg L^{-1}	PAC 10 mg L^{-1}	PAC 20 mg L^{-1}	PAC 50 mg L^{-1}	PAC 100 mg L^{-1}
0.2	417	422	417	407	397
0.4	422	412	422	412	412
0.6	417	417	417	407	407
0.8	412	412	397	397	397
1.0	397	407	407	412	402

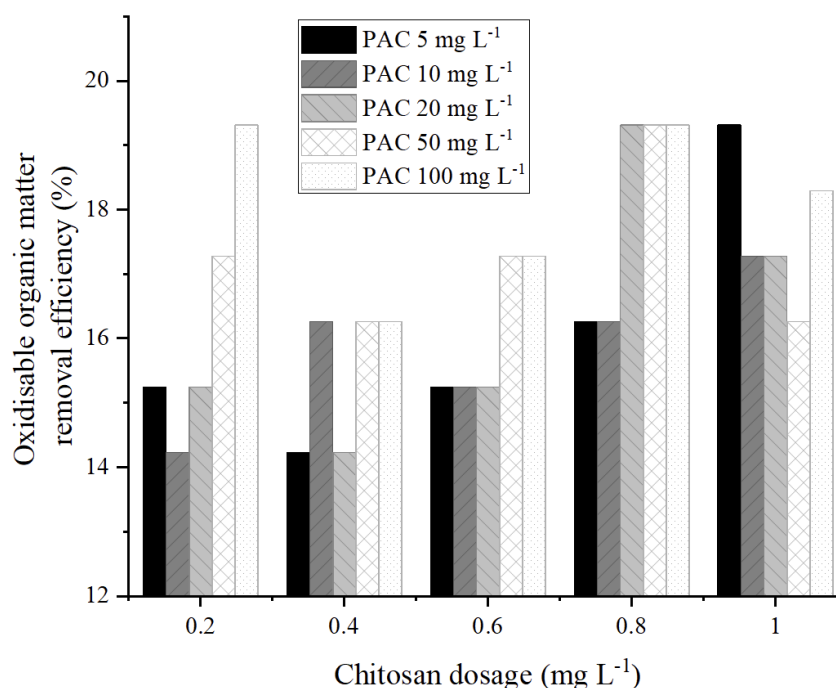


Figure 3. Effect of chitosan dosage (0.2–1.0 mg L⁻¹) on the removal of organic matter (permanganate index) at PAC dosages of 5, 10, 20, 50, and 100 mg L⁻¹.

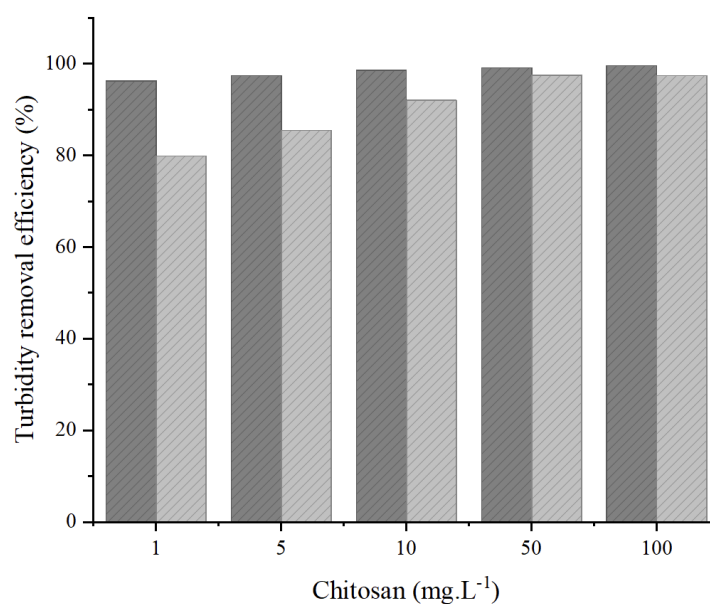


Figure 4. Comparison of turbidity removal efficiency obtained using chitosan dissolved in 2% (v/v) acetic acid (Chit-AA; black bars) and 2% (v/v) hydrochloric acid (Chit-HCl; grey bars) at chitosan dosages of 1, 5, 10, 50, and 100 mg L⁻¹.

