

Effectiveness of Banana Stem, Lemongrass and Pandan Leaves Powder as Bio-coagulant and Biosorbent in Water Treatment

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Abstract

Water quality is a critical global concern, and conventional water treatment using chemical coagulants like aluminum sulfate often has environmental drawbacks. This study evaluates the potential of agricultural by-products such as banana stem, lemongrass, and pandan leaves as sustainable alternatives for water treatment. The bio-coagulants and biosorbents were extracted using sodium chloride solution and characterized using Fourier-transform infrared spectroscopy (FTIR). Their effectiveness in reducing turbidity, stabilizing pH, and improving dissolved oxygen levels in the Muar River's polluted water was tested using jar tests. Results demonstrated not significant turbidity reduction as its only reduce 4.6% for banana stem bio-coagulant, 10.2% for combination bio-coagulant while 6% for banana stem biosorbent and combination biosorbent. The pH stabilization for the banana stem bio-coagulant caused a decrease in pH from 7.32 to 6.71, combination bio-coagulant maintained stable pH levels between 6.19 and 6.29 while the banana stem biosorbent exhibited a slight increase in pH, rising from 5.69 to 6.88 at a 1.0 g dose, The combination biosorbent showed minimal changes in pH (5.82 to 6.08), indicating a balanced chemical composition that avoids significant fluctuations. The findings suggest that bio-coagulant and biosorbent are eco-friendly and cost-effective alternatives for enhancing water quality, promoting public health, and minimizing ecological impact.

1. Introduction

Water is an essential resource that supports life, ecosystems, and economic growth. However, the quality of water sources globally has been increasingly compromised due to pollution from industrial discharge, agricultural runoff, and domestic waste. These pollutants introduce turbidity, harmful chemicals, and pathogens into water bodies, making effective treatment processes a necessity for ensuring safe and clean water for consumption, agriculture, and industrial use [1]. Traditional water treatment relies heavily on chemical coagulants, such as aluminum sulfate (alum) and ferric chloride, to remove suspended particles and contaminants. To ensure high effectiveness, these methods present several challenges. The high costs of chemical coagulants, particularly in rural or resource-limited areas, the production of large volumes of sludge, and potential residual chemical contamination in treated water have driven the search for alternative solutions. Moreover, the environmental concerns associated with chemical coagulants have prompted researchers to explore natural and biodegradable materials as viable substitutes [2].

Natural coagulants derived from agricultural by-products, such as banana stems, lemongrass, and pandan leaves, offer an eco-friendly and cost-effective solution. These materials contain bioactive compounds such as phenols, glycosides, and flavonoids, which neutralize the charges of suspended particles and facilitate their aggregation and removal. Additionally, they are biodegradable and non-toxic, making them a sustainable alternative to conventional coagulants. Previous studies have demonstrated the potential of these natural coagulants in reducing turbidity, stabilizing pH, and improving water quality parameters [3][4].

The study on banana stem, lemongrass, and pandan leaf powder as bio-coagulants and biosorbents for water treatment coincides with sustainable water management trends. Due to their biodegradability and non-toxicity, natural coagulants are a feasible alternative to artificial coagulants like alum[5]. These natural coagulants may reduce water sample turbidity, TDS, and BOD, which are important water treatment parameters. Biopolymers like Zeoturb in aided electrocoagulation could revolutionise surface water pollution removal[5].

Despite these hopeful improvements, insufficient studies exist. More research is needed on these bio-coagulants' long-term stability and efficiency in different environments. Bio-coagulants are affected by pH, temperature, and starting turbidity[6]. Natural coagulants provide environmental benefits, but their scalability and cost-effectiveness compared to traditional methods need further study[6][7]. To maintain uniform performance across applications, bio-coagulants must be extracted and purified using standardised methods[6]. These gaps must be closed for bio-coagulants to be widely used in water treatment.

2. Materials and Methods

This study employed a systematic approach to investigate the use of banana stems, lemongrass, and pandan leaves as natural bio-coagulants and biosorbents in water treatment. The process involved three main stages: the preparation of materials, characterization of functional groups, and performance evaluation in treating water from the Muar River.

2.1 Preparation of Materials

The raw materials, including banana stems, lemongrass, and pandan leaves, were sourced locally. The fresh banana stems were washed thoroughly, cut into small pieces, and dried in an oven at 60°C for 24 hours. Once dried, they were ground into a fine powder using a grinder. Similarly, the lemongrass and pandan leaves were washed, chopped, and dried at a temperature between 103°C and 110°C for 24 hours before being ground into powder. These powders were sieved using a 0.5 mm sieve to ensure uniform particle size, as recommended in [4].

