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Effectiveness of Green Mussel (Perna viridis) and PAC in Reducing TSS and Turbidity in River Water

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A B S T R A C T

Contamination of river water by suspended particles and organic matter increases total suspended solids (TSS) and turbidity, degrading water quality and posing risks to aquatic ecosystems and public health. This study evaluated the performance of chitosan derived from green mussel shells (*Perna viridis*) compared to polyaluminium chloride (PAC), a conventional coagulant, in reducing TSS and turbidity. Chitosan was selected due to its cationic polymer properties, which are obtained through the conversion of chitin, enhancing its coagulation–flocculation effectiveness. The experiment employed a jar test with variations in pH (5, 7, and 9), coagulant dosage, and standardized mixing protocols. Results showed that chitosan achieved optimal performance at pH 5 with a 150 mg/L dosage, resulting in 82% TSS removal and 87% turbidity reduction. In contrast, PAC performed best at pH 7 with a 20 mg/L dosage, achieving 85% TSS removal and 87% turbidity reduction. Particle Size Analyzer (PSA) results indicated that PAC produced larger and more uniform flocs (Xav = 1796.71 nm; PI = 0.403) compared to chitosan (Xav = 1070.28 nm; PI = 0.444). Although PAC had slightly higher efficiency, chitosan from mussel shell waste shows strong potential as an environmentally friendly coagulant for treating river water.

Contribution to Sustainable Development Goals (SDGs):
SDG 6: Clean Water and Sanitation
SDG 11: Sustainable Cities and Communities

1. INTRODUCTION

1.1. Research Background

River water quality is increasingly threatened by domestic and industrial activities that discharge wastewater containing suspended solids and organic matter. These pollutants elevate total suspended solids (TSS) and turbidity, reduce light penetration, and lower dissolved oxygen levels, which are crucial for maintaining the balance and biodiversity of aquatic ecosystems [1]. Untreated or inadequately treated wastewater can disrupt aquatic biological activity, degrade water quality, and pose health risks to surrounding communities. Conventional chemical coagulants, such as polyaluminium chloride (PAC), are commonly used to remove TSS and turbidity; however, they may leave residual metals in the treated water and produce large volumes of sludge that require proper disposal [4]. Therefore, developing environmentally friendly and sustainable alternatives that are both effective and safe is essential for modern water treatment practices.

Chitosan, a cationic biopolymer derived from chitin, has emerged as a promising natural coagulant due to its biodegradability, biocompatibility, and strong coagulation performance [2]. Its amino groups ($–NH_2$) can be protonated ($–NH_3^+$) under acidic conditions, allowing electrostatic interactions with negatively charged particles and promoting the formation of stable flocs [14]. Green mussel (Perna viridis) shells, which are widely available in coastal regions, contain substantial chitin

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content, making them a potential local raw material for chitosan production. Previous studies have demonstrated that chitosan can achieve high turbidity removal efficiency and produce significantly less sludge compared to chemical coagulants. However, limited research has explored the potential of Perna viridis-based chitosan in treating river water, leaving a gap that this study aims to address.

This research evaluates the performance of chitosan extracted from green mussel shells in reducing TSS and turbidity levels, with comparative assessment against conventional PAC. The morphology of flocs generated during the coagulation–flocculation process was analyzed using Particle Size Analyzer (PSA) technology to determine aggregate size, uniformity, and sedimentation characteristics under optimal operational conditions [3]. The findings aim to provide a sustainable and economically viable alternative coagulant, promote the valorization of shell waste, and support environmentally responsible water treatment practices in Indonesia [5]. Furthermore, this study bridges laboratory-scale experiments with practical applications, providing insights into the feasibility of implementing natural coagulants in real-world water treatment operations.

1.2. Literature Review

1.2.1. Coagulation – Flocculation

Coagulation – flocculation is a physicochemical process that destabilizes colloidal particles and aggregates them into settleable flocs. Coagulants neutralise the negative surface charges on particles, reducing electrostatic repulsion and facilitating floc formation through gentle mixing [16]. Coagulants are classified into two types: chemical types (aluminium and iron-based compounds) and natural types derived from biological sources. Natural coagulants have gained attention due to concerns regarding aluminum residuals, excessive sludge production, and environmental impacts associated with chemical alternatives [11].