Effect of Solvent Type on Chitosan Performance

The performance of chitosan was further evaluated by comparing chitosan dissolved in 2% (v/v) acetic acid and 2% (v/v) hydrochloric acid. The effects of

the acid medium on turbidity and oxidisable organic-matter removal are presented in **Figures 4 and 5**, respectively. **Figure 4** shows that chitosan dissolved in acetic acid (Chit-AA) produced higher turbidity removal than chitosan dissolved in HCl (Chit-HCl) at

all tested dosages. At 1 mg L⁻¹, Chit-AA achieved approximately 96% turbidity removal, whereas Chit-HCl achieved approximately 80%. The difference between the two preparations gradually decreased as the chitosan dosage increased. At 50–100 mg L⁻¹, both preparations produced turbidity removal above 97%, although Chit-AA remained slightly higher. These results indicate that the acid medium had a greater effect on chitosan performance at lower dosages.

The higher turbidity removal obtained using Chit-AA is consistent with previous findings for peat-water coagulation reported by Irawati et al. [11]. The difference may be related to the protonation environment produced by each acid medium. Acetic acid may provide sufficient protonation of the amine groups while maintaining a polymer conformation that supports charge neutralisation and interparticle bridging. Chitosan prepared in HCl showed lower removal at the lower dosages, suggesting that the different protonation conditions may affect the interaction between chitosan chains and suspended particles. At higher dosages, turbidity removal approached a plateau for both preparations, indicating that further chitosan addition produced only a limited improvement after particle destabilisation had been achieved.

The oxidisable organic-matter removal pattern shown in **Figure 5** differed from the turbidity-removal behaviour. At chitosan dosages of 1–10 mg L⁻¹, both preparations showed relatively low removal efficiencies of approximately 17–21%, with only small differences between Chit-AA and Chit-HCl. The highest removal was obtained at 5–10 mg L⁻¹, after which the efficiency decreased sharply at higher dosages. At 100 mg L⁻¹, both preparations produced negative removal efficiencies, with a greater decrease observed for Chit-AA, indicating that the permanganate index after treatment was higher than the untreated peat water. This does not indicate the formation of new natural organic matter, but may result from excessive chitosan remaining unadsorbed in the aqueous phase and contributing to KMnO₄ consumption. This behaviour is consistent with the characteristics of peat-water natural organic matter, which contains substantial amounts of dissolved humic substances that are less readily incorporated into chitosan flocs. An earlier study by Irawati et al. [23] showed that chitosan is generally more effective in destabilising suspended and colloidal particles than in removing dissolved organic matter. The decline at high dosages may be associated with polymer overdosing and steric hindrance, which reduce effective bridging, weaken the formed flocs, and may release previously incorporated organic substances during floc disruption.

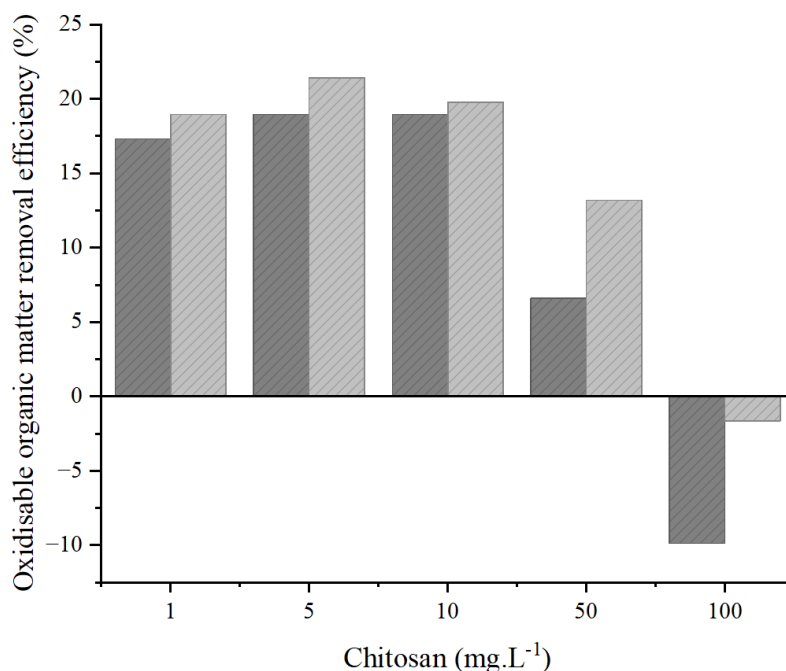


Figure 5. Comparison of oxidisable organic-matter removal efficiency obtained using chitosan dissolved in 2% (v/v) acetic acid (Chit-AA; black bars) and 2% (v/v) hydrochloric acid (Chit-HCl; grey bars) at chitosan dosages of 1, 5, 10, 50, and 100 mg L⁻¹.