2.2 Extraction of Bio-coagulant and Biosorbent

The powdered materials were separated into two portions: one for direct use as biosorbents and the other for bio-coagulant preparation. For the latter, 1 g of each powder was mixed with 1M sodium chloride (NaCl) solution to extract the active coagulation compounds. The mixture was stirred at 70 rpm for 20 minutes at 41.5°C to ensure proper extraction. After settling for 30 minutes, the supernatant was filtered using a rugged filter paper (0.45 microns) to obtain the crude bio-coagulant solution. The filtered bio-coagulants were stored at 4°C in a refrigerator for subsequent testing. As for the combination of bio-coagulant, the ratio that used 50% banana stem extract, 30% pandan leaves extract and 20% lemongrass extract while for the biosorbent was 50% banana powder, 30% pandan leaves powder and 20% lemongrass powder.

2.3 Characterization using FTIR

Fourier-transform infrared spectroscopy (FTIR) was used to identify the functional groups present in the bio-coagulants and biosorbents. The analysis was conducted with a Spectrum 65 FTIR spectrophotometer over a range of 4000 to 400 cm^{-1} . Functional groups such as hydroxyl (-OH), carbonyl (C=O), and C-H stretching vibrations were identified based on their characteristic peaks, consistent with prior research.[2]

2.4 Performance Evaluation via Jar Test

The effectiveness of the bio-coagulants was assessed using the jar test method. Muar River water samples were collected and divided into six 500 mL beakers. A measured dose of bio-coagulant (5 mL) was added to each beaker. The samples underwent rapid mixing at 100–250 rpm for 1 minute to disperse the coagulant, followed by slow mixing at 60 rpm for 15 minutes to promote particle collision and floc formation. The flocs were allowed to settle for 30 minutes, after which the turbidity, pH, conductivity, and dissolved oxygen levels were measured [3].

3. Result and Discussion

The results of this study revealed the potential of banana stems, lemongrass, and pandan leaves as effective natural coagulants and biosorbents for water treatment.

3.1 Fourier-transform Infrared Spectroscopy (FTIR) Analysis

FTIR analysis provided insights into the functional groups present in the bio-coagulants and biosorbents, which play a critical role in their water treatment efficacy. The bio-coagulants exhibited peaks corresponding to hydroxyl (-OH) groups at 3350.26 cm^{-1} , indicating their hydrophilic nature and potential for solubility in water. Carbonyl (C=O) groups observed at 1634.60 cm^{-1} suggest the presence of aldehydes, ketones, or carboxylic acids, which enhance their ability to interact with and neutralize charged particles. Similar functional groups were identified in the biosorbents, suggesting comparable organic and hydrophilic properties.[4]

