

APPLICATION OF A 50:50 COMBINATION OF ALUMINUM SULFATE ($\text{Al}_2(\text{SO}_4)_3$) AND PAPAYA (*Carica papaya* L.) SEED POWDER COAGULANTS ON TSS, COD, AND pH IN KARANG MUMUS RIVER WATER

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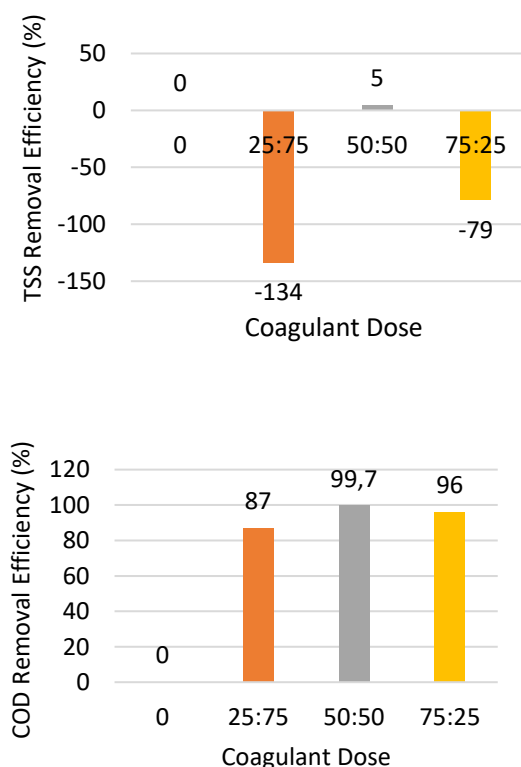
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Graphical abstract



ABSTRACT

The Karang Mumus River in Samarinda City has experienced declining water quality due to domestic and urban activities, particularly affecting Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and pH. This study evaluates the effectiveness of aluminum sulfate and papaya seed powder, individually and in combination, in improving river water quality through laboratory-scale coagulation-flocculation using jar tests. Water samples were collected near Perniagaan Bridge, Samarinda. The results showed that aluminum sulfate at an optimum dose of 0.08 g achieved COD and TSS removal efficiencies of 54%, while papaya seed powder at 1 g achieved 91% COD removal and maintained a neutral pH. However, papaya seed powder was less effective in reducing TSS due to residual unsettled organic particles. The combination of both coagulants at a 50:50 ratio achieved the highest COD removal efficiency of 99.7%, with a final pH of 6.62, meeting the applicable pH standard. Nevertheless, the final TSS concentration of 48 mg/L remained above the regulatory limit of 40 mg/L. These findings highlight the potential of combining chemical and natural coagulants to enhance COD removal, although further optimization is required to improve TSS reduction and overall treatment performance.

Keywords: Aluminum Sulfate, Papaya Seed Powder, Coagulation-Flocculation, Chemical Oxygen Demand, Total Suspended Solids.

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1. INTRODUCTION

Karang Mumus River is a tributary of the Mahakam River that flows through Samarinda City and serves as the main raw water source for PDAM Tirta Kencana Samarinda. However, increasing domestic, commercial, and residential activities along the riverbanks have resulted in declining water quality. This condition may be exacerbated by the discharge of wastewater from activities around the river, including wastewater discharged through the Segiri Market drainage channel directly into the Karang Mumus River. According to Makbul et al. (2022), market wastewater is generated from various activities, including trading, office operations, bathrooms, and food stalls, which contribute to increased pollutant loads in receiving water bodies. The water quality of the Karang Mumus River is classified as poor, with a Water Quality Index (IKA) value of 37,5 (Pramaningsih et al., 2023). The location with the highest level of pollution is around the Perniagaan Bridge, as indicated by elevated Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD) levels that exceed the applicable quality standards.

One method that can be used to improve water quality is the coagulation-flocculation process. Coagulation is the process of destabilizing colloidal particles through the addition of a coagulant, whereas flocculation is the process of forming flocs through slow mixing, allowing destabilized particles to aggregate into larger and more readily settleable flocs (Said, 2017). This method is widely used because it is effective in reducing suspended particles and some organic matter present in water.