Effect of Solvent on PAC–Chitosan Coagulation Performance

Based on the preceding broad-dose evaluation, high turbidity removal was obtained at the lower PAC dosages, whereas increasing the PAC dosage to 20–100 mg L⁻¹ reduced the performance of the combined system. Therefore, PAC dosages of 5 and 10 mg L⁻¹

were selected for further evaluation, while 1 mg L⁻¹ PAC was included to determine whether the inorganic coagulant dosage could be reduced further. The effects of the acid medium used for chitosan preparation on turbidity and oxidisable organic-matter removal are presented in **Figures 6** and **7**, respectively. The condition without chitosan served as the corresponding PAC-only control.

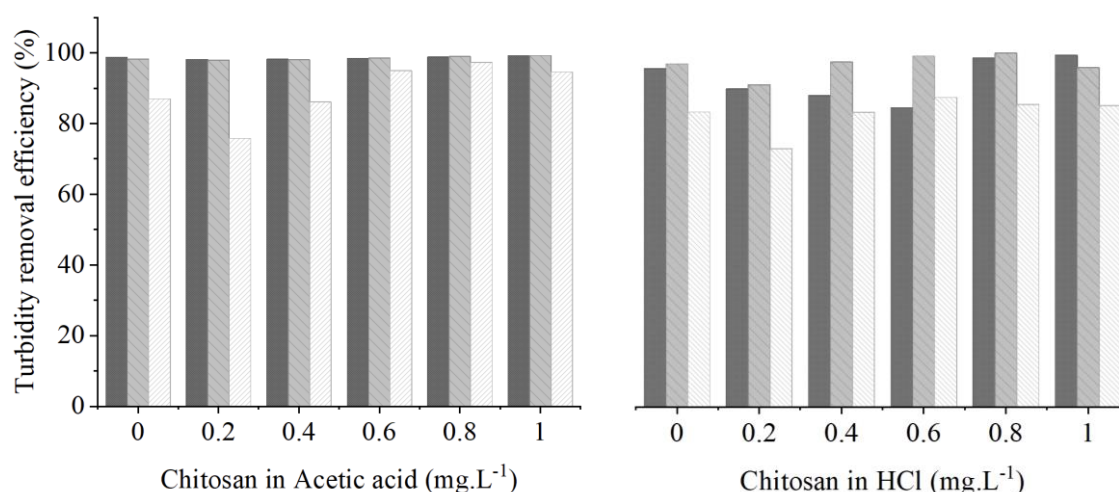


Figure 6. Effect of chitosan dosage on turbidity removal efficiency in PAC–chitosan coagulation systems prepared using 2% (v/v) acetic acid (left) and 2% (v/v) hydrochloric acid (right). Black, grey, and white bars represent PAC dosages of 1, 5, and 10 mg L⁻¹, respectively.