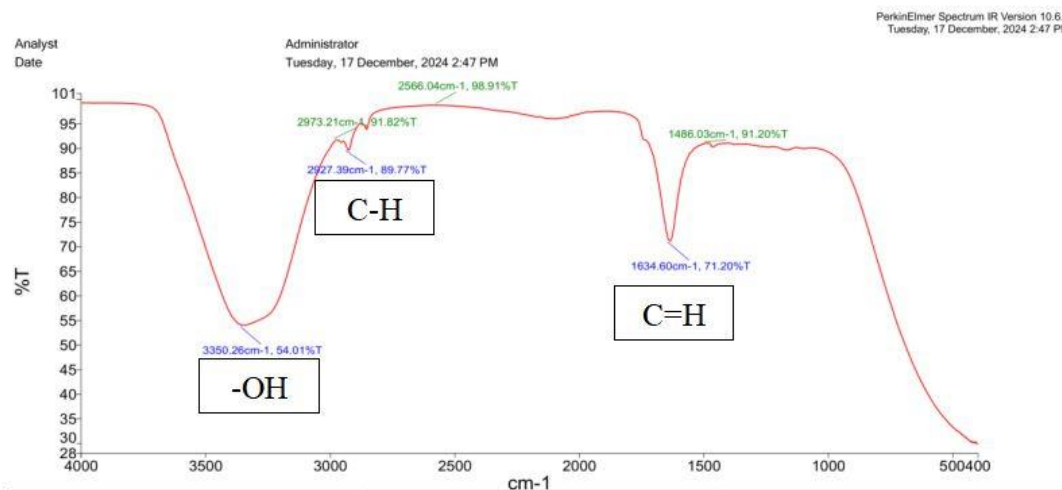


Fig. 1: FTIR graph combination bio-coagulant

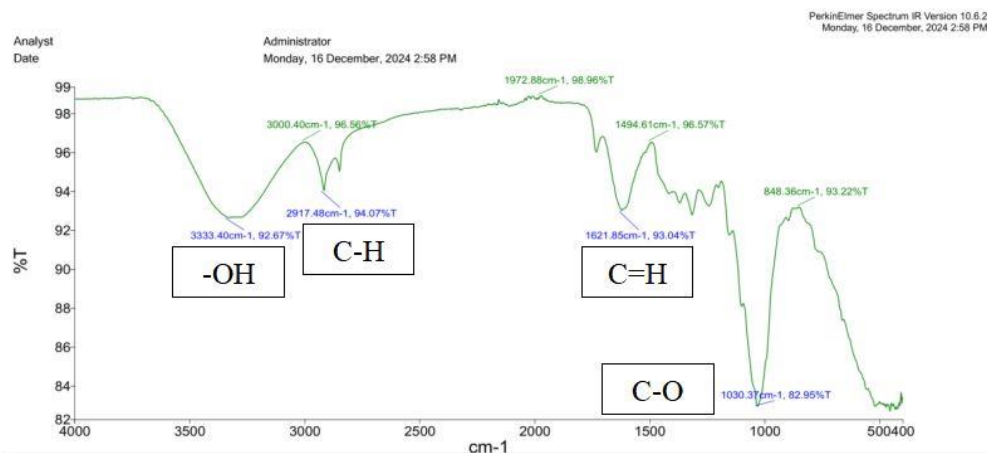


Fig. 2: FTIR graph combination biosorbent

3.2 Effectiveness in Turbidity Reduction

The effectiveness of various bio-coagulants and biosorbents in reducing turbidity was assessed through jar tests, revealing significant variations in performance and shows in table 1. The banana stem bio-coagulant showed limited effectiveness, with turbidity only marginally decreasing from an initial value of 54.7 NTU to a final range of 52.2–54.5 NTU, indicating a maximum reduction of about 4.6%. This minimal improvement suggests that the banana stem bio-coagulant lacks sufficient coagulation activity to aggregate and settle suspended particles effectively, potentially due to inadequate floc formation [8].

In contrast, the combination bio-coagulant performed moderately better, achieving a turbidity reduction from 73.4 NTU to a range of 65.9–67.8 NTU, which corresponds to a reduction of approximately 10.2%. While this result indicates a stronger coagulation effect compared to the banana stem bio-coagulant, it still falls short of the efficiency levels required for stringent water quality standards, which typically demand turbidity levels below 1 NTU. Previous research supports the notion that combining coagulants can enhance effectiveness by targeting a wider range of particle sizes and charges; however, further optimization is necessary to improve performance. [9]

The banana stem biosorbent demonstrated negligible impact on turbidity reduction, with values decreasing from an initial 120 NTU to a final range of 113–117 NTU, representing a mere 6% decrease. This limited performance suggests that the biosorbent may have low adsorption capacity due to factors such as insufficient surface area or weak interactions with suspended solids. Additionally, the combination biosorbent exhibited minimal turbidity reduction and even showed an increase in turbidity at higher doses due to leaching of fine particles from the biosorbent material. These findings highlight the need for pretreatment methods to enhance adsorption capacity and minimize leaching for effective turbidity removal.[10]

Table 1: Turbidity Reduction Result

Sample	Initial Turbidity (NTU)	Final Turbidity (NTU)	Turbidity Reduction (%)
Banana Stem Bio-coagulant (Extracted by NaCl)	54.7	52.2 – 54.5	0.37 – 4.57
Combination Bio-coagulant (Extracted by NaCl) (50% banana stem extract, 30% pandan leaves extract, 20% lemongrass extract)	73.4	65.9 – 73.4	0.00 – 10.22
Banana Stem Biosorbent (100% banana stem powder)	120.0	113 – 120	0.00 – 5.83
Combination Biosorbent (50% banana stem powder, 30% pandan leaves powder, 20% lemongrass powder)	47.3	43.5 – 53.2	-12.46 – 8.03

