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Treatment of Laundry Wastewater using Papaya and Okra Seed Bio-coagulant

Mohamad Rakizi Sidi[1], Norhafezah Kasmuri[1,2]*, Khuriah Abdul Hamid[3], Satoto Endar Nayono[4], Mohd Fuad Miskon[5] and Amin Mojiri[6]
[1]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2]Centre of Foundation Studies, Universiti Teknologi MARA, Cawangan Selangor, Kampus Dengkil 43800, Selangor, Malaysia
[3]Department of Pharmaceutics, Faculty of Pharmacy, Universiti Teknologi MARA Cawangan Selangor, Puncak Alam 42300, Selangor, Malaysia
[4]Department of Civil Engineering and Planning, Faculty of Engineering, Universitas Negeri Yogyakarta, Jalan Colombo 1, Yogyakarta 55281, Indonesia
[5]Institute of Oceanography and Maritime Studies (INOCEM), Kulliyyah of Science, International Islamic University Malaysia, Bandar Indera Mahkota, 25200 Kuantan, Pahang, Malaysia
[6]Nanosystems Engineering Research Centre for Nanotechnology-Enabled Water Treatment, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287, USA
*Corresponding author (e-mail: norhafezahkasmuri@uitm.edu.my)

Laundry wastewater contains high levels of organic and chemical pollutants that are often discharged untreated, threatening aquatic ecosystems. It can be noted that most of the laundry wastewater is directly discharged to the monsoon drains without proper pretreatment. Thus, this scenario creates pollutant hazards to the water bodies due to the accumulation of high organic substances in the discharges. This study aimed to evaluate the effectiveness of natural coagulants, specifically papaya seed powder and a combination of papaya seed with okra seed, in treating laundry wastewater. This study also compared natural and chemical coagulants, such as polyaluminium chloride (PAC). The samples of wastewater were collected from the laundry shop in Shah Alam. A jar test experiment evaluated parameters such as pH, turbidity, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrate-nitrogen, nitrite-nitrogen and ammonia-nitrogen. Fourier-transform infrared spectroscopy was used to signify the coagulant's chemical transformation before and after the jar test experiment. The morphology using a Scanning Electron Microscope (SEM) was also done to visualise the changes before and after the treatment. The results demonstrated that papaya seed powder achieved 93.98% reduction in COD, 84.44% decrement in BOD, and 94.54% depletion in turbidity, showing that this coagulant was the most effective treatment among other coagulants. Compared to PAC, the natural coagulants were more potent in reducing turbidity and COD, though PAC showed higher efficiency in BOD removal. FTIR analysis indicated that functional groups such as O-H and C-H were consistently present before and after treatment, suggesting the stability and effectiveness of these natural coagulants. It concludes that natural coagulants, particularly papaya seed powder, are not only effective in removing pollutants from laundry wastewater but also align with the principles of environmental stewardship. Beyond meeting water quality standards, this green technology offers a low-cost, scalable, and sustainable alternative to chemical coagulants. Its adoption can reduce ecological impacts, lower operational expenses, and accelerate the transition toward cleaner production systems. The findings call for broader implementation of such bio-based solutions in wastewater treatment policies, industry practices, and future research to drive global progress toward sustainable water management.

Keywords: Coagulant; Okra seed; papaya seed; polyaluminium chloride

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Laundry is an essential activity that aids humans daily, especially during rainy seasons. The demand for launderettes in communities has been increasing. This laundry shop needs to be equipped with an adequate piping system and installation of pretreatment for wastewater disposal [1, 2]. Laundry wastewater contains high phosphate, which can cause eutrophication due to algae blooms. High levels of chemicals in the detergents used in the laundry wastewater can also harm aquatic life and create water pollution issues [3 – 5]. Coagulation, the process of destabilising colloidal particles, and flocculation, the process of forming larger particles from the destabilised ones, are common processes in the treatment of water. This

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selection method has several reasons: this treatment is low-cost, easy to handle, and energy-saving. Therefore, coagulation and flocculation in treating laundry wastewater are considered suitable options. Among the treatments for laundry wastewater, physical and chemical treatments are reported to be effective in pollutant removal [6 – 8].

Using bio-coagulants, typically green materials, such as papaya seed and okra seed, in the coagulation and flocculation process can reduce harm to human health compared to conventional methods [9 – 11]. The positively charged proteins in papaya seeds are attached to negatively charged particles such as silt, clay, and bacteria in forming flocs, which later can settle by gravity. Water contaminated with faecal bacteria can also be treated with papaya seeds [9]. Moreover, hydroxyl groups in okra powder are active sites that can remove colloidal particles that cause water turbidity. Okra demonstrates potential as a cost-effective, biodegradable bio-flocculant, augmenting water treatment processes and inspiring further exploration and innovation in the use of bio-coagulants.

This study aims to characterise laundry wastewater by analysing its turbidity, pH, suspended solids (SS), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate-nitrogen, nitrite-nitrogen, and ammonia-nitrogen levels. The research evaluates the optimum dosage of bio-coagulants derived from papaya seeds and a novel combination of papaya and okra seeds, benchmarking their performance against conventional polyaluminium chloride (PAC) in reducing pollutants. The effectiveness of the coagulation–flocculation process was assessed based on the percentage removal of contaminants in treated effluent.

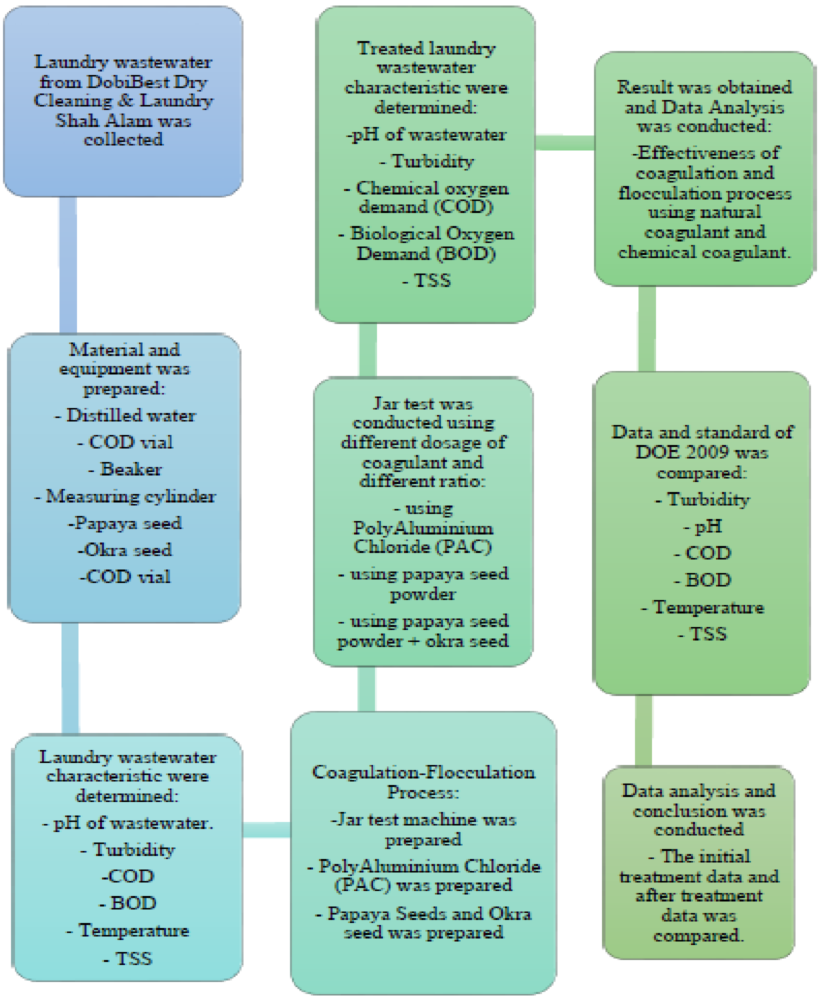


Figure 1. Flowchart of the methodology.