A commonly used coagulant in water treatment is aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3$). Aluminum sulfate has a strong capacity to aggregate suspended particles into readily settleable flocs, thereby improving water quality. Aluminum sulfate reduced TSS by 96,84% and COD by 81,32% in motorcycle manufacturing wastewater (Mursitaningrum et al., 2024). However, continuous use of aluminum sulfate has several disadvantages, including high costs, residual aluminum that may pose health risks, and dependence on chemical substances (Hasan & Khoirunnisa, 2024). One alternative for reducing the use of chemical coagulants is the utilization of natural coagulants. Papaya seeds (*Carica papaya* L.) have potential as a biocoagulant because they contain proteins that can facilitate the coagulation process. Papaya seed powder at doses of 1 – 3 g effectively reduced COD by up to 93% in domestic wastewater (Lestari et al., 2021). The use of papaya seeds as a biocoagulant in batik wastewater reduced TSS by 90,8% and COD by 89,5% (Dewi et al., 2025). Papaya seeds therefore have potential as an environmentally friendly, economical, and readily available natural coagulant.

Previous studies have generally evaluated aluminum sulfate and papaya seeds separately. Research on the combination of these two coagulants remains very limited, particularly for treating water from the Karang Mumus River, which has a relatively high level of pollution. The combination of chemical and natural coagulants may provide synergistic effects and improve the efficiency of water treatment. Although chemical coagulants such as aluminum sulfate are effective, they generate sludge containing inorganic residues that are difficult to degrade (Diver et al., 2023). In contrast, natural coagulants tend to produce less sludge that is more readily biodegradable and environmentally friendly (Afrianisa & Yasmine, 2025). Therefore, combining aluminum sulfate and papaya seeds may not only improve turbidity removal efficiency but also improve the settling characteristics of the resulting sludge.

This study was conducted to determine the effectiveness of aluminum sulfate, papaya seed powder, and their combination in reducing TSS and COD and maintaining pH in Karang Mumus River

water. In addition, this study aimed to determine the optimum dose of each coagulant based on the most effective reduction in the measured parameters as a basis for testing the coagulant combination in the coagulation-flocculation process

2. MATERIALS AND METHODS

This study employed a laboratory-scale coagulation-flocculation method using a jar test apparatus to evaluate the effectiveness of aluminum sulfate, papaya seed powder, and a combination of the two coagulants in reducing TSS and COD and improving the pH of Karang Mumus River water. Water samples were collected from the Karang Mumus River behind Segiri Market, near the Perniagaan Bridge, Samarinda City, East Kalimantan. The sampling location was selected because it has a relatively high level of pollution based on previous water quality monitoring results.

Aluminum sulfate was tested at doses of 0,02; 0,04; 0,06; 0,08; and 0,10 g. A 2% solution was prepared by dissolving 2 g of aluminum sulfate in 0,1 L of distilled water, after which the required volume was pipetted into the water samples according to the designated dose. Papaya seed powder with a particle size of 150 mesh, oven-dried at 150°C for 1,5 hours, was tested at doses of 1, 2, 3, 4, and 5 g. A papaya seed powder solution was prepared by mixing each dose with 0,1 L of distilled water, followed by filtration to obtain the filtrate used as the coagulant. The optimum dose of each coagulant was then combined at aluminum sulfate-to-papaya seed powder ratios of 75:25, 50:50, and 25:75. The following table presents the amounts of aluminum sulfate and papaya seed powder in each dose used in the study.

Table 1. Coagulant Content of Aluminum Sulfate and Papaya Seeds at Each Dose

No.	Aluminum Sulfate		Papaya Seed	
	Dose Volume (L)	Content (g)	Volume of Filtrate (L)	Content (g)
1.	0,001	0,02	0,1	1
2.	0,002	0,04	0,1	2
3.	0,003	0,06	0,1	3
4.	0,004	0,08	0,1	4
5.	0,005	0,1	0,1	5

The coagulation-flocculation process consisted of rapid mixing at 120 rpm for 1 minute, followed by slow mixing at 30 rpm for 20 minutes, and sedimentation for 60 minutes. After sedimentation, the samples were analyzed to determine TSS, COD, and pH values. TSS was determined using the gravimetric method in accordance with SNI 6989.3:2019, COD was analyzed using the closed reflux spectrophotometric method in accordance with SNI 6989.2:2019, and pH was measured using a pH meter in accordance with SNI 6989.11:2019. The effectiveness of parameter removal was calculated using the following equation:

$$\%P = \frac{(C_0 - C_e)}{C_0} \times 100\% \quad (1)$$

Where %P is the removal efficiency(%), C_0 is the concentration before treatment (mg/L), and C_e is the concentration after treatment (mg/L). The optimum dose was determined based on the highest removal of TSS and COD while considering the stability of the pH following treatment. Each

treatment at each dose was performed in triplicate. The measurement data are presented as the mean and standard deviation (SD) of the three replicates to indicate variation in the measurement results. The data obtained were analyzed by comparing the results for each coagulant and dose with the river water quality standards specified in Annex VI of Government Regulation Number 22 of 2021, Class I (raw water for drinking water), concerning the Implementation of Environmental Protection and Management.