1.2.2. TSS and Turbidity

Total Suspended Solids (TSS) and turbidity are critical indicators of water quality that directly impact aquatic ecosystems and treatment efficiency. TSS measures suspended particle concentration (mg/L), while turbidity quantifies water clarity through light scattering (NTU). Research indicates that TSS levels above 50 mg/L significantly impair photosynthetic activity and reduce dissolved oxygen in rivers [16]. Strong correlations have been documented between TSS and turbidity ($r = 0.89$, $p < 0.01$) in tropical rivers, although both parameters require distinct treatment approaches [10].

1.2.3. Chitosan Extracted from Green Mussel (Perna Viridis)

Green mussel (Perna Viridis) shells are valuable sources for chitosan-based natural coagulants. Chitosan extracted form these shells demonstrates effective coagulation through charge neutralization and bridging mechanisms. Studies report that green mussel-derived coagulants achieve 70-85% TSS removal and 75-88% turbidity reduction at dosages of 50-150 mg/L [10]. Extraction methods, molecular weight, pH conditions, and initial water quality influence performance. These coagulants offer several advantages, including biodegradability, non-toxicity, reduced sludge production, and environmental sustainability, compared to synthetic alternatives [6], making them a promising option for developing countries seeking cost-effective water treatment solutions.

1.2.4. Polyaluminum Chloride (PAC)

Polyaluminum Chloride (PAC) is a highly efficient synthetic coagulant widely used in water treatment for particle destabilization through charge neutralization and sweep flocculation. Studies on turbid river water show PAC achieves 85-92% turbidity reduction at optimal dosages of 15-30 mg/L with TSS removal exceeding 80% within 30-45 minutes [13]. PAC effectiveness is influenced by pH (optimal 6.5-8.0), mixing intensity, temperature, and water quality characteristics. Compared to traditional alum, PAC offers a broader pH range, 30-40% less sludge production, lower residual aluminium, and faster floc formation [7]. However, concerns regarding aluminium residuals and environmental impacts have motivated research into natural alternatives.

1.3. Research Objective

This research aims to evaluate the effectiveness of chitosan extracted from green mussel (Perna viridis) shells as a natural coagulant for reducing total suspended solids (TSS) and turbidity in river water. It also seeks to compare its coagulation–flocculation performance with that of conventional polyaluminium chloride (PAC) by optimising parameters such as pH and coagulant dosage to determine the most effective treatment conditions, as well as to characterise the floc morphology using a Particle Size Analyser (PSA) under the optimised operational conditions.

2. MATERIALS AND METHODS

Water samples were collected from three locations along the Jagir River in Wonokromo District, Surabaya City, using grab sampling in accordance with SNI 6989.57:2008. Chitosan was synthesized from green mussel (*Perna viridis*) shells and dissolved in 1% acetic acid. Polyaluminium chloride (PAC) served as comparative coagulant. pH adjustments utilized NaOH and HCl solutions. Laboratory instruments included jar test apparatus, pH meter, turbidimeter, oven, analytical balance, and Particle Size Analyzer.

Chitosan synthesis involved three sequential stages: deproteinization, demineralization, and deacetylation. The powdered shells were treated with 3.5% NaOH to remove proteins, followed by 1 N HCl to eliminate minerals, and finally 50% NaOH at 90 °C for two hours to achieve deacetylation. The resulting chitosan was rinsed to a neutral pH, dried at 60 °C, and dissolved in 1% acetic acid to prepare the coagulant solution.

Coagulation–flocculation efficiency was evaluated via jar tests at pH 5, 7, and 9. Coagulation was initiated by rapid mixing at 150 rpm for one minute, followed by slow mixing at 60 rpm for fifteen minutes. The samples were then allowed to settle for 30 minutes before the supernatant was analysed for TSS and turbidity. Removal efficiency was calculated by comparing the initial and final concentrations. Floc size distribution and uniformity were further characterized using PSA for both coagulants.

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3. RESULT AND DISCUSSION

3.1. Baseline Water Quality Characteristic

The physicochemical characterisation of the river water was conducted prior to treatment. Parameters assessed included pH, TSS, turbidity, and temperature, evaluated against Indonesian Government Regulation No. 22/2021 on Surface Water Quality Standards (Table 1).

Table1 Initial Water Quality

Parameter	Unit	Measured Value	Quality Standards
TSS	mg/L	105	105
pH	-	7.4	6 – 9
Turbidity	Pt-Co	27	25

TSS and turbidity exceeded permissible limits, indicating water quality degradation requiring treatment intervention. Coagulation-flocculation was selected for its effectiveness in reducing suspended solids through particle destabilization and floc formation.