The novelty of this research lies in the first-time application and comparative evaluation of papaya seed–okra seed bio-coagulant blends for laundry wastewater treatment, offering an eco-friendly, sustainable, and cost-effective alternative to chemical coagulants. By exploring synergistic effects between the two bio-coagulants, this study not only addresses environmental concerns related to chemical sludge generation but also contributes to advancing green treatment technologies tailored for high-strength laundry effluents.

MATERIALS AND METHOD

Experimental Works

All the materials and equipment were prepared according to standard methods [12]. The experiment was conducted in the Environmental Laboratory in the Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia. Figure 1 presents the flowchart of the research activities, outlining the procedure from the preparation stage through to the evaluation of results. Table 1 provides a summary of each experimental stage along with its corresponding objectives and expected outcomes.

Preparation of Coagulants

Papaya and okra are easily obtained and available at orchards and markets. The seeds of papaya and okra were collected and extensively cleaned to reduce impurities. The seeds were dried in the oven for ten hours at 110°C. The dried seeds were crushed and sieved to form papaya and okra seed powder. Figure 2 displays the crushing process of the papaya and okra seeds.

Table 1. Summarise the experimental stage and the expected outcome.

Stage	Description / Purpose	Key Activities	Expected Outcome
1. Sample Collection	Obtain a representative laundry wastewater sample	Collect from DobiBest Dry Cleaning & Laundry (Shah Alam)	Sufficient raw wastewater sample for analysis
2. Material Preparation	Prepare equipment and materials for experiments	Distilled water, COD vials, beakers, measuring cylinder, papaya seed, okra seed	All materials are ready for characterisation and treatment
3. Initial Characterisation	Determine baseline water quality	Measure pH, turbidity, COD, BOD, temperature, and TSS	Baseline pollutant profile of raw wastewater
4. Jar Test Setup	Assess coagulant performance at various dosages	Prepare PAC, papaya seed powder, papaya–okra seed blend; run jar tests	Coagulation–flocculation data for each coagulant
5. Post-treatment Characterisation	Evaluate treatment efficiency	Measure the same parameters as baseline	Quantified pollutant removal efficiencies
6. Data Analysis	Compare results to DOE 2009 standards	Statistical analysis (e.g., ANOVA), removal efficiency calculations	Determination of optimal coagulant and dosage
7. Conclusion	Interpret findings and assess applicability	Synthesise results for discussion	Recommendations for sustainable laundry wastewater treatment

(a) (b)

Figure 2: Sample of (a) papaya seed powder and (b) okra seed powder.

Laundry Wastewater

The wastewater samples were taken from the laundry shop located at Shah Alam, Selangor, Malaysia. Approximately 15 litres of laundry wastewater samples were collected in the container, and the characteristics were determined in-situ and the laboratory [12].

The Jar Test Experiment

The jar test was conducted with different parameters, including dosages and laundry wastewater samples. This laboratory test used three types of coagulants: PAC, papaya seed, and okra seed powder. The three types of coagulants, papaya seed, papaya with okra seed, and PAC, were tested similarly using the same jar test procedure. Firstly, the sample was set on the jar test apparatus with 1-litre beakers; each beaker received a different coagulant dosage. For each coagulant, three different dosages were used in this investigation: 5, 10 and 15 g. For the coagulation phase, the jar test apparatus was set up to operate at 140 rpm for three minutes, and for the flocculation process, it ran continuously at 70 rpm for five minutes. The mixture had to rest for 15 minutes to allow the floc to settle and initiate sedimentation. One additional beaker containing laundry wastewater without coagulants was added as a control. The jar test experiment was done in triplicate.

Fourier Transform Infrared (FTIR)

Fourier Transform Infrared (FTIR) Spectroscopy was used to analyse the structural and chemical characteristics of the coagulants before and after the coagulation–flocculation process. The analysis was conducted with a Perkin Elmer FTIR Spectrometer (TGA/SDTA 851, USA) over the spectral range of 4000–650 cm^{-1} [13]. This technique identifies functional groups and molecular bonds by detecting their characteristic absorption bands. Coagulant samples were collected before and after the jar test experiments to evaluate changes resulting from interactions with wastewater contaminants. Variations in peak positions, intensity, or the appearance/disappearance of specific bands were interpreted as evidence of chemical reactions or molecular interactions during treatment, providing insights into the mechanisms underlying pollutant removal.

Scanning Electron Microscope

Scanning Electron Microscopy (SEM) was used to examine the surface morphology and structural changes of the bio-coagulants before and after their application in the coagulation–flocculation process (jar test method). The analysis aimed to visualize the interactions between the bio-coagulants and wastewater pollutants, as well as to assess the physical effects of the treatment process on coagulant surfaces. SEM analysis was conducted under the following conditions: accelerating voltage of 5–15 kV, magnification range of 500× to 50,000×, working distance of 8–10 mm, high-vacuum mode ($\leq 10^{-4}$ Pa), and spot size enabling 3–5 nm resolution. A secondary electron (SE) detector was used to capture detailed surface topography.

Anova: Two-Factor Without Replication

A One-Way Analysis of Variance (ANOVA) was conducted to evaluate differences in pollutant removal efficiency among the bio-coagulant treatments. This statistical method tests whether the means of independent groups differ significantly, making it suitable for comparing factors such as coagulant type, dosage, or contact time in water treatment studies.

RESULTS AND DISCUSSION

Effect of Coagulation-Flocculation on Turbidity Removal

Figure 3 shows the turbidity affected by the coagulant papaya seed powder and a combination of papaya seed and okra seed. Based on the data obtained, the highest percentage removal of turbidity using papaya seed powder is 94.54% with 5 g of papaya seed powder. Then, the highest percentage of removal using papaya with okra powder is at 15 g, which is 90.91%. Next, according to [14], applying carica papaya seeds at the recommended dose of 200 mg/L produced the highest turbidity reduction efficacy of 89% after 30 minutes of treatment. Furthermore, the turbidity of the Skudai River and Melana River can be significantly reduced by using a natural coagulant made from deshelled Carica papaya seeds, which are 88.3% and 87.6%, respectively [15].