3. RESULT AND DISCUSSION

Initial Characteristics of Karang Mumus River Water

The Karang Mumus River water samples were collected behind Segiri Market, Samarinda, during a period of low river water levels. Low water levels reduce the dilution of pollutants, resulting in a tendency for organic matter and suspended solids concentrations in the water to increase. The initial characterization results presented in Table 2 show that the pH value remained within the applicable quality standard, whereas the TSS and COD values in the samples exceeded the established quality standards. This condition was influenced by the sampling location, which was situated near one of the wastewater discharge channels from Segiri Market that flows directly into the river, as well as by the low water level at the time of sampling. Therefore, this study was conducted to evaluate the effectiveness of aluminum sulfate, papaya seed powder, and a combination of the two coagulants in reducing TSS and COD concentrations while maintaining the water pH within the applicable quality standard range through the coagulation-flocculation process.

Table 2. Initial Characterization Results of Karang Mumus River Water

Water Sample Collection	TSS (mg/L)	COD (mg/L)	pH
Sample I (Aluminum Sulfate Treatment)	49,33	679,24	7,07
Sample II (Papaya Seed and Combined Coagulant Treatment)	50,67	840,73	7,27
Quality Standard, Annex VI of Government Regulation Number 22 of 2021, Class I	40	10	6 – 9

Effects of Aluminum Sulfate and Papaya Seeds on Water Quality Parameters

Based on Table 3, the test results show that the addition of aluminum sulfate coagulant affected the TSS, COD, and pH parameters of Karang Mumus River water. The initial TSS concentration was 49,33 mg/L, the COD concentration was 679,24 mg/L, and the water pH was 7,07. Following the addition of the coagulant at different doses, the TSS concentration decreased progressively, indicating that the coagulant was effective in reducing suspended solids and achieved compliance with the applicable quality standard (40 mg/L). The COD concentration showed a fluctuating trend and did not meet the quality standard (10 mg/L). The pH decreased significantly with increasing coagulant dose, reaching acidic conditions with pH values ranging from 5,26 to 4,59 and consequently falling below the applicable quality standard (6 – 9).

Table 3. Results of Water Quality Parameter Testing of The Karang Mumus River Using Aluminum Sulfate as a Coagulant

Coagulant Dose (g)	TSS (mg/L) ±SD	TSS Removal Efficiency (%)	COD (mg/L) ±SD	COD Removal Efficiency (%)	pH ±SD
0	49,33 ±6,11	-	679,24 ±35	-	7,07 ±0,06
0,02	44 ±4	11	591,91 ±14,12	13	6,78 ±0,07
0,04	38,67 ±2,31	22	440,82 ±1,01	35	6,19 ±0,08
0,06	30,67 ±2,31	38	549,16 ±9,61	19	5,26 ±0,07
0,08	22,67 ±2,31	54	315,30 ±6,58	54	4,69 ±0,02
0,1	14,67 ±2,31	70	596,34 ±4,61	12	4,59 ±0,03

Table 4. Results of Water Quality Parameter Testing of The Karang Mumus River Using Papaya Seed Powder as a Coagulant

Coagulant Dose (g)	TSS (mg/L) ±SD	TSS Removal Efficiency (%)	COD (mg/L) ±SD	COD Removal Efficiency (%)	pH ±SD
0	50,67 ±2,3	-	840,73 ±39,3	-	7,27 ±0,02
1	49,33 ±6,11	3	74,67 ±9,22	91	7 ±0,07
2	60 ±6,93	-18	154,75 ±5,39	82	6,93 ±0,06
3	62,67 ±15,14	-24	197,32 ±9,55	77	6,84 ±0,02
4	89,33 ±1,52	-76	246,47 ±11,13	71	6,76 ±0,03
5	52 ±13,86	-3	305,76 ±13,63	64	6,77 ±0,01

Based on Table 4, the test results show that the addition of papaya seed powder as a biocoagulant affected the TSS, COD, and pH parameters of Karang Mumus River water. The initial TSS concentration was 50,67 mg/L, the COD concentration was 840,73 mg/L, and the water pH was

7,27. Following the addition of the biocoagulant at different doses, the TSS concentration showed a fluctuating trend. TSS decreased at a dose of 1 g; however, the concentrations increased at doses of 2 – 4 g and remained above the applicable quality standard. The COD concentration decreased considerably compared with the initial condition, particularly at a dose of 1 g. The pH remained relatively stable and within the applicable quality standard range (6 – 9), with values ranging from 6,77 to 7,00.