3.3 pH Stabilization and Conductivity Changes

The assessment of pH changes resulting from the application of different bio-coagulants and biosorbents reveals varying impacts on water chemistry. The banana stem bio-coagulant caused a decrease in pH from 7.32 to 6.71, indicating mild acidification, which may introduce challenges for applications that require pH neutrality, such as drinking water treatment. This acidification could result from the release of organic acids or hydrolysis of active compounds within the coagulant. While this level of pH change is not extreme, it is significant enough to warrant consideration in contexts where maintaining neutral pH is crucial for preventing corrosion and ensuring effective disinfection. [8]

In contrast, the combination bio-coagulant maintained stable pH levels between 6.19 and 6.29, suggesting that it does not introduce significant acidic or basic compounds into the water. This stability is advantageous for applications requiring tight pH control, such as coagulation-flocculation processes and chlorine-based disinfection, which are most effective within a specific pH range. The observed stability may result from the interaction of the combined materials neutralizing each other’s effects, enhancing its suitability for water treatment applications.[9]

The banana stem biosorbent exhibited a slight increase in pH, rising from 5.69 to 6.88 at a 1.0 g dose, although variability was noted at higher doses. This behavior suggests that the biosorbent may release alkaline compounds or adsorb acidic species from the water. However, the inconsistent performance at higher doses raises concerns regarding its reliability in systems requiring precise pH control. Such fluctuations highlight the need for potential chemical or thermal modifications to enhance the biosorbent’s stability and performance.[11] The combination biosorbent showed minimal changes in pH (5.82 to 6.08), indicating a balanced chemical composition that avoids significant fluctuations.

Regarding conductivity, the banana stem bio-coagulant caused a substantial increase from 31 μS/m to 1,217 μS/m at a 25 mL dose, suggesting significant ion leaching into the water, which can be detrimental for

applications requiring low conductivity levels. In contrast, the combination bio-coagulant effectively reduced conductivity from 109.8 $\mu\text{S/m}$ to as low as 5.7 $\mu\text{S/m}$, indicating successful ion removal through adsorption mechanisms. The banana stem biosorbent also increased conductivity significantly from 37.3 $\mu\text{S/m}$ to 536 $\mu\text{S/m}$ at higher doses due to potential leaching of ions from its material composition. Meanwhile, the combination biosorbent exhibited a moderate increase in conductivity (from 75.7 $\mu\text{S/m}$ to 188.2 $\mu\text{S/m}$), suggesting some ion exchange or leaching occurs but is less severe than with single-material biosorbents. Overall, understanding these interactions is essential for selecting suitable materials for specific water treatment objectives and highlights the importance of optimizing coagulants and biosorbents for effective performance. [12]

Sample	Initial pH	Final pH range
Banana Stem Bio-coagulant (Extracted by NaCl)	7.32	6.71 – 7.66
Combination Bio-coagulant (Extracted by NaCl)	6.19	6.21 – 6.39
Banana Stem Biosorbent	5.69	5.69 – 6.88
Combination Biosorbent	5.82	5.99 – 6.08

(a)

Sample	Initial Conductivity ($\mu\text{S/m}$)	Final Conductivity Range ($\mu\text{S/m}$)
Banana Stem Bio-coagulant (Extracted by NaCl)	31.0	32.0 – 1217.0
Combination Bio-coagulant (Extracted by NaCl)	109.8	5.70 – 23.5
Banana Stem Biosorbent	37.3	37.3 – 536.0
Combination Biosorbent	75.7	48.0 – 188.2

(b)

Fig. 2: Parameter Result (a) pH Stability; (b) Conductivity Changes

3.4 Analysis of Methodological Flaws and Resulting Inefficiencies in Water Treatment Study

The intention of the study was to treat Muar River water in order to assess how well natural coagulants banana stem, lemongrass, and pandan leaves improve water quality. Although there is a lot of promise in using these natural coagulants, the methodology and findings highlight important issues that could lead to the approach's failure or poor performance. The preparation of natural coagulants relied on using 1M sodium chloride for the extraction process. While this method is effective in dissolving active compounds, it raises questions about the purity and stability of the extracted bioactive components. Sodium chloride might interact with the coagulant compounds, influencing their efficacy in removing turbidity, pH stabilization, and dissolved oxygen levels. As indicated by prior studies, alternative solvents or techniques, such as ethanol extraction, might yield more robust and efficient coagulants.[13]