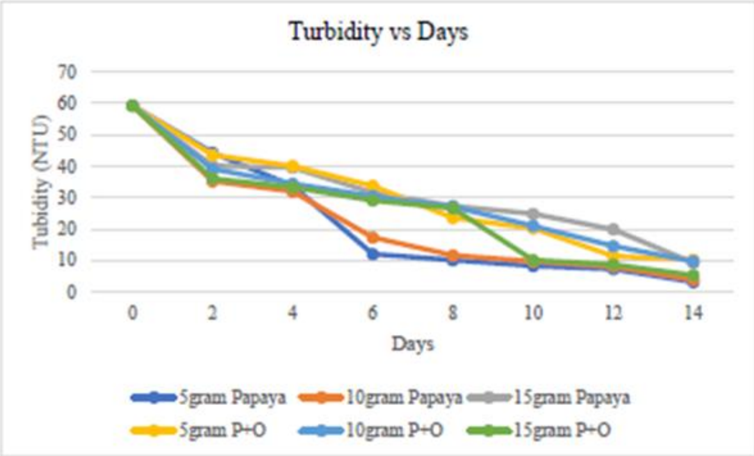


Figure 3.: Effect of varying coagulant dosage on turbidity reduction efficiency.

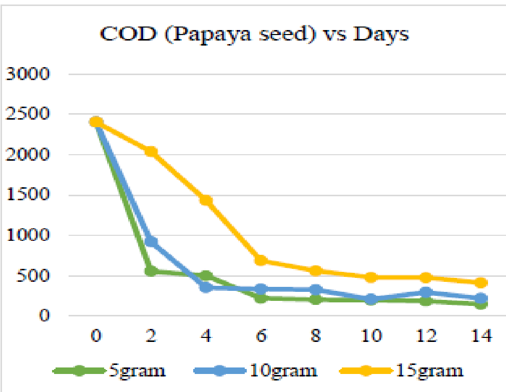
Effect of Coagulation-Flocculation on pH

One crucial factor affecting laundry wastewater's overall quality and possible environmental effects is its pH. The data show that different quantities of papaya seed powder may successfully regulate and stabilise the wastewater's pH values. For instance, 5 g of papaya seed powder lowered the pH to 7.35 and 10 g to 7.12. Ali et al. (2020) [16] showed that natural coagulants, such as papaya seeds, are useful for stabilising wastewater pH levels and generating ideal pH ranges that resemble the presented data.

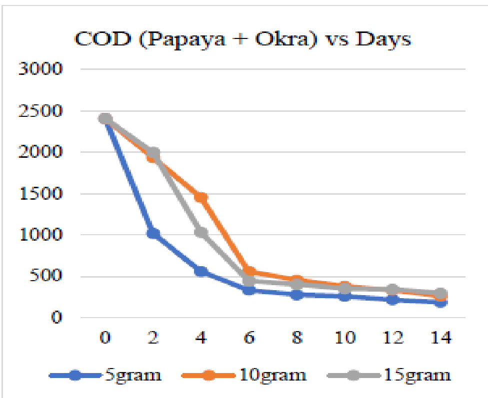
Effect of Coagulation-Flocculation on COD and BOD Removal

According to Figure 4, the decrease in chemical oxygen demand using papaya seed is 93.98% at 5 g. This shows the effectiveness of the papaya seed as a natural coagulant in removing the chemical oxygen demand in laundry wastewater. Using this combination, the percentage removal of chemical oxygen demand is 92.31% at 5 g. Then, the chemical coagulant of polyaluminium chloride (PAC) was compared, and the optimum dosage using the chemical coagulant was 15 g, resulting in a 94.77% removal percentage.

For biological oxygen demand (BOD), the optimum dosage that provided the highest percentage removal of BOD by natural coagulant is 10 g of a combination of papaya seed powder with okra seed powder, which is 83.77% (see Figure 5). Papaya seed powder was utilised by [17] to clean the municipal wastewater regarding the COD (66.7%) removals; the results were remarkable. Then, drimarene dark red (DDR), which contains synthetic textile effluent, was treated using papaya seeds [18].

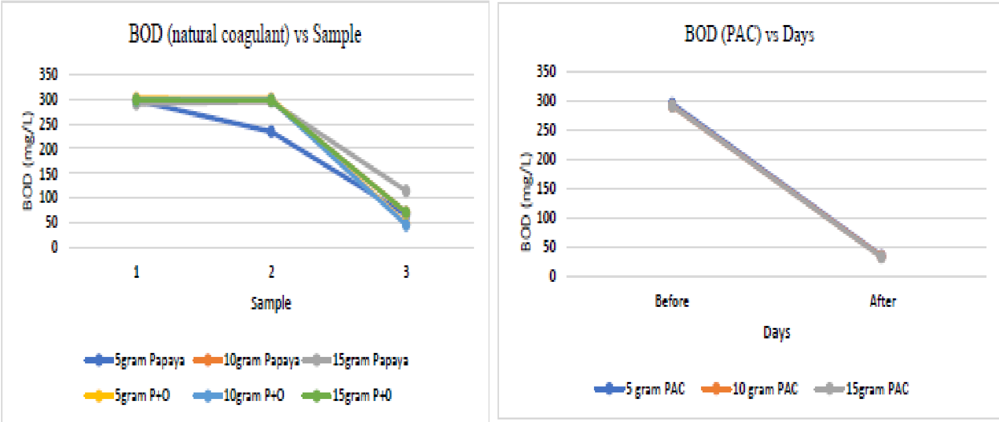


(a)



(b)

Figure 4. Graph of COD reduction using (a) Papaya Seed and (b) a combination of Papaya + Okra seed.



(a) (b)

Figure 5. Graph of BOD reduction using (a) Papaya Seed and (b) a combination of Papaya + Okra seed.

Effect of Coagulation-Flocculation on TSS Removal

The percentage of suspended solids removal is 100% by applying 10 g of papaya seed powder. For the combination of papaya seed with okra seed powder, the highest percentage removal is 96.80%, using 10 g of the combination natural coagulant. Moreover, Figure 6 shows the data obtained by applying PAC in laundry wastewater treatment. The percentage of removal using PAC is 100%. It shows the effectiveness of PAC in suspended solid removal for laundry wastewater treatment.

In addition, according to [19], total suspended solids (TSS) decreased from 60 mg/L before treatments to 22.80 mg/L after six weeks in laundry wastewater. It shows that the TSS has been reduced by 62% of suspended solids in the laundry wastewater.

Effect of Coagulation-Flocculation on Nitrate-nitrogen and Nitrite-nitrogen Removal

Laundry wastewater contains nitrate-nitrogen (NO_3-N) and nitrite-nitrogen (NO_2-N) derived from organic matter such as dirt, detergents, and cleaning agents used during the washing process. These substances can decompose into nitrate-nitrogen and nitrite-nitrogen, posing serious health and environmental hazards if improperly handled. Figure 7 shows the pattern of nitrate-nitrogen for 14 days using a natural coagulant of papaya seed and papaya seed with okra seed powder. The data show that the percentage of nitrate-nitrogen removal in laundry wastewater is 100%.