Aluminum sulfate contributes to the coagulation process through the formation of aluminum hydroxide flocs ($\text{Al}(\text{OH})_3$) resulting from the hydrolysis of Al^{3+} ions. The resulting flocs can neutralize the charges of suspended particles, adsorb organic matter, and aggregate small particles into larger flocs, thereby contributing to reductions in TSS and COD. The hydrolysis of aluminum sulfate also produces H^+ ions, which are acidic and can cause a decrease in water pH. As the aluminum sulfate dose increases, more H^+ ions are formed, resulting in a greater tendency for the pH to decrease (Nur et al., 2020).

Papaya seeds act as a biocoagulant because they contain proteins composed of amino acids with amino ($-\text{NH}_2$) and carboxyl ($-\text{COOH}$) groups. The amino groups can become protonated to form positively charged ammonium groups ($-\text{NH}_3^+$), enabling them to neutralize negatively charged colloidal particles and promote the formation of flocs that settle more readily (Fessenden & Fessenden, 1989). This mechanism contributes to reductions in TSS and COD through the binding and sedimentation of particles and organic matter in the water. The presence of amino groups enables interactions with H^+ ions in the solution, thereby helping maintain pH stability during the coagulation-flocculation process. The effects of amino and carboxyl groups on coagulation and pH changes indicate that papaya seeds function not only as a natural coagulant but also contribute to maintaining the pH within the range that complies with the applicable quality standard (Dewi & Rahmayanti, 2022).

TSS Parameter

The results presented in Table 3 show a progressive decrease in TSS following the addition of aluminum sulfate coagulant. The initial TSS concentration was 49,33 mg/L, indicating that it did not meet the established quality standard (40 mg/L). Following the addition of 0,02 g of aluminum sulfate, the TSS concentration decreased to 44 mg/L (11%); at a dose of 0,04 g, it decreased to 38,67 mg/L (22%); at 0,06 g, it decreased to 30,67 mg/L (38%); at 0,08 g, it decreased to 22,67 mg/L (54%); and it reached the lowest value at a dose of 0,1 g, decreasing to 14,67 mg/L (70%). Aluminum sulfate produces $\text{Al}(\text{OH})_3$ flocs through hydrolysis, which can neutralize the charges of suspended particles and aggregate small particles into larger flocs. These flocs subsequently settle under gravitational force, thereby reducing the concentration of suspended solids (Nur et al., 2020). The results indicate that increasing the coagulant dose from 0,02 to 0,1 g promotes greater formation of $\text{Al}(\text{OH})_3$ flocs, thereby enhancing the adsorption and sedimentation of suspended particles, as indicated by the decrease in TSS at each successive dose. The addition of aluminum sulfate can effectively reduce TSS in wastewater through the coagulation-flocculation process, with increasing coagulant doses up to the optimum dose resulting in progressively higher TSS removal efficiency (Pampang et al., 2022).

The TSS measurements presented in Table 4 show a fluctuating trend following the addition of papaya seed coagulant. The initial TSS concentration was 50,67 mg/L, indicating that it did not meet the established quality standard (40 mg/L). Following the addition of 1 g of papaya seed powder, the TSS concentration decreased to 49,33 mg/L (3%). The TSS concentration subsequently

increased to 60 mg/L (-18%) at a dose of 2 g, increased to 62.67 mg/L (-24%) at 3 g, and increased further to 89,33 mg/L (-76%) at 4 g. The TSS concentration decreased again to 52 mg/L (-3%) at a dose of 5 g. The positively charged functional groups in papaya seed proteins can neutralize the negative charges of colloidal particles, destabilizing the particles and promoting their aggregation into flocs (Fessenden & Fessenden, 1989). The decrease in TSS observed only at the 1 g dose indicates that floc formation occurred, although its effect was relatively limited. The increase observed at doses of 2 – 5 g was presumably attributable to the high coagulant doses applied. Excessive amounts of papaya seed powder may prevent all positively charged functional groups from interacting with colloidal particles, causing unreacted papaya seed powder to remain suspended and form additional suspended solids, thereby increasing the TSS concentration (Bhernema et al., 2023). The decrease in TSS at the 5 g dose may have resulted from the formation of larger flocs than those formed at the 4 g dose, allowing some suspended particles to settle. However, the resulting TSS concentration remained higher than the initial concentration, indicating that the decrease reflected fluctuations during the treatment process. These findings are consistent with those of Dewi et al. (2025), who reported that increasing the dose of papaya seed powder coagulant can result in decreased TSS removal efficiency. The use of papaya seed powder as a natural coagulant was not effective in reducing TSS in Karang Mumus River water because, in addition to producing only a limited reduction, it may increase the suspended solids load due to organic particles that are not completely removed through sedimentation.