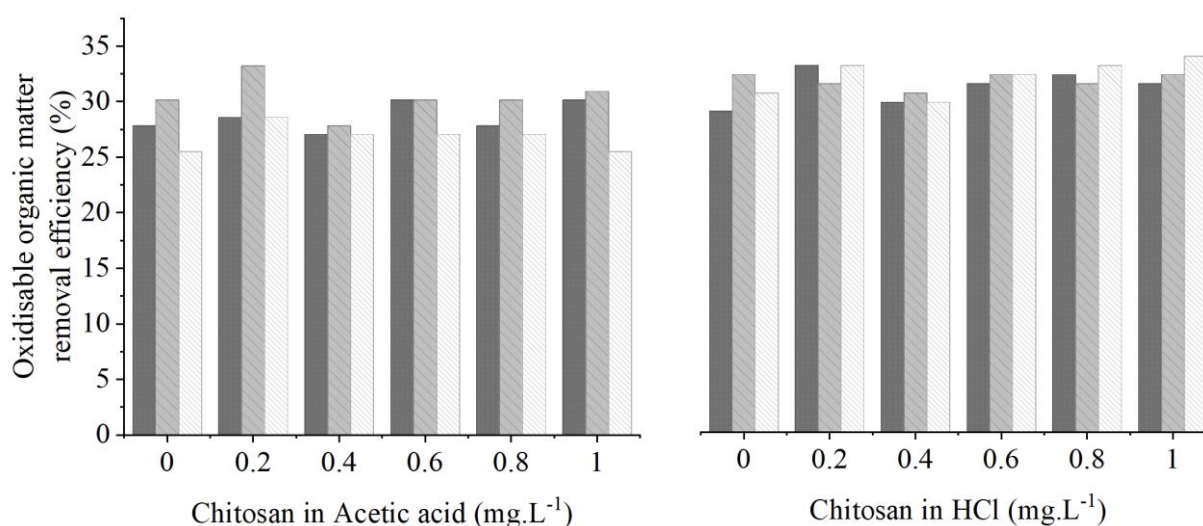


Figure 7. Effect of chitosan dosage on oxidisable organic-matter removal efficiency in PAC–chitosan coagulation systems prepared using 2% (v/v) acetic acid (left) and 2% (v/v) hydrochloric acid (right). Black, grey, and white bars represent PAC dosages of 1, 5, and 10 mg L⁻¹, respectively.

The turbidity-removal profiles showed that the acetic-acid system generally produced higher and more consistent treatment performance than the HCl system. In the acetic-acid system, PAC dosages of 1 and 5 mg L⁻¹ maintained turbidity removal at approximately 98–99% across the tested chitosan dosages. At 10 mg L⁻¹ PAC, turbidity removal was lower at 0–0.4 mg L⁻¹ chitosan but increased to approximately 94–97% when the chitosan dosage was increased to 0.6–1.0 mg L⁻¹. This result indicates that the addition of chitosan improved the performance of the 10 mg L⁻¹ PAC treatment after a sufficient chitosan dosage was reached.

The HCl system showed greater fluctuations with changes in chitosan dosage. At 1 mg L⁻¹ PAC, turbidity removal decreased from approximately 94% in the PAC-only control to approximately 83–89% at chitosan dosages of 0.2–0.6 mg L⁻¹, before increasing to approximately 97% at 0.8–1.0 mg L⁻¹. At 5 mg L⁻¹ PAC, the removal efficiency ranged from approximately 89% to 98%, whereas at 10 mg L⁻¹ PAC it remained lower, at approximately 72–85%. Compared with the HCl system, chitosan prepared in acetic acid therefore maintained high turbidity removal over a wider range of PAC and chitosan dosages.

The removal of oxidisable organic matter showed a narrower response than turbidity removal. In the acetic-acid system, removal efficiencies generally ranged from approximately 25% to 33%. The highest observed value was obtained using 5 mg L⁻¹ PAC and 0.2 mg L⁻¹ chitosan, which produced approximately 33% removal. In the HCl system, the removal efficiencies remained within approximately 27–32% across the tested conditions. Increasing the chitosan dosage did not produce a consistent increase in oxidisable organic-matter removal in either acid medium.

The differences between the two acid media were therefore more apparent for turbidity removal than for oxidisable organic-matter removal. Chitosan prepared in acetic acid provided a more stable turbidity-removal response, particularly at PAC dosages of 1 and 5 mg L⁻¹. In contrast, the oxidisable organic-matter removal values for both acid media remained within a relatively narrow range, suggesting that this response was influenced more strongly by PAC coagulation than by the acid medium used for chitosan preparation.

CONCLUSION

This study demonstrated that both PAC and chitosan are effective coagulants for peat-water treatment, but their performance strongly depends on dosage and solvent conditions. PAC showed excellent turbidity removal at 20 mg L⁻¹, while overdosing caused restabilisation and a sharp decline in efficiency.