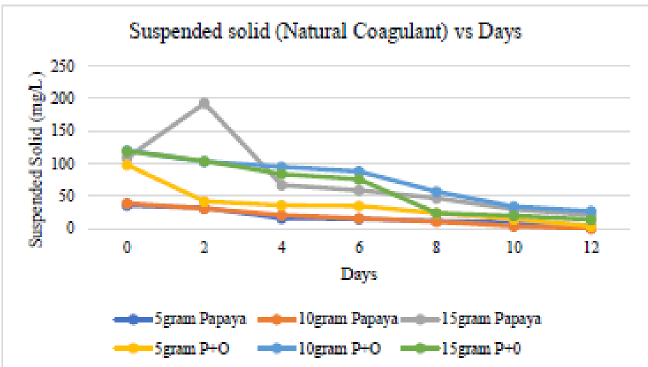


Figure 6. Graph of TSS along 14 days using natural coagulant for laundry wastewater treatment.

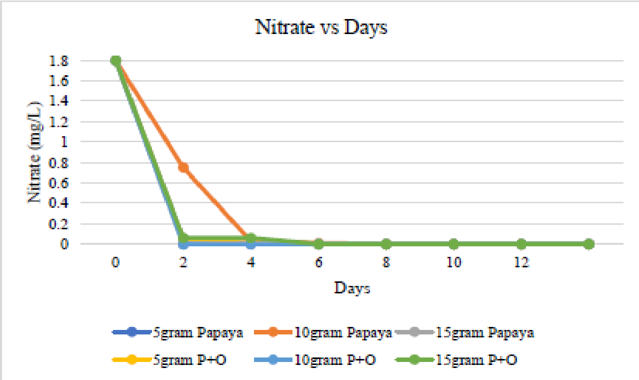


Figure 7. Graph of nitrate-nitrogen using papaya seed powder and a combination of papaya and okra powder with different dosages.

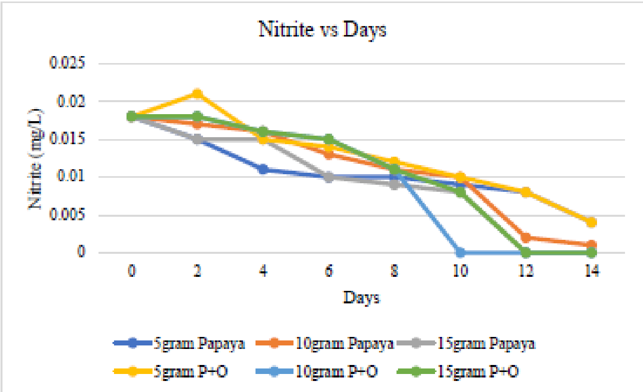


Figure 8. Graph of nitrite-nitrogen using papaya seed powder and a combination of papaya and okra powder with different dosages.

Next, Figure 8 shows the data on the nitrite-nitrogen used in the natural coagulant during the study. Using the papaya seed powder, the optimum dosage for removing the highest nitrite-nitrogen is 15 g, which is 100% removal. The optimum dosage for combining papaya seed with okra seed powder is 15 g, with 100% nitrate-nitrogen removal in laundry wastewater.

Moreover, according to [20], Skudai River water had the highest nitrate-nitrogen removal effectiveness, with a mean removal of 82.3%. Melana River and Tukang Batu River water followed, with mean removals of 49.5% and 32.2%, respectively.

Effect of Coagulation-Flocculation on Ammonia-nitrogen Removal

Laundry wastewater contains ammonia-nitrogen (NH_3-N), mostly caused by the decomposition of organic materials and the use of detergents and cleaning solutions containing ammonia-based chemicals. Figure 9 demonstrates that applying papaya seed powder and a combination of papaya and okra seeds affects laundry wastewater ammonia-nitrogen levels over time. The optimum dosage for the removal of ammonia-nitrogen is 5 g. It shows that the highest percentage of ammonia-nitrogen removal is 5 g papaya seed powder, which has 94.64% removal. Then, combining papaya with okra seed powder is more effective in removing ammonia-nitrogen, achieving a 97.89% removal rate using 5 g of papaya seed and okra seed powder.

Furthermore, the current study focused on using natural coagulants for ammonia-nitrogen removal in laundry wastewater and compared these results with subsequent articles. For example, a study by [16] used natural coagulants to obtain a removal efficiency of 75% for ammonia nitrogen. Then, Kumar et al. (2021) [21] investigated the use of okra and other natural coagulants for ammonia-nitrogen removal in industrial wastewater. The investigations discovered that natural coagulants may successfully lower ammonia-nitrogen concentrations.

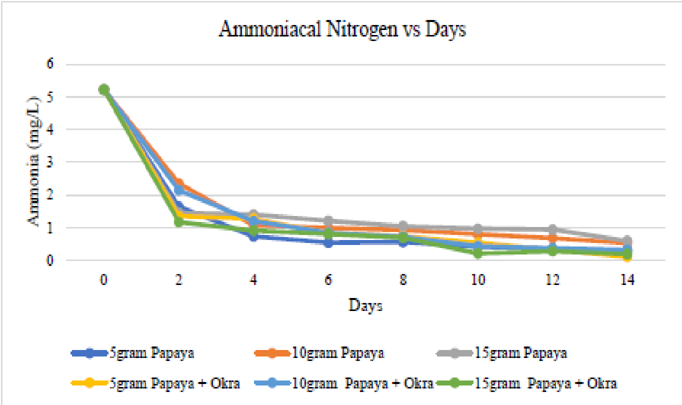
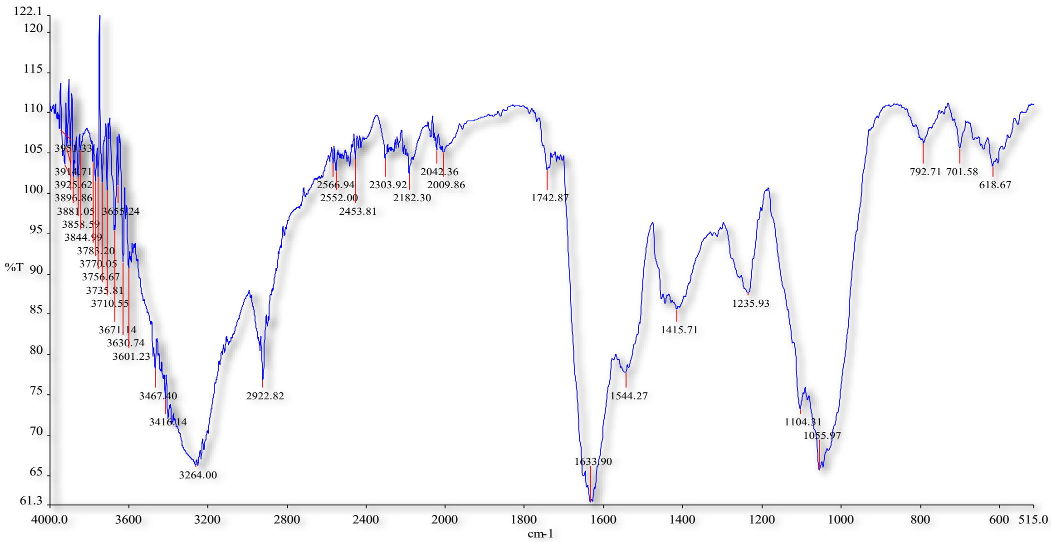
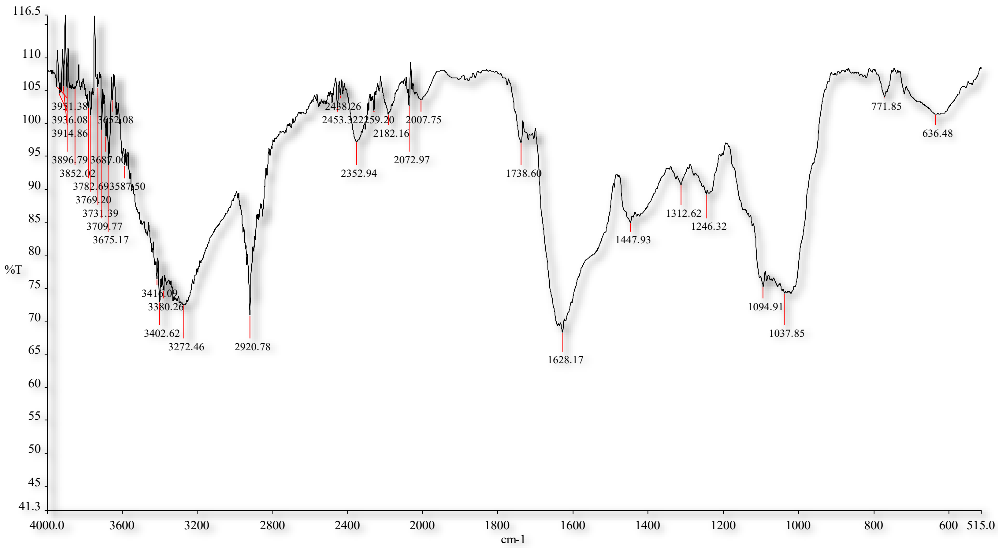