3.2. Influence of pH and Coagulant Concentration on Suspended Solids Reduction

Both natural and synthetic coagulants were evaluated for their ability to remove suspended solids under varying acidity levels (pH 5, 7, and 9) and concentration gradients.

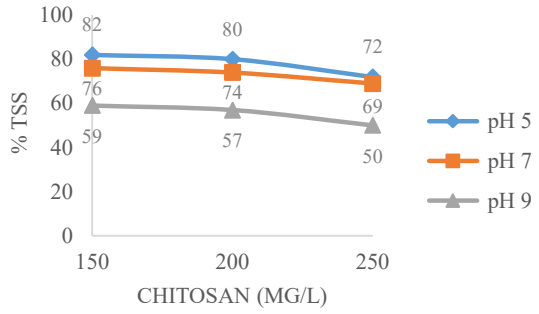

Fig. 1 Chitosan Performance in TSS Removal at Different pH and Dosage

The biopolymer coagulant reached maximum removal efficiency (82%) under acidic conditions (pH 5) at a dosage of 150 mg/L. The superior performance at low pH results from amine group protonation ($–NH_2 \rightarrow –NH_3^+$), enhancing electrostatic attraction with negatively charged colloids and promoting aggregation [14]. Efficiency decreased to 76% at neutral pH and 50% at alkaline pH (9) due to reduced protonation, which weakens particle binding. Increasing the dosage beyond 150 mg/L caused lower performance across all pH levels, likely due to charge reversal and colloid restabilization.

Polyaluminium chloride (PAC) achieved maximum removal efficiency (85%) at neutral pH (7) with an optimal dosage of 20 mg/L. The high performance is attributed to $Al(OH)_3$ precipitates that capture suspended solids through enmeshment. Under acidic conditions (pH 5), PAC showed moderate efficiency (77%) and declined markedly at alkaline pH (9) to 55%. The decrease at high pH corresponds to the formation of soluble aluminate ions [$Al(OH)_4^-$], reducing the availability of hydroxide flocs [8]. Doses exceeding 20 mg/L also resulted in efficiency loss due to charge imbalance and colloid restabilization.

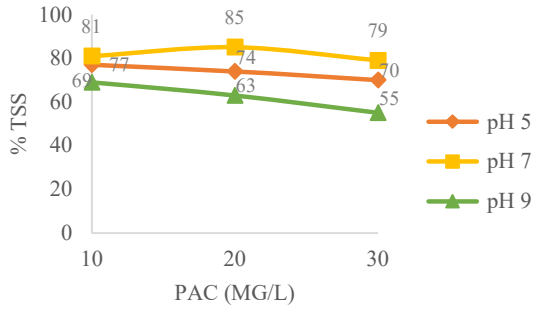

Fig. 2 PAC Performance in TSS Removal at Different pH and Dosage

3.3. pH and Coagulant Effect on Turbidity Elimination

Both coagulants were examined to determine the effect of pH variation on floc size and compactness during coagulation–flocculation processe

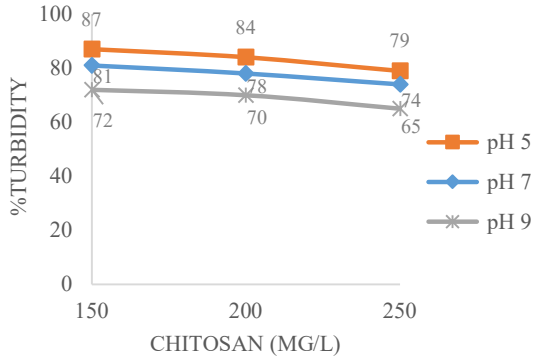

Fig. 3 Chitosan Performance in Turbidity Removal at Different pH and Dosage

The biopolymer coagulant achieved maximum turbidity reduction (87%) under acidic conditions (pH 5) at a dosage of 200 mg/L. The strong performance at low pH indicates that protonated amine sites ($–NH_3^+$) enhance electrostatic attraction and polymer bridging, promoting fine colloid destabilization [14]. Turbidity showed greater sensitivity to pH changes than suspended solids, suggesting that charge neutralization rather than sedimentation governs removal efficiency. Under alkaline conditions, turbidity removal declined to 65% at pH 9 due to amine deprotonation that weakens particle interactions. These results confirm that acidic environments are crucial for achieving optimal biopolymer performance in terms of clarity improvement.