Parameter COD

The COD measurements presented in Table 3 showed a fluctuating trend. The initial COD concentration was 679,24 mg/L, indicating that it did not meet the established quality standard (10 mg/L). Following the addition of 0,02 g of aluminum sulfate coagulant, the COD concentration decreased to 591,9 mg/L (13%), and at a dose of 0,04 g, it decreased further to 440,82 mg/L (35%). The COD concentration subsequently increased to 549,2 mg/L (19%) at a dose of 0,06 g but decreased again to its lowest value of 315,3 mg/L (54%) at a dose of 0,08 g. At a dose of 0,1 g, the COD concentration increased again to 596,3 mg/L (12%). The decrease in COD observed with aluminum sulfate at doses of 0,02 g and 0,04 g occurred because Al^{3+} ions underwent hydrolysis to form $\text{Al}(\text{OH})_3$ flocs. These flocs adsorbed and entrapped the organic matter contributing to COD, causing it to settle with the flocs, thereby reducing the concentration of organic matter in the water and consequently decreasing the COD value (Nur et al., 2020). The increase in COD at a dose of 0,06 g may have resulted from particle destabilization not occurring optimally. Although Al^{3+} ions from aluminum sulfate were able to form flocs, the flocs may not have been sufficiently stable, allowing some organic matter to remain dissolved or suspended in the water. The formed flocs may also have undergone breakage due to charge imbalance during the coagulation-flocculation process. A similar phenomenon was reported by Prameswara & Sa'diyah (2024), who observed fluctuations before the optimum dose, whereby the organic matter content in the samples increased again, resulting in a higher COD value than that at the preceding dose. At a dose of 0,08 g, the COD concentration decreased again, indicating that the reformed flocs adsorbed and entrapped organic matter, which subsequently settled with the flocs. At a dose of 0,1 g, the COD concentration increased again, which may have resulted from particle restabilization or the formation of less stable flocs. The results indicate that increasing the aluminum sulfate dose did not consistently result in COD reduction. All COD concentrations after treatment remained above the applicable quality standard, indicating that

aluminum sulfate was effective in reducing COD in Karang Mumus River water but was unable to achieve the required water quality standard.

The COD measurements presented in Table 4 showed a considerable decrease compared with the initial condition, particularly at a dose of 1 g, at which the COD concentration decreased to 74,67 mg/L (91%). The initial COD concentration was 840,73 mg/L, indicating that it did not meet the established quality standard (10 mg/L). As the dose increased, the COD concentration increased again relative to the preceding dose. Following the addition of 2 g, the COD concentration increased to 154,75 mg/L (82%); at a dose of 3 g, it increased to 197,32 mg/L (77%); at 4 g, it increased to 246,47 mg/L (71%); and at 5 g, it increased to 305,76 mg/L (64%). The results indicate that papaya seeds performed more effectively at a low dose, whereas excessive dosing may reduce coagulation performance. The positively charged amino groups in papaya seed proteins bind and adsorb organic matter, which is generally negatively charged, thereby entrapping the organic matter within the flocs and promoting its sedimentation. This process reduces the concentration of organic matter in the water and consequently decreases the COD value (Fessenden & Fessenden, 1989). The amino groups in papaya seed proteins can contribute to COD reduction. The results show that all doses reduced the initial COD concentration; however, as the dose increased (2 – 5 g), the ability of papaya seeds to reduce COD progressively decreased. This may be attributed to the excessive presence of residual papaya seed powder, which is rich in organic compounds, in the water samples (Dewi et al., 2025). Thus, papaya seed powder was effective in reducing COD in Karang Mumus River water, particularly at the optimum dose of 1 g, although it was unable to reduce the COD concentration to the established quality standard.

pH Parameter

The use of aluminum sulfate as a coagulant for Karang Mumus River water, as presented in Table 3, showed a considerable decreasing trend in pH with increasing coagulant dose. Aluminum sulfate tends to decrease water pH because it produces hydrogen ions (H^+), which are acidic, during hydrolysis in water. As the dose increases, more H^+ ions are generated, resulting in a greater decrease in water pH. The initial water pH was 7,07, which was within the applicable quality standard range (6 – 9). Following the addition of aluminum sulfate, the pH decreased to 6,78 at a dose of 0,02 g and continued to decline to 4,59 at a dose of 0,1 g (Nur et al., 2020). These findings are consistent with Pampang et al. (2022), who reported that increasing the amount of aluminum sulfate coagulant at the applied doses increases the acidity of the sample water. Aluminum sulfate has a pH in the range of 2,5 – 4, and its acidic solution can substantially decrease water pH (Prameswara & Sa'diyah, 2024). These findings indicate that increasing the aluminum sulfate dose makes the water increasingly acidic, resulting in a continuous decrease in pH with increasing coagulant dose.