Figure 9. Graph of ammonia-nitrogen using papaya seed powder and a combination of papaya and okra powder with different dosages.



(a)



(b)

Figure 10. FTIR Spectra of papaya seed a) before and b) after coagulation.

Table 2. Functional group of papaya seed after degradation.

Coagulant	Condition	Wavenumber (cm^{-1})	Functional Similar	Changes
Papaya seed	Before	3264	O-H	Formation
		2922.82	C-H	Formation
	After	3272.46	O-H	Formation
		2920.78	C-H	Formation

Analysis of Fourier Transform Infrared (FTIR)

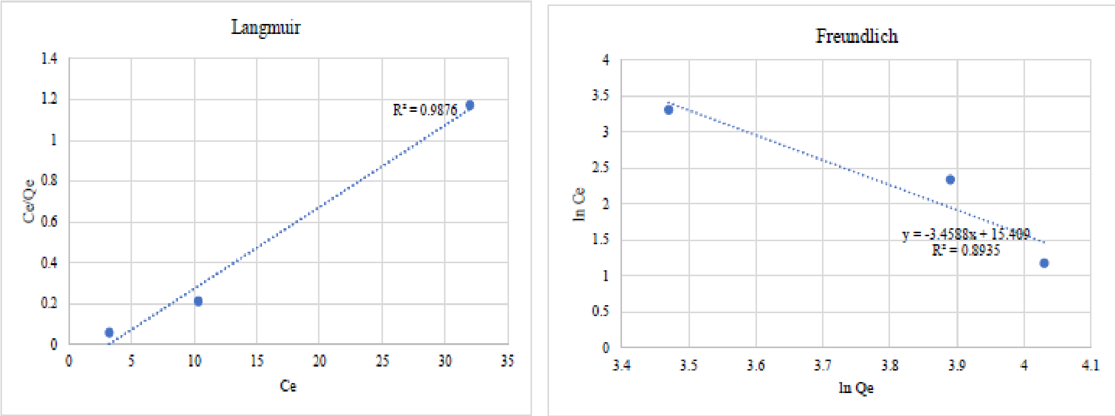
Papaya and okra seeds were examined using an FTIR spectrophotometer to determine their functional groups. The FTIR test analyses the functional groups and chemical bonds in pollutants before and after treatment. Figure 10 shows the wavelength of the papaya seed powder before and after the coagulation process.

The FTIR spectrum reveals a peak at 3264 cm^{-1} before degradation, corresponding to O-H stretching vibrations and indicating the presence of hydroxyl groups, normally present in alcohols and phenols (see Table 2). The existence of aliphatic hydrocarbons, abundant in organic molecules, is suggested by another significant peak at 2922.82 cm^{-1}, corresponding to C-H stretching vibrations. Despite minor wavenumber shifts, these functional groups remain visible in the FTIR spectrum during degradation. From 3264 cm^{-1} to 3272.46 cm^{-1}, the O-H stretching vibration changes, suggesting that although the hydroxyl groups are still present, their surroundings might have changed. In comparison, the C-H stretching vibration had shifted from 2922.82 cm^{-1} to 2920.78 cm^{-1}, indicating the presence of aliphatic hydrocarbons. Table 3 shows the data for before and after degradation of a combination of papaya seed and okra seed powder.

The mixture's FTIR spectrum shows numerous important functional groups prior to degradation. C-H stretching vibrations, which suggest the existence of aliphatic hydrocarbons frequently present in organic molecules, correlate to a peak at 2921.93 cm^{-1}. Another strong peak reflects carbonyl groups such as ketones, aldehydes, or carboxylic acids at 1743.21 cm^{-1}, linked to C=O stretching vibrations. Following degradation, the C-H stretching vibration in the FTIR spectrum shows a minor shift, going from 2921.93 cm^{-1} to 2920.63 cm^{-1}. This shift suggests that the aliphatic hydrocarbons are still there. Significant stretching of the hydroxyl (O-H) and primary amine groups (N-H) in Carica papaya seed macromolecules, such as protein and starch, suggested intermolecular hydrogen bonding [22].

Table 3. Functional group of papaya seed with okra seed after degradation.

Coagulant	Condition	Wavenumber (cm^{-1})	Functional Similar	Changes
Papaya Seed with Okra Seed	Before	2921.93	C-H	Formation
		1743.21	C=O	Formation
	After	2920.63	C-H	Formation
		1627.75	C=C	Absence



(a) (b)

Figure 11. Linear graph of (a) Langmuir and (b) Freundlich.

Isotherm Mechanism

These isotherms are most often used to evaluate the removal properties. The experiment's results determined the ideal single- and mixed-scenario coagulant.

Based on correlation coefficients, R^2, the Langmuir model fits the data more accurately than the Freundlich model for both situations. Langmuir's R^2 for both situations are 0.9876, greater than 0.9; by contrast, Freundlich's R^2 is only 0.8671 (see Figure 11). The value indicated strong removal bonding between coagulants and showed the suitability and fitness of the Langmuir model compared to the Freundlich model. However, the marginally higher values for the Langmuir isotherm suggest that monolayer adsorption on a homogeneous surface is a slightly better fit for these materials, with natural coagulants performing better than PAC.