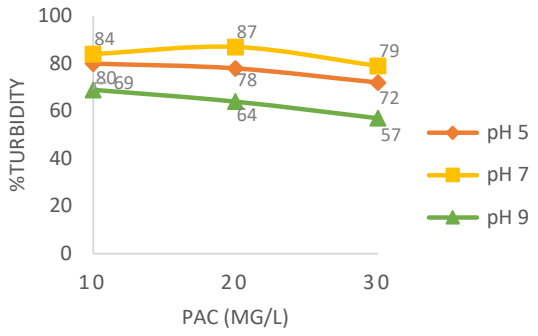

Fig. 4 PAC Performance in Turbidity Removal at Different pH and Dosage

Polyaluminium chloride (PAC) reached comparable maximum turbidity removal (87%) at neutral pH (7) with an optimal dosage of 20 mg/L. The high efficiency reflects the predominance of $Al(OH)_3$ precipitates that capture colloidal particles through sweep flocculation. Under acidic conditions (pH 5), removal slightly decreased, while a major decline to 57% occurred in alkaline media (pH 9). The reduced performance at high pH corresponds to the formation of soluble aluminate ions $[Al(OH)_4^-]$, which limit hydroxide precipitation and particle capture. The similarity between TSS and turbidity trends demonstrates PAC's dependence on hydroxide chemistry for effective floc formation.

3.4. Floc Size Distribution Analysis

PAC generated significantly larger and more uniform flocs ($\bar{X}_{av}$ = 1796.71 nm; PI = 0.403) compared to chitosan ($\bar{X}_{av}$ = 1070.28 nm; PI = 0.444). The formation of denser, larger flocs by PAC enhances gravitational settling and facilitates more efficient TSS removal. Despite producing smaller flocs, chitosan maintained a comparable removal efficiency due to its porous structure, which provides a higher specific surface area and superior adsorption capacity [5]. These morphological differences reflect the fundamental coagulation mechanisms of each material. PAC operates through sweep coagulation, precipitating compact aluminum hydroxide aggregates that entrap suspended particles. In contrast, chitosan's long polymeric chains form (Table 2). flexible, interconnected floc networks stabilized by hydrogen bonding and electrostatic interactions [15].

Table 2. Particle size characterization under optimal treatment conditions revealed distinct floc morphologies between coagulants.

Coagulant	Xav (nm)	D10 (µm)	D50 (µm)	D90 (µm)
Chitosan (150 mg/L)	1070,28	0,27	0,59	1,28
PAC (20 mg/L)	1796,71	0,49	1,03	2,17

PAC generated significantly larger and more uniform flocs ($\bar{X}_{av}$ = 1796.71 nm; PI = 0.403) compared to chitosan ($\bar{X}_{av}$ = 1070.28 nm; PI = 0.444). The formation of denser, larger flocs by PAC enhances gravitational settling and facilitates more efficient TSS removal. Despite producing smaller flocs, chitosan maintained a comparable removal efficiency due to its porous structure, which provides a higher specific surface area and superior adsorption capacity [5]. These morphological differences reflect the fundamental coagulation mechanisms of each material. PAC operates through sweep coagulation, precipitating compact aluminum hydroxide aggregates that entrap suspended particles. In contrast, chitosan's long polymeric chains form flexible, interconnected floc networks stabilized by hydrogen bonding and electrostatic interactions [15].

4. CONCLUSION

The coagulation-flocculation efficiency of Jagir River water proved to be highly sensitive to pH and coagulant concentration. Green mussel shell-derived chitosan achieved optimal performance at pH 5 (150 mg/L), removing 82% TSS and reducing turbidity by 87%. PAC outperformed at pH 7 (20 mg/L) with 85% TSS removal and 87% turbidity reduction. Particle Size Analysis revealed PAC generated larger, more uniform flocs (Xav = 1796.71 nm; PI = 0.403) and chitosan (Xav = 1070.28 nm; PI = 0.444), consistent with documented superior floc stability of synthetic polyaluminum agents. Despite this gap, chitosan's biodegradability positions it as a viable sustainable alternative. Pilot-scale validation and expanded water quality assessment are needed to confirm field applicability.

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