The use of papaya seed powder as a natural coagulant for the pH parameter, as presented in Table 4, showed relatively small changes and a tendency toward stability across the different doses. The initial water pH was 7,27 and decreased following the addition of the coagulant. At a dose of 1 g, the pH decreased to 7,00; at 2 g, to 6,93; at 3 g, to 6,84; and at 4 g, to 6,76. The pH increased again to 6,77 at a dose of 5 g. These findings are consistent with Bhernama et al. (2023), who reported an increase in pH following the addition of 5 g of papaya seed coagulant. The decrease in pH occurs because proteins in papaya seeds contain carboxyl functional groups ($-COOH$) that can interact with the solution and release H^+ ions (Dewi & Rahmayanti, 2022). This differs from chemical

coagulants such as aluminum sulfate, which tend to cause a substantial decrease in pH (Nur et al., 2020). Thus, papaya seeds offer an advantage in maintaining water pH stability and may be used without requiring subsequent pH adjustment.

Optimum Dose

Based on the study results, the optimum dose of aluminum sulfate was 0,08 g, as it provided the best treatment performance compared with the other doses. At this dose, the COD concentration decreased from 679,24 mg/L to 315,3 mg/L, with a removal efficiency of 54%, while the TSS concentration decreased to 22,67 mg/L, meeting the applicable quality standard. Although the 0,1 g dose resulted in greater TSS removal, its COD removal efficiency decreased and the pH became more acidic. Therefore, the 0,08 g dose was selected as the optimum dose because it achieved the highest COD reduction and reduced TSS to within the applicable quality standard while maintaining a more favorable pH condition.

Based on the study results, the optimum dose of papaya seed powder was determined to be 1 g. This dose provided the highest COD removal efficiency of 91%, while the pH remained within the required quality standard range. Although TSS removal efficiency was relatively low at 3%, the 1 g dose was still selected as the optimum condition because it provided the best performance in reducing the organic pollutant load without causing significant changes in pH.

Effect of Coagulant Combinations on Water Quality Parameters

The results of the single-coagulant tests showed that aluminum sulfate was effective in reducing TSS and COD but caused a relatively substantial decrease in pH. In contrast, papaya seed powder maintained pH stability and provided high COD removal efficiency but was less effective in reducing TSS. Based on these findings, the two coagulants were combined to utilize their respective advantages and improve the effectiveness of water treatment for the Karang Mumus River. The combination treatments consisted of ratios of 25:75, 50:50, and 75:25 based on the optimum dose of each coagulant. These combinations were intended to determine the most effective composition for reducing TSS and COD while maintaining the pH within the applicable quality standard range.

Table 5. Results of Water Quality Parameter Testing of the Karang Mumus River Using a Combination of Coagulants

Coagulant Dose (g)	TSS (mg/L) ±SD	TSS Removal Efficiency (%)	COD (mg/L) ±SD	COD Removal Efficiency (%)	pH ±SD
0	50,67 ±2,3	-	840,73 ±39,37	-	7,27 ±0,02
25:75	118,67 ±6,11	-134	111,46 ±1,91	87	6,86 ±0,03
50:50	48 ±4	5	2,59 ±0,96	99,7	6,62 ±0,02
75:25	90,67 ±18,04	-79	31,37 ±4,21	96	6,37 ±0,03

Based on Table 5, the test results showed that the use of combined coagulants affected the TSS, COD, and pH parameters of Karang Mumus River water. The initial pH was 7,27, with TSS and COD concentrations of 50,67 mg/L and 840,73 mg/L, respectively. Following the addition of the combined coagulants at different dose ratios, the TSS concentrations varied. In contrast, the COD concentration decreased substantially compared with the initial condition. The pH tended to decrease, ranging from 6,37 – 6,86, but remained within the applicable quality standard range (6 – 9).