Additionally, the higher R^2 values obtained for the Langmuir model (0.9876) compared to the Freundlich model (0.8671) indicate that pollutant adsorption by the coagulants is best represented by monolayer adsorption on a homogeneous surface, where all adsorption sites are identical and energetically equivalent. This suggests that once a pollutant molecule occupies a site, no further adsorption can occur at that location, resulting in the formation of a uniform single layer on the coagulant surface. Such behaviour implies a predictable maximum adsorption capacity (q_m), which is advantageous for process design and scale-up, as it allows for accurate estimation of the optimal coagulant dosage while avoiding unnecessary material use [23]. The strong agreement with the Langmuir model also points to strong and specific interactions between the pollutants and the coagulant's active sites, likely driven by functional groups such as hydroxyl, amine, or carboxyl groups that facilitate binding with charged or polar molecules. In contrast, the weaker fit to the Freundlich model suggests that multilayer adsorption on heterogeneous surfaces is less significant in this system [24]. Overall, the results confirm that natural coagulants, particularly papaya and okra seed powders, can provide efficient and targeted pollutant removal through uniform monolayer adsorption, outperforming PAC under the same experimental conditions.

Morphology in Scanning Electron Microscopy (SEM)

SEM produces a range of signals at the surface of solid specimens by focusing a high-energy electron beam. The sample's atoms and electrons interact to produce signals that provide details about the sample's composition, surface topography, and other characteristics. The surface morphology of the papaya seed coagulant particles is seen in Figure 12 in the SEM image, which highlights their inconsistent, rough texture and points to a complex surface structure. A rough and porous surface increases the surface area accessible for the adsorption of pollutants, which might be useful for adsorption procedures in water treatment. The surface properties are important because morphology influences the effectiveness of particle contact during the coagulation process, while the rough texture increases the surface area for adsorption.

Moreover, the treated papaya seed coagulant has a rough surface roughness and a highly porous structure, as seen in Figure 13. Coagulant materials treated to increase their surface area and adsorption capacity are known for their porosity. The coagulant's microstructure looks complicated and asymmetrical, which is good for coagulation because it allows the rough, interwoven network to trap and bind contaminants efficiently.

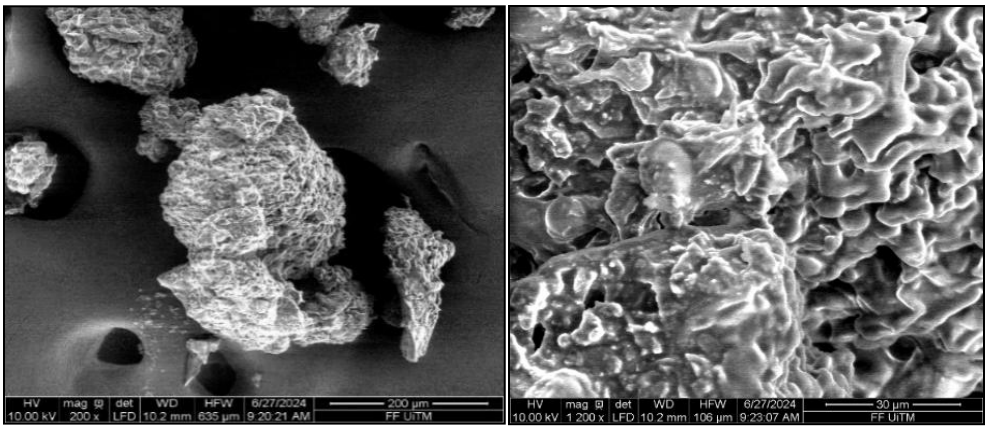


Figure 12. SEM image of papaya seed coagulant before treatment.

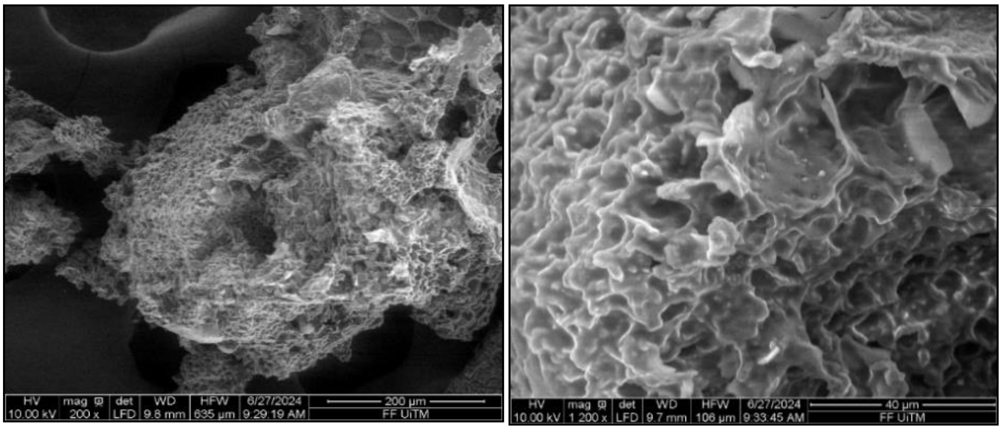


Figure 13. SEM image of papaya seed coagulant after treatment.

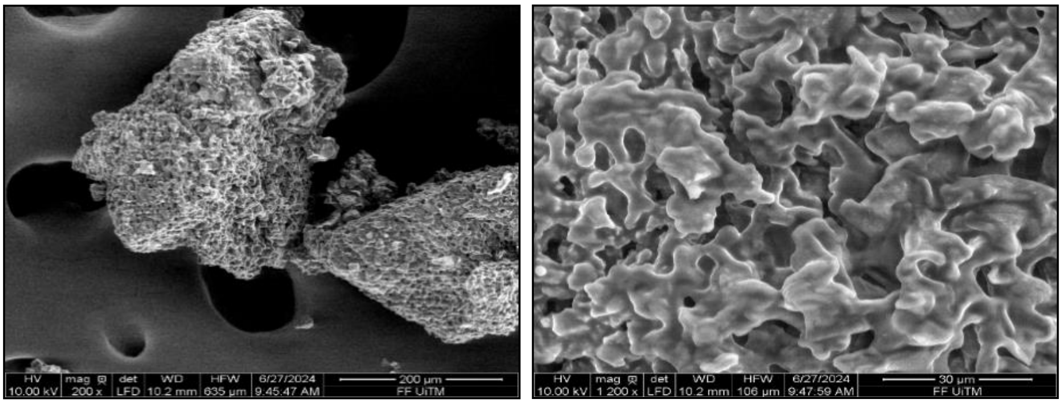


Figure 14. SEM image of a combination of papaya seed with okra seed coagulant before treatment.

After that, the pretreatment SEM picture of the papaya and okra seeds reveals a comparatively smooth and less porous surface, as shown in Figure 14. It shows that the seeds' natural state must still be changed to improve their surface qualities. Larger, more distinct particles make up the microstructure, which seems dense and less complicated. However, some imperfections and roughness are not as noticeable as in treated samples, indicating that the seeds' inherent structure can be altered to improve their coagulation qualities.