The jar test used to evaluate coagulation effectiveness did not sufficiently optimize dosage and mixing conditions. Rapid mixing at inconsistent speeds (100–250 rpm) and settling periods lacked a rigorous optimization framework, which is crucial to maximize the effectiveness of natural coagulants. Literature suggests that fine-tuning mixing speeds and times based on specific water chemistry is essential for effective coagulation.[2] While the study observed significant turbidity reduction, it did not explore critical trade-offs, such as conductivity increases due to the added salts from the extraction process. Additionally, the lack of comparison with conventional chemical coagulants under identical conditions diminishes the reliability of the results. Effective benchmarking against industry standards is necessary to assess the practicality of natural coagulants [14].

Fourier Transform Infrared Spectroscopy (FTIR) analysis identified functional groups, such as hydroxyl (-OH) and carbonyl (C=O), but failed to correlate these groups with coagulation performance metrics. Without a detailed functional analysis, it becomes challenging to establish a mechanistic link between the chemical structure of the coagulants and their performance. Studies on coagulant mechanisms emphasize the importance of such correlations to refine coagulant design [15].

4. Conclusion

This study evaluated the effectiveness of banana stem, lemongrass, and pandan leaves as natural coagulants and biosorbents for improving water quality from the Muar River. The results indicated that these natural coagulants not significantly reduced turbidity, with combination bio-coagulant showing the highest efficiency in term of turbidity reduction that is 10.6% reduction, has stable pH values between 6.19 and 6.29 while reduced the conductivity from 109.8 $\mu\text{S/m}$ to as low as 5.7 $\mu\text{S/m}$, indicating successful ion removal through adsorption mechanisms. This shown that the combination have potential to be a pH stabilizer for water treatment.

However, comparison with traditional chemical coagulants like alum shows that this type of agricultural waste no suitable for an option to replace the traditional coagulant.

In conclusion, while the research highlights the potential of agricultural waste products as sustainable alternatives for water treatment, further investigation is necessary to refine methodologies and optimize performance for scalability in broader applications. The eco-friendly nature of these coagulants could provide a cost-effective solution for enhancing water quality, particularly in regions facing clean water shortages, but addressing economic feasibility and practical implementation remains essential for their widespread adoption.

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Conflict of Interest

The author declares no conflict of interest regarding the publication of this article.

Appendix A : Jar Tests Result for Bio-coagulant

Result for banana stem bio-coagulant extracted by NaCl

Banana Stem Bio-coagulant	Beaker					
	Blank	1	2	3	4	5
Volume of coagulant, mL	-	5	10	15	20	25
Initial pH	7.32	7.32	7.32	7.32	7.32	7.32
Initial turbidity, NTU	54.7	54.7	54.7	54.7	54.7	54.7
Initial conductivity, $\mu\text{S/m}$	31.0	31.0	31.0	31.0	31.0	31.0
Initial temperature	26.9	26.9	26.9	26.9	26.9	26.9
Initial DO, mg/L	6.36	6.36	6.36	6.36	6.36	6.36
Final pH	7.66	7.23	7.04	6.86	6.83	6.71
Final turbidity, NTU	54.5	52.2	53.9	52.7	52.9	53.0
Final conductivity, $\mu\text{S/m}$	32.0	180	506	933	1217	776
Final Temperature	24.2	24.2	24.2	24.2	24.2	24.2
Final DO, mg/L	6.01	5.52	5.09	5.28	5.10	5.03

Result for combination bio-coagulant extracted by NaCl

Combination Bio-coagulant	Beaker					
	Blank	1	2	3	4	5
Volume of coagulant, mL	0	100	110	120	130	140
Initial pH	6.19	6.19	6.19	6.19	6.19	6.19
Initial turbidity, NTU	73.4	73.4	73.4	73.4	73.4	73.4
Initial conductivity, $\mu\text{S/m}$	109.8	109.8	109.8	109.8	109.8	109.8
Initial temperature	25.2	25.2	25.2	25.2	25.2	25.2
Initial DO, mg/L	5.03	5.03	5.03	5.03	5.03	5.03
Final pH	6.33	6.21	6.26	6.39	6.33	6.29
Final turbidity, NTU	73.4	67.1	67.1	67.8	66.6	65.9
Final conductivity, $\mu\text{S/m}$	23.5	11.12	5.73	5.98	5.70	14.43
Final Temperature	23.8	23.8	23.4	23.2	22.9	23.0
Final DO, mg/L	5.64	6.50	5.72	5.98	5.34	5.44