Chitosan used alone also produced high turbidity removal at moderate doses, with performance decreasing at high concentrations due to polymer oversaturation. The combined PAC–chitosan system provided clear synergistic effects, especially at low PAC doses (5–10 mg L⁻¹), yielding the highest turbidity removal among all treatments. Organic-matter removal remained modest across all systems, indicating that dissolved humic substances are less responsive to coagulation. The choice of solvent had a significant influence on chitosan behaviour. Chitosan dissolved in acetic acid consistently resulted in higher and more stable turbidity removal than chitosan dissolved in HCl, both when applied alone and in combination with PAC. In contrast, solvent effects on organic removal were minimal. Overall, the results highlight that optimum coagulation performance for peat water is achieved using low PAC doses coupled with acetic-acid-based chitosan, offering efficient turbidity reduction while maintaining system stability.

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REFERENCES

1. Jalilov, S. M., Rochmayanto, Y., Hidayat, D. C., Raharjo, J. T., Mendham, D. and Langston, J. D. (2025) Unveiling economic dimensions of peatland restoration in Indonesia: A systematic literature review. *Ecosystem Services*, **71**(101693), 1–12.
2. Herawati, H., Kartini, Akbar, A. A. and Abdurrahman, T. (2021) Strategy for realizing regional rural water security on tropical peatland. *Water (Switzerland)*, **13**(18).
3. Suherman, D. and Sumawijaya, N. (2013) Menghilangkan Warna dan Zat Organik Air Gambut dengan Metode Koagulasi-Flokulasi Suasana Basa. *Jurnal Riset Geologi dan Pertambangan*, **23**(2), 125.
4. Ali, F., Lestari, D. L. and Putri, M. D. (2021) Peat Water Treatment as an Alternative for Raw water in Peatlands Area. *IOP Conference Series: Materials Science and Engineering*, **1144**(1), 012052.
5. García-Ávila, F., Encalada-Alvear, T., Alvarez-Altamirano, L. M., Avilés-Añazco, A., Valdiviezo-Gonzalez, L. and Alfaro-Paredes, E. (2025) Human health risk assessment of aluminium in water treated with aluminium-based coagulants in a rural area. *Results in Engineering*, **25**.