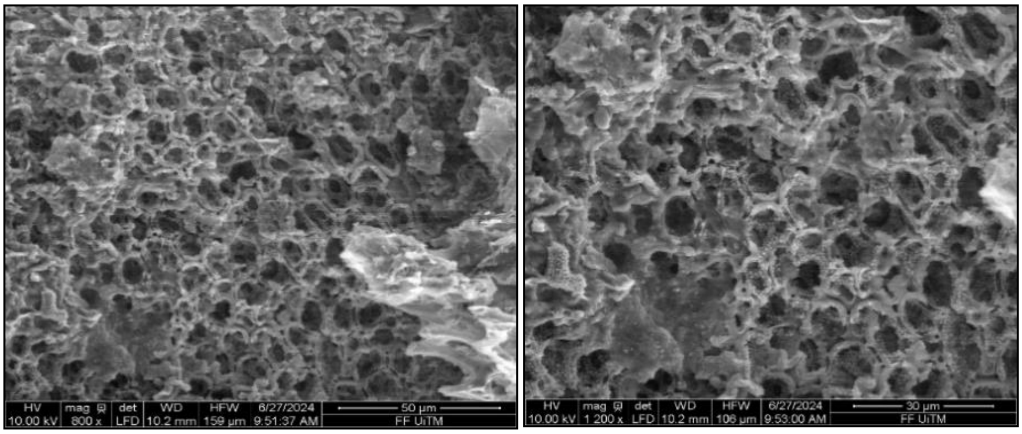


Figure 15: SEM image of a combination of papaya seed with okra seed coagulant after treatment

Compared to their untreated state, the treated papaya and okra seeds show a rougher surface roughness and a highly porous structure, as shown in Figure 15. It shows that the surface of seeds has been successfully modified throughout the treatment process to improve porosity and roughness, both of which are advantageous for adsorption and coagulation. The microstructure is intricate and strongly linked, with many apparent pores and channels. The extensive structure of the seeds improves their coagulant efficiency by strengthening their capacity to bind and trap contaminants.

The result of the laundry wastewater after the Coagulation-Flocculation Process

According to a study [25], they used papaya seed powder and okra seed powder as natural coagulants to treat laundry effluent, significantly improving water quality parameters. After decreasing from 2407 mg/L to 145 mg/L, the Chemical Oxygen Demand (COD) reached the DOE standard of 200 mg/L. Although the concentration was above the permissible limit of 20 mg/L, the biological oxygen demand (BOD) decreased from 297 mg/L to 67 mg/L (see Table 4). Research by [25 – 26], which also emphasises the effectiveness of papaya seeds in wastewater treatment, verify these findings. 5 g of papaya seed powder was shown to be the optimum amount for minimising contaminants in laundry effluent. These results confirm that powdered papaya seed is a highly efficient and environmentally friendly replacement for chemical coagulants that may be used for a wider range of wastewater treatment applications while meeting regulatory requirements.

Table 4. Results of the laundry wastewater sample characteristics after treatment.

Parameter	Before	After	DOE Standard [27]	Unit	Compliance with DOE
pH	8.97	7.01	5.5 – 9		Yes
Turbidity	59.3	3.24	100	NTU	Yes
Chemical Oxygen Demand (COD)	2407	145	200	mg/L	Yes
Biological Oxygen Demand (BOD)	297	67	20	mg/L	No
Temperature	25.1	24.8	<40	ºC	Yes
Suspended Solid	125	5	100	mg/L	Yes
Nitrate-nitrogen	1.80	0	<20	mg/L	Yes
Nitrite-nitrogen	0.018	0	<1	mg/L	Yes
Ammonia-nitrogen	5.22	0.11	20	mg/L	Yes

Table 5. Anova: Two-Factor Without Replication for Parameters of Pollutants (before and after treatment).

Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Turbidity	3	157.0	52.3	2119.8
Chemical Oxygen Demand (COD)	3	2645.9	881.9	1744888
Biological Oxygen Demand (BOD)	3	441.4	147.1	16869.1
Suspended Solid	3	226	75.3	3920.3
Nitrate-nitrogen	3	101.8	33.9	3274.4
Nitrite-nitrogen	3	100.0	33.3	3332.7
Ammonia-nitrogen	3	103.2	34.4	3029.3
Before treatment	7	2895.3	413.6	783910.2
After treatment	7	220.3	31.4	3102.2
Percentage Removal (%)	7	659.8	94.2	60.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1755483	6	292580.6	1.18	0.377	2.996
Columns	587911.5	2	293955.8	1.18	0.338	3.885
Error	2966956	12	247246.3			
Total	5310351	20				

Two-Factor ANOVA without replication showed no statistically significant differences in pollutant removal efficiency between coagulant types (p = 0.377) or among water quality parameters (turbidity, COD, BOD, suspended solids, nitrate–nitrogen, nitrite–nitrogen, and ammonia–nitrogen; p = 0.338) (see Table 5). This indicates that removal performance was consistent across coagulants and parameters under the tested conditions. The absence of statistically significant differences in removal efficiency between coagulant types or among water quality parameters suggests that the tested bio-coagulants performed consistently across multiple pollutant classes. This uniformity indicates their potential as broad-spectrum treatment agents for laundry wastewater [28 – 29].

CONCLUSION

The study demonstrates that papaya seed powder, combined with okra seed and PAC, is an effective natural coagulant for treating laundry wastewater. The treatment significantly improved key water quality indicators, including pH, COD, BOD, suspended solids, nitrate-nitrogen, nitrite-nitrogen, and ammonia-nitrogen, within or below the Department of Environment (DOE) Malaysia's standards. Papaya seed powder alone achieved a 93.98% removal of COD and 77.44% removal of BOD, while the combination of papaya and okra seeds reached an 84.44% BOD removal. Despite these successes, BOD levels still exceeded DOE standards, indicating a need for further treatment optimisation. The study shows that the most effective natural coagulant is at 5 g dosage of papaya seed powder in laundry wastewater treatment. This study also supports using bio-coagulants as a sustainable, natural coagulant for improving laundry wastewater quality, though additional research is required to fully meet all regulatory requirements. Utilising natural coagulants in wastewater treatment can benefit the environment and humans.

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The authors declare that they have no conflict of interest.

REFERENCE

1. Handayani, Y., Syafrudin, S. & Suherman, S. (2023) The effectiveness of domestic wastewater treatment in reducing BOD and COD levels: a literature review. *In AIP Conf. Proc.* **2683(1)**.

2. Thesni, S. D. R. & Soundhirarajan, K. (2021) Treatment of municipal wastewater using naturally available coagulant. *Middle East J. Appl. Sci*., **4(3)**, 29–39.

3. Khee, Y. L., Kiew, P. L., Chung, Y. T. (2023) Valorising papaya seed waste for wastewater treatment: a review. *Int. J. Environ. Sci. Technol*., **20(2)**, 2327–2346.

4. Dimoglo, A., Sevim-Elibol, P., Dinç Gökmen, K. & Erdoğan, H. (2019) Electrocoagulation/ electroflotation as a combined process for laundry wastewater purification and reuse. *J. Water Process. Eng.*, **31**, 100877.