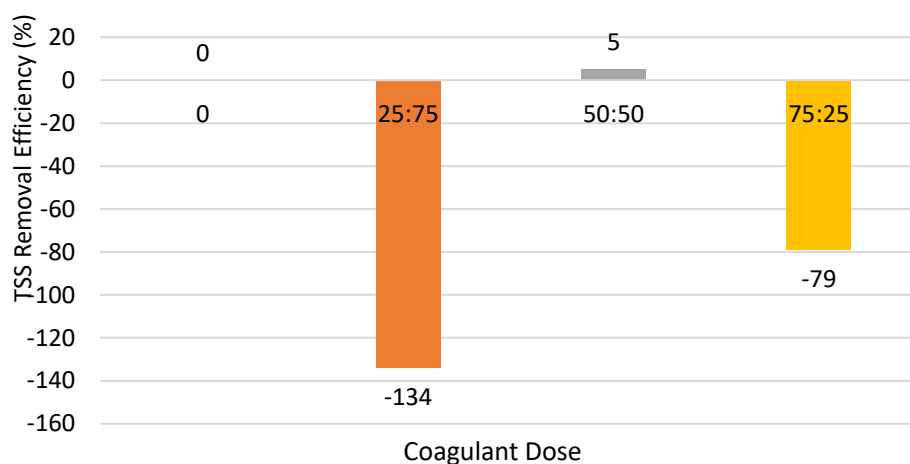


Figure 1. TSS Removal Efficiency with a Combination of Coagulants

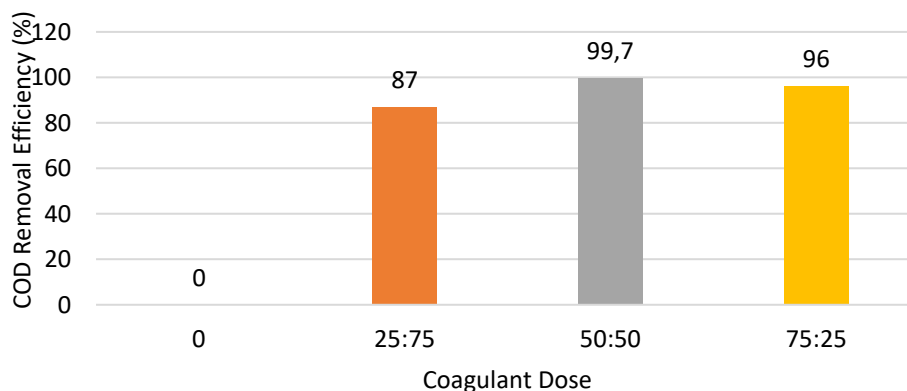


Figure 2. COD Removal Efficiency with a Combination of Coagulants

The effectiveness of the combined coagulants on the TSS parameter, as shown in Figure 1, indicated an increase in TSS, suggesting that the treatment was not yet optimal, with an initial TSS concentration of 50,67 mg/L. The increase and decrease in TSS concentrations across the combined coagulant ratios were influenced by the interaction between the coagulation mechanisms of aluminum sulfate and proteins in papaya seeds. Aluminum sulfate undergoes hydrolysis in water, producing $\text{Al}(\text{OH})_3$ flocs that neutralize the charges of suspended particles and aggregate smaller

particles into larger flocs, thereby facilitating sedimentation (Nur et al., 2020). Proteins in papaya seeds contain amino groups that can become -NH_3^+ , generating positive charges that neutralize negatively charged colloidal particles through charge neutralization (Fessenden & Fessenden, 1989).

The 25:75 combined coagulant ratio showed a removal efficiency of -134%, with a TSS concentration of 118,67 mg/L. The higher proportion of papaya seed coagulant resulted in an increase in TSS. The 75:25 combined coagulant ratio showed a removal efficiency of -79%, with a TSS concentration of 90,67 mg/L. The higher proportion of aluminum sulfate also resulted in an increase in TSS. This indicates that, under imbalanced compositions, the coagulation process did not proceed optimally, resulting in an increase in suspended particles, potentially due to the contribution of residual organic matter from papaya seeds (Dewi et al., 2025). Excessive addition of aluminum sulfate can reduce its effectiveness in decreasing TSS (Prameswara & Sa'diyah, 2024). The 50:50 ratio produced the best result, with a TSS concentration of 48 mg/L and a positive removal efficiency of 5%, although the value remained above the established quality standard of 40 mg/L. This finding indicates that a balanced coagulant composition provides better performance in reducing TSS than the other ratios. Thus, although it did not fully meet the applicable quality standard, the 50:50 ratio represented the condition closest to optimal for the TSS parameter.