Appendix B : Jar Tests Result for Biosorbent

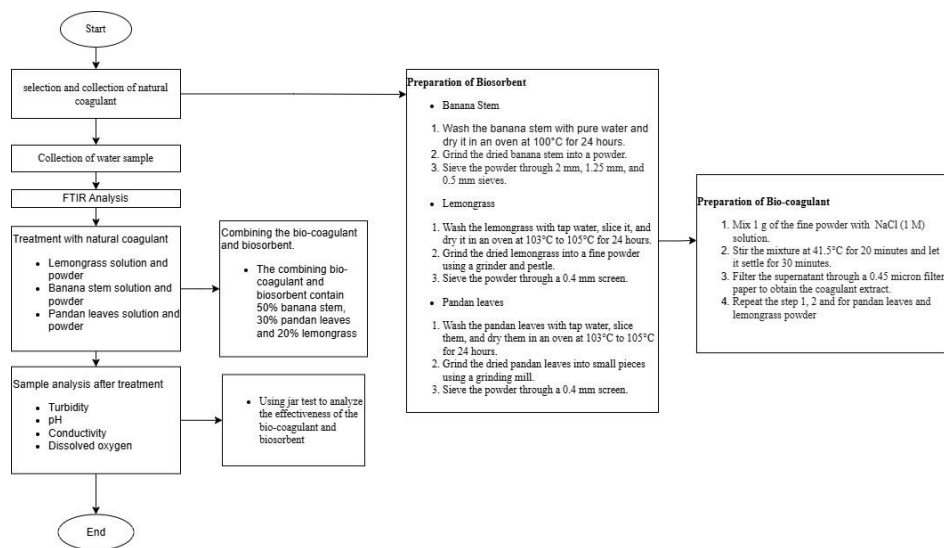
Result for banana stem biosorbent

Banana Stem Biosorbent	Beaker					
	Blank	1	2	3	4	5
Volume of coagulant, g	0	0.5	1.0	1.5	2.0	2.5
Initial pH	5.69	5.69	5.69	5.69	5.69	5.69
Initial turbidity, NTU	120	120	120	120	120	120
Initial conductivity, $\mu\text{S/m}$	37.3	37.3	37.3	37.3	37.3	37.3
Initial temperature	25.2	25.2	25.2	25.2	25.2	25.2
Initial DO, mg/L	4.42	4.42	4.42	4.42	4.42	4.42
Final pH	5.69	6.30	6.88	5.82	5.80	5.72
Final turbidity, NTU	120	113	117	115	114	116
Final conductivity, $\mu\text{S/m}$	37.3	71.6	251.2	361	437	536
Final Temperature	23.5	23.2	23.2	23.2	23.2	23.0
Final DO, mg/L	4.42	4.64	4.65	4.65	4.48	4.32

Result for combination biosorbent

Combination Biosorbent	Beaker					
	Blank	1	2	3	4	5
Volume of coagulant, g	0	0.5	1.0	1.5	2.0	2.5
Initial pH	5.82	5.82	5.82	5.82	5.82	5.82
Initial turbidity, NTU	47.3	47.3	47.3	47.3	47.3	47.3
Initial conductivity, $\mu\text{S/m}$	75.7	75.7	75.7	75.7	75.7	75.7
Initial temperature	24.7	24.7	24.7	24.7	24.7	24.7
Initial DO, mg/L	3.50	3.50	3.50	3.50	3.50	3.50
Final pH	5.99	6.05	6.06	6.08	6.07	6.04
Final turbidity, NTU	45.4	43.5	48.3	48.9	51.1	53.2
Final conductivity, $\mu\text{S/m}$	48.0	80.5	75.6	146.1	168.9	188.2
Final Temperature	23.9	23.8	23.6	23.6	23.5	23.2
Final DO, mg/L	4.00	4.05	4.13	4.01	4.44	4.21