6. Wang, W., Yue, Q., Li, R., Song, W., Gao, B. and Shen, X. (2017) Investigating coagulation behavior of chitosan with different Al species dual-coagulants in dye wastewater treatment. *Journal of the Taiwan Institute of Chemical Engineers*, **78**, 423–430.
7. Jia, R. and Wang, W. (2023) Performance of chitosan/PAC enhanced coagulation for low-temperature and low-turbidity Pi River source water. *Desalination and Water Treatment*, **306**, 199–207.
8. Zhang, Z., Jing, R., He, S., Qian, J., Zhang, K., Ma, G., Chang, X., Zhang, M. and Li, Y. (2018) Coagulation of low temperature and low turbidity water: Adjusting basicity of polyaluminum chloride (PAC) and using chitosan as coagulant aid. *Separation and Purification Technology*, **206**, 131–139.
9. Ng, M., Liu, S., Chow, C. W. K., Drikas, M., Amal, R. and Lim, M. (2013) Understanding effects of water characteristics on natural organic matter treatability by PACl and a novel PACl-chitosan coagulants. *Journal of Hazardous Materials*, **263**, 718–725.
10. Bakri, B., Selintung, M., Hamdani, R. N., Ihsan, M. and Arai, Y. (2019) The Effectiveness of PAC and Chitosan Usage in Jeneberang River Raw Water Treatment. In *IOP Conference Series: Materials Science and Engineering*, IOP Publishing Ltd., **676**.
11. Irawati, U., Hikmah, F. A. and Junaidi, A. B. (2023) The Effect of Acetic Acid and Hydrochloric Acid as a Solvent for Chitosan to Reduce Turbidity in Eutrophic Water. *International Journal of Environmental Science and Development*, **14**(5), 287–291.
12. Arfan, A. R., Irawati, U., Indah, R. and Hikmah, N. (2025) Potential of Moringa oleifera Seeds as a Natural Coagulant for Turbidity and LAS Removal from Detergent Wastewater. *Fullerene Journal of Chemistry*, **10**(2), 87.
13. Badan Standardisasi Nasional (2004) Air dan Air Limbah-Bagian 22: Cara Uji Nilai Permanganat secara Titrimetri. In *Standar Nasional Indonesia: Air dan Air Limbah, Serpong: Badan Standarisasi Nasional*.
14. Wahyuni, R., Hidayat, M. Y., Saragih, G. S., Efadeswarni, E., Siswadi, S., Pitalokasari, O. D. and Pandiangan, Y. S. H. (2021) Peat water quality in Block C Pulang Pisau Regency, Central Kalimantan. In *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd., **909**.
15. Qadafi, M., Wulan, D. R., Notodarmojo, S. and Zevi, Y. (2023) Characteristics and treatment methods for peat water as clean water sources: A mini review. *Water Cycle*, **4**, 60–69.
16. Sedyaningsih, E. R. (2010) Peraturan Menteri Kesehatan Republik Indonesia Nomor 492/Menkes/ Per/IV/2010.
17. Nawan, N., Priskila, H., Shinta, H. E., Septi Handayani and Ravenalla Abdurahman (2023) Quality of the peat water and its association with public health problems in the community of the Danau Tundai area. *Jurnal Kedokteran dan Kesehatan Indonesia*, 163–171.
18. Zevi, Y., Qadafi, M. and Notodarmojo, S. (2022) The Presence of Trihalomethanes and Haloacetic Acids in Tropical Peat Water. *Journal of Engineering and Technological Sciences*, **54**(3).
19. Miranda, R., Latour, I. and Blanco, A. (2020) Understanding the Efficiency of Aluminum Coagulants Used in Dissolved Air Flotation (DAF). *Frontiers in Chemistry*, **8**. <https://doi.org/10.3389/fchem.2020.00027>.
20. Arakeri, V. S. and N, P. (2025) Performance Analysis of Poly Aluminium Chloride (PAC) in Turbidity, COD, and Microbial Load Reduction from Domestic Washing Machine Effluent and Urban Lake Water. *International Journal for Research in Applied Science and Engineering Technology*, **13**(8), 1716–1727.
21. Badawi, A. K., Hasan, R. and Ismail, B. (2025) Sustainable coagulative removal of microplastic from aquatic systems: recent progress and outlook. *RSC Advances*, **15**, 25256–25273.
22. Nti, S. O., Buamah, R. and Atebiya, J. (2021) Polyaluminium chloride dosing effects on coagulation performance: case study, barekese, ghana. *Water Practice and Technology*, **16**(4), 1215–1223.
23. Irawati, U., Maharini, G. and Ariyani, D. (2023) Comparing the performance of chitosan in two different solvents for coagulation of peat water. In *The 4th International Conference on Life Science and Technology (ICoLiST)*, AIP Publishing, **2634**, 020071.
24. Prasetyo, S., Santos, C. A., Sugih, A. K. and Kristianto, H. (2025) Utilization of chitosan as a natural coagulant for polyethylene microplastic removal. *Sustainable Chemistry for the Environment*, **9**, 100225.
25. Loganathan, P., Gradzielski, M., Bustamante, H. and Vigneswaran, S. (2020) Progress, challenges,

- and opportunities in enhancing NOM flocculation using chemically modified chitosan: A review towards future development. *Environmental Science: Water Research and Technology*, **6**, 45–61.
26. Yousefi, M., Jabbari, E. and Sedighi, M. (2022) *Experimental study of polyaluminum chloride-chitosan coagulant for water treatment using response surface methodology. Journal of Applied Research in Water and Wastewater*, **9**, 23–29.
27. Trinh, T. K. and Kang, L. S. (2015) Coagulation of phosphorus: effects of Al(III) species (Ala, Alb, and Alc). *Desalination and Water Treatment*, **53(2)**, 485–492.
28. El Foulani, A. -A., Jamal-eddine, J. and Lekhlif, B. (2022) Study of aluminium speciation in the coagulant composite of polyaluminium chloride-chitosan for the optimization of drinking water treatment. *Process Safety and Environmental Protection*, **158**, 400–408.
29. De-Paz-Arroyo, G., Torres-Irube, A. M., Picos-Corrales, L. A., Licea-Claverie, A., Crini, G., García-Armenta, E., and Félix-Alcalá, D. V. (2025) Synergy Between Low-Cost Chitosan and Polyaluminum Chloride (PAC) Improves the Flocculation Process for River Water Treatment. *Polymers*, **17(13)**.