The effectiveness of the combined coagulants on the COD parameter, as shown in Figure 2, demonstrated a substantial reduction from the initial COD concentration of 840,73 mg/L. At the 25:75 ratio, COD decreased to 111,46 mg/L, with a removal efficiency of 87%, whereas the 75:25 ratio resulted in a COD concentration of 31,37 mg/L, with a removal efficiency of 96%. The best result was obtained at the 50:50 ratio, with a COD concentration of 2,59 mg/L and the highest removal efficiency of 99,7%, which not only met but was substantially below the established quality standard of 10 mg/L. The high COD removal efficiency across all combined coagulant ratios indicates that aluminum sulfate and papaya seeds acted synergistically to remove organic matter from the water. Aluminum sulfate undergoes hydrolysis to produce Al(OH)_3 flocs capable of adsorbing, entrapping, and precipitating both dissolved and suspended organic matter, thereby reducing its concentration in the water (Nur et al., 2020). The amine groups (-NH_2) in papaya seeds can be protonated to form positively charged groups (-NH_3^+), which neutralize negatively charged colloidal particles and organic compounds, destabilizing these particles and promoting their aggregation into larger flocs that are more readily settled during the coagulation-flocculation process (Fessenden & Fessenden, 1989). The combination of these two mechanisms enhances the removal of organic matter responsible for the high COD concentration. Thus, the combined aluminum sulfate and papaya seed coagulants were highly effective in reducing COD, particularly at the 50:50 ratio, which represented the optimum condition for this parameter.

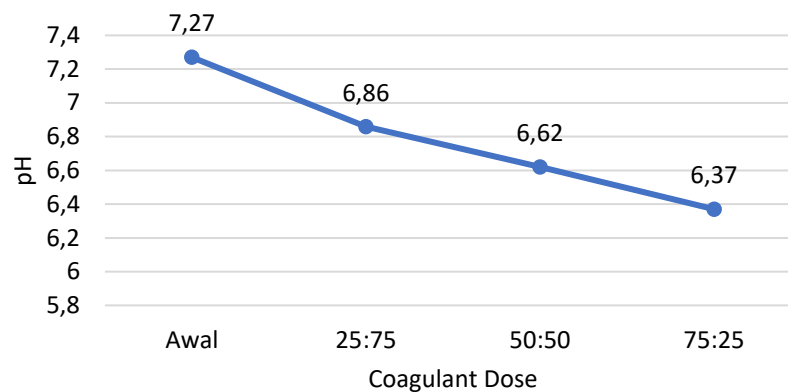


Figure 3. pH Measurement Results with a Combination of Coagulants

The use of combined coagulants for the pH parameter, as shown in Figure 3, indicated that the pH tended to decrease with increasing aluminum sulfate content in the coagulant combination. Initially, the water pH was 7,27, which decreased to 6,86 at the 25:75 ratio, 6,62 at the 50:50 ratio, and 6,37 at the 75:25 ratio. Despite this decrease, all pH values remained within the established quality standard range (6 – 9). Changes in pH following the use of combined coagulants were influenced by the interaction between aluminum sulfate and proteins present in papaya seeds during the coagulation-flocculation process. Aluminum sulfate dissolved in water undergoes hydrolysis, producing $\text{Al}(\text{OH})_3$ flocs and acidic H^+ ions. As the amount of aluminum sulfate increases, more H^+ ions are generated, causing the water pH to decrease (Nur et al., 2020). In contrast, proteins in papaya seeds contain amine groups ($-\text{NH}_2$) that can accept protons (H^+) and form ammonium groups ($-\text{NH}_3^+$) in an aqueous medium. This protonation process helps reduce the effect of free H^+ ions in the solution, thereby mitigating the decrease in pH (Fessenden & Fessenden, 1989). The presence of papaya seeds in the combined coagulants used in this study played an important role in maintaining pH stability, whereas increasing the aluminum sulfate content in the combined doses tended to decrease the pH. This study demonstrates that the use of combined coagulants can maintain water pH stability compared with the use of aluminum sulfate alone. Thus, combining the two coagulants provides an advantage in maintaining the pH within the range that meets water quality standards.

4. CONCLUSION

The results showed different performance characteristics for each coagulant. Aluminum sulfate reduced TSS by 70% at a dose of 0,1 g. However, the optimum dose was determined to be 0.08 g based on the highest COD removal efficiency of 54%, with a 54% reduction in TSS that met the applicable quality standard. Papaya seeds maintained pH stability within the applicable quality standard range and were highly effective in reducing COD, with the highest removal efficiency of 91% at the optimum dose of 1 g. However, they were less effective in reducing TSS because several doses increased TSS due to residual organic particles that had not completely settled. The combination of aluminum sulfate and papaya seeds was effective for treating Karang Mumus River water. The 50:50 combination ratio reduced TSS and COD while maintaining the pH within the applicable quality standard range, although the TSS concentration did not meet the quality

standard. The initial TSS concentration of 50,67 mg/L decreased to 48 mg/L (quality standard: 40 mg/L), with a removal efficiency of 5%; the initial COD concentration of 840,73 mg/L decreased to 2,59 mg/L (quality standard: 10 mg/L), with a removal efficiency of 99,7%; and the initial pH of 7,27 decreased to 6,62 (quality standard: 6 – 9), thereby meeting the applicable quality standard based on Government Regulation Number 22 of 2021, Class I.

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