Appendix C : Flowchart of Bio-coagulant and Biosorbent Preparation



Flowchart of Bio-coagulant and Biosorbent Preparation

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References

- [1] Ireland, T. (2021, November 1). This is why water is essential for life on Earth... and perhaps the rest of the Universe. *Www.sciencefocus.com*. <https://www.sciencefocus.com/nature/does-all-life-need-water>
- [2] Asharuddin, S. M., Othman, N., Zin, N. S. M., Din, M. F. M., & Kumar, V. (2020). Synthesis and Characterization of Dual Properties Coagulant from Natural Precursors for Raw Water Treatment. *International Journal of Integrated Engineering*, 12(8), 257–267. <https://penerbit.uthm.edu.my/ojs/index.php/ijie/article/view/7115>
- [3] Muda, K., Shahidah, N., Ali, A., Abdullah, N., & Sahir, A. (2020). Potential Use of Fruit Seeds and Plant Leaves as Coagulation Agent in Water Treatment. *Journal of Environmental Treatment Techniques*, 2020(3), 971–977. <https://core.ac.uk/download/395090295.pdf>
- [4] Getachew Semegn Tiruneh, Wondalem Misganaw Golie, Fasil Alemayehu Hailu, Assefa Melaku Endris, & Getahun Demeke. (2023). Extraction and Characterization of Natural Coagulant Made from Banana Plant Stems (*Musa acuminata*) for the Removal of Turbidity from Wastewater. *International Journal of Polymer Science*, 2023, 1–10. <https://doi.org/10.1155/2023/5574706>
- [5] Tech, G. W. (2023, September 7). Natural Coagulants: What is Best for Water Treatment? *Genesis Water Technologies*. <https://genesiswatertech.com/blog-post/natural-coagulants-what-is-best-for-water-treatment/>

- [6] Abderrezzaq Benalia, Kerroum Derbal, Zahra Amrouci, Ouiem Baatache, Amel Khalfaoui, & Pizzi, A. (2024). Application of Plant-Based Coagulants and Their Mechanisms in Water Treatment: A Review. *Journal of Renewable Materials*, 12(4), 667–698. <https://doi.org/10.32604/jrm.2024.048306>
- [7] Abdullahi Sanda Ndayako, Badruddeen Saulawa Sani, Umar Alfa Abubakar, Isama, S. U., & A. Yakubu. (2023). Assessing the Efficacy of Bio-Coagulants in Water Treatment. *Deleted Journal*, 1(1), 20–29. [https://doi.org/10.59324/ejaset.2023.1\(1\).03](https://doi.org/10.59324/ejaset.2023.1(1).03)
- [8] Yin, C.-Y. (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. *Process Biochemistry*, 45(9), 1437–1444. <https://doi.org/10.1016/j.procbio.2010.05.030>
- [9] Valverde, K. C., Paccola, E. A. de S., Pomini, A. M., Yamaguchi, N. U., & Bergamasco, R. (2018). Combined water treatment with extract of natural *Moringa oleifera* Lam and synthetic coagulant. *Ambiente E Agua - an Interdisciplinary Journal of Applied Science*, 13(3), 1. <https://doi.org/10.4136/ambi-agua.2135>
- [10] Bhatnagar, A., & Sillanpää, M. (2010). Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment—A review. *Chemical Engineering Journal*, 157(2-3), 277–296. <https://doi.org/10.1016/j.cej.2010.01.007>
- [11] Foo, K. Y., & Hameed, B. H. (2010). Insights into the modeling of adsorption isotherm systems. *Chemical Engineering Journal*, 156(1), 2–10. <https://doi.org/10.1016/j.cej.2009.09.013>
- [12] Staszak, K., & Regel-Rosocka, M. (2024). Removing Heavy Metals: Cutting-Edge Strategies and Advancements in Biosorption Technology. *Materials*, 17(5), 1155–1155. <https://doi.org/10.3390/ma17051155>
- [13] Sharma, S., Sharma, S., & Soni, K. (2020). Lemongrass: it's uses, medicinal and industrial properties. <https://justagriculture.in/files/newsletter/nov/065.%20Lemongrass.pdf>
- [14] Ganna Trokhymenko, & Yuliia Chestnykh. (2024). Analysis of the efficiency of the application of natural coagulants. *Technology Audit and Production Reserves*, 2(3(76)), 48–52. <https://doi.org/10.15587/2706-5448.2024.303190>
- [15] Jaganathan, J. S., Abdullah, S. R. S., Ismail, N. 'Izzati, & Sharuddin, S. S. N. (2022). Coagulation-Flocculation Process of Nutrient-Rich Suspended Solids from Aquaculture Effluent Using Bioflocculant. *Journal of Biochemistry, Microbiology and Biotechnology*, 10(SP2), 46–56. <https://doi.org/10.54987/jobimb.v10isp2.728>