5. Audria, M. R., Joko. T. & Sulistiyani S. (2022). The effectiveness of poly aluminium chloride (PAC) on chemical oxygen demand (COD) levels of laundry wastewater in Batam City, Indonesia. *Int. J. Environ. Agric. & Biotechnol.*, **7(2),** 120–126.

6. Diver, D., Nhapi, I. & Ruziwa, W. R. (2023) The potential and constraints of replacing conventional chemical coagulants with natural plant extracts in water and wastewater treatment. *Environ. Adv.*, **13**, 100421.

7. Ang, W. L. & Mohammad A. W. (2020) State-of-the-art and sustainability of natural coagulants in water and wastewater treatment. *J. Clean Prod*., **262**, 121267.

8. Bilad, M. R., Mat Nawi, N. I., Subramaniam, D. D., Shamsuddin, N., Khan, A. L., Jaafar, J. & Nandiyanto A. B. D. (2020) Low-pressure submerged membrane filtration for potential reuse of detergent and water from laundry wastewater. *J. Water Process. Eng*., **36**, 101264.

9. Kristanda, J., Sintiago, K. S., Kristianto, H., Prasetyo, S., Sugih, A. K. (2021) Optimisation study of Leucaena leucocephala seed extract as a natural coagulant for decolourisation of aqueous Congo red solutions. *Arab J. Sci. Eng*., **46,** 6275–6286.

10. Dollah, Z., Masbol, N. H., Musir, A. A., Karim, N. A., Hasan, D. & Tammy, N. J. (2021) Utilisation of citrus microcarpa peels and papaya seeds as a natural coagulant for turbidity removal in IOP Conf. *Ser. Earth Environ. Sci*., **920(1)**, 012001.

11. Nweke, M. M., Chukwuma, F. O., Evbuomwan, B. O. & Akuma Oji (2021) Factorial optimisation of Coagulation-Flocculation process for Abattoir Wastewater using Carica Papaya seed extract as bio-coagulant. *Glob. J. Eng. Technol. Adv*., **9(2)**, 009–016.

12. Baird, R. B., Eaton, A. D., Rice, E. W. (2017) Standard Methods for the Examination of Water and Wastewater, 23rd Edition. *American Public Health Association, American Water Works Association, Water Environment Federation*.

13. Hussain, S. M. S., Kamal, M. S., Fogang, L. T. (2019) Synthesis and physicochemical investigation of betaine type polyoxyethylene zwitterionic surfactants containing different ionic headgroups. *J. Mol. Struct.*, **1178,** 83 – 88.

14. Putra, R. S., Arirahman, I., Iqbal, A., & Sobari, M. (2021) Enhancement of electroflotation using papaya seeds (Carica papaya) as bio-coagulant for laboratory wastewater treatment. *Key Eng. Mater*., **884**, 3–9.

15. Amir, H. A., Zaidi, N. S., Muda, K., Bahrodin, M. B. & Loan, L. W. (2021) Deshelled Carica papaya Seeds as Natural Coagulant for Improvement Quality of River Water. *Sains Malays*., **50(6),** 1521-1529.

16. Ali, K., Zeidan, H. & Amar, R. B. (2023) Evaluation of the use of agricultural waste materials as low-cost and eco-friendly sorbents to remove dyes from water: a review. *Desalin. Water Treat.*, **302**, 231–252.

17. Maurya, S. & Daverey, A. (2018) Evaluation of plant-based natural coagulants for municipal wastewater treatment. *3 Biotech, Heidelberg*, **8(1)**, 1 – 4.

18. Kristianto, H., Kurniawan, M. A. & Soetedjo, J. N. M. (2018) Utilisation of papaya seeds as a natural coagulant for synthetic textile colouring agent wastewater treatment. *Int. J. Adv. Sci. Eng. Inf. Technol.*, **8(5),** 2071.

19. Watiniasih, N. L., Purnama, I. G. H., Padmanabha, G., Merdana, I. M. & Antara, I. N. G. (2019). Managing laundry wastewater. *IOP Conf. Ser.: Earth Environ. Sci*., **248,** 012084.

20. Amran, A. H., Zaidi, N. S., Syafiuddin, A., Zhan, L. Z., Bahrodin, M. B., Mehmood, M. A. & Boopathy, R. (2021) Potential of carica papaya seed-derived bio-coagulant to remove turbidity from polluted water assessed through experimental and modeling-based study. *Appl. Sci*., **11(12)**, 5715.

21. Kumar, P. S., Varshini, P., Shruthi, T. V. & Sudhakar, K. (2020) A comprehensive review on the efficacy of orange peel for the removal of contaminants in water: Mechanism, isotherms, kinetics and future research directions. *J. Water Process Eng*., **38**, 101566.

22. Benalia, A., Atime, L., Baatache, O., et al. (2024) Removal of lead in water by coagulation flocculation process using Cactus-based natural coagulant: optimization and modeling by response surface methodology (RSM). *Environ. Monit. Assess*., **196**, 244.

23. Dewi, V. M. I. & Rahmayanti, M. (2022) The interaction mechanism of papaya seeds (Carica papaya L.) as a natural coagulant and remazol red under different pH conditions. *Indo. J. Chem. Res.*, **10(1**), 14–18.

24. Cheng, K. C., Khoo, Z. S., Lo, N. W., Tan, W. J. & Chemmangattuvalappil, N. G. (2020). Design and performance optimisation of a detergent product containing a binary mixture of anionic-nonionic surfactants. Heliyon, **6(5)**, e03861.

25. Corona R. R., Sad, C. M., da Silva, M., Lopes, D. L., Leite, J. S. de F. Viegas G. M, Gonçalves G. R., Filgueiras, P. R., & de Castro E. V. (2021). Adsorption of anionic surfactant in graphite oxide: A study for the treatment of laundry wastewater. *J. Environ. Chem. Eng.* **9(6),** 106858.

26. Kusniawati E., Nuryanti R., Walici A. S. (2023). Utilization of papaya seeds (carica papaya l.) as bio-coagulants to improve the quality of well water using parameters of pH, TSS, TDS, and turbidity. *Jurnal Cakrawala Ilmiah*, **2(5)**, 2177-2184.

27. National Water Services Commission, Third Edition (2009) Malaysian Sewerage Industry Guidelines.

28. Lestari, D. Y., Darjati, D. & Marlik, M. (2021) Penurunan kadar BOD, COD, dan total coliform dengan penambahan biokoagulan biji pepaya (carica papaya L) (Studi pada limbah cair domestik industri baja di Surabaya Tahun 2020). *J. Kesehat. Lingkung.: J. & Aplikasi Tek. Kesehat. Lingkung*. **18(1)**, 49–54.

29. Goriainov, S., Orlova, S., Nikitina, E., Vandishev, V., Ivlev, V., Esparza, C., Vasil'e, V., Platonov, E., Sheremeta, A. & Kalabin, G. (2023) Study of the chemical composition of Carica papaya L. seed oils of various geographic origins. *Hortic*, **9(11)**, 1227.