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OPTIMIZATION OF TURBIDITY REMOVAL FROM WASTEWATER USING *CARICA PAPAYA* SEED EXTRACT VIA RESPONSE SURFACE METHODOLOGY

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ABSTRACT

This study focuses on optimizing turbidity removal from wastewater using Carica papaya seed extract as a natural coagulant. While conventional chemical coagulants such as alum and ferric chloride are effective, they produce toxic sludge that poses environmental and health concerns. In contrast, papaya seeds contain bioactive compounds such as cysteine protease, offering a biodegradable and eco-friendly alternative. Response Surface Methodology (RSM) was employed to evaluate the effects of coagulant dosage, stirring speed, and pH on treatment efficiency. A jar test was conducted to simulate the coagulation and flocculation process, with 13 experimental runs designed using Central Composite Design (CCD) through Design-Expert software. The papaya seed extract was prepared with sodium hydroxide to enhance the release of active compounds. Statistical modelling identified the optimum conditions at a coagulant dosage of 125 mg/L, stirring speed of 175 rpm, and pH 7.75. Under these conditions, the model predicted a turbidity removal efficiency of 84.18%, while the actual mean removal from validation experiments was 87.78%, indicating good agreement with a percentage deviation of 4.27%. These findings demonstrate the potential of papaya seed extract as a sustainable alternative to chemical coagulants, with reduced sludge production and improved environmental outcomes. This research supports Sustainable Development Goal 6 by promoting innovative and environmentally friendly approaches to wastewater treatment and clean water management

Keywords: *Turbidity, Natural coagulant, Carica Papaya seed, Optimization, RSM*

INTRODUCTION

Urbanization, industrial growth, and climate change have heightened global concerns over water quality and availability. In Malaysia, rising wastewater discharge from various sectors strains existing treatment systems. High turbidity in untreated wastewater reduces transparency, depletes dissolved oxygen, and threatens ecosystems and public health. Conventional chemical coagulants like aluminium sulphate and ferric chloride are effective for turbidity removal but pose environmental risks and generate toxic sludge.

Natural coagulants, such as *Carica papaya* seeds, offer a sustainable alternative (Cadena-Álava et al., 2024). Rich in water-soluble proteins like cysteine protease, they promote floc formation, are biodegradable, and reduce sludge and residual chemicals. However, their application in wastewater treatment is underexplored, particularly in terms of dosage, stirring speed, and pH. NaCl was used in this study as an extraction medium due to its pH stability, with the aim of improving coagulant performance.

This study investigates the optimal conditions for turbidity removal using papaya seed extract and models the effects of key variables through Response Surface Methodology (RSM). Laboratory tests were conducted to validate the model, with a focus on NaCl-based extraction and turbidity reduction due to time and material limitations. By addressing the drawbacks of chemical coagulants, this research supports sustainable water treatment solutions and contributes to SDG 6 and SDG 12 by promoting clean water access and responsible consumption.

METHODS

Sample Collection and Preparation

Wastewater samples were collected from the inlet of the wastewater treatment plant (WWTP) at Kolej Mawar, UiTM Shah Alam. After collection, the samples were stored in clean plastic bottles to preserve their original characteristics. Initial parameters such as turbidity and pH were then measured using calibrated instruments to establish baseline conditions.

Papaya Seed Extract Preparation

Papaya seeds were collected from MBG Fruits, Shah Alam. After thorough washing and removal of the surface membrane, seeds were oven-dried at 50°C for 24 hours, ground into powder, and sieved for uniform particle size. The resulting papaya seed powder is shown in Figure 3. The extraction solution involved dissolving 87.66 g NaCl into 1 L of distilled water, creating a 1.5 M solution. Subsequently, 10 g of seed powder was mixed with the NaCl solution, stirred for 15 minutes, allowed to settle for 5 hours, and filtered to obtain a concentrated extract.

Jar Test and Evaluation

Wastewater samples were prepared in batches, with each sample consisting of 1 litre of untreated wastewater placed into separate beakers. The pH levels were carefully adjusted within the range of 6.5 to 9 using either NaOH or HCl, as excessive amounts could compromise the integrity of the samples. Coagulant dosages ranged from 50-250 mg/L. Samples underwent rapid mixing (100-300 rpm for 3 minutes) and slow mixing (30 rpm for 15 minutes), followed by a settling period of 30 minutes.

- pH measurement: pH was measured before and after treatment using a calibrated pH meter, ensuring the values remained within the acceptable range of 6.5 to 9.0.
- Turbidity testing: Treated samples were analysed using a turbidimeter. The percentage of turbidity removal was calculated using following equation:

$$\% \, Turbidity \; Removal = \left(\frac{Initial \; Turbidity - Final \; Turbidity}{Initial \; Turbidity}\right) \times 100$$

Optimization via Response Surface Methodology (RSM)

RSM with Central Composite Design (CCD) was used to optimize turbidity removal using *Carica papaya* seed extract. Implemented via Design of Experiments (DoE) software, this method efficiently evaluated the effects and interactions of three key parameters: coagulant dosage (50–200 mg/L), stirring speed (100–250 rpm), and pH (6.5–9). A total of 13 experimental runs were generated, providing comprehensive coverage across the variable ranges. The results were used to develop a predictive model and identify optimal conditions for maximum turbidity removal.

Validation of Optimal Conditions

To validate the RSM-identified optimal conditions, three replicate experiments were conducted. The actual mean results from validation experiments were compared to the RSM-predicted values. A percentage error below 5% was considered acceptable to confirm the reliability of the optimization model.

RESULTS AND DISCUSSION

ANOVA Analysis

The model's validity was evaluated through Analysis of Variance (ANOVA), as presented in Table 1. The model was statistically significant (F = 9.67, p = 0.0440), confirming that the input variables had a meaningful influence on turbidity removal. Significant terms included coagulant dosage (A), interaction

AB, and quadratic terms B^2 and C^2, all with p-value < 0.05. The lack-of-fit was not significant (*p* = 0.3873), indicating the model fits well. Model fit statistics indicate an R^2 of 0.9667, supporting its predictive capability. These findings highlight the importance of optimizing operational parameters for efficient treatment performance.

Table 1. ANOVA for Turbidity Removal

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	988.95	9	109.88	9.67	0.0440	significant
A - Coagulant Dosage	140.62	1	140.62	12.37	0.0390	
B - Stirring Speed	7.45	1	7.45	0.6556	0.4774	
C - pH	87.91	1	87.91	7.74	0.0689	
AB	121.93	1	121.93	10.73	0.0466	
AC	73.93	1	73.93	6.51	0.0839	
BC	94.51	1	94.51	8.32	0.0633	
A^2	0.2320	1	0.2320	0.0204	0.8954	
B^2	322.08	1	322.08	28.34	0.0129	
C^2	369.58	1	369.58	35.52	0.0107	
Residual	34.09	3	11.36			
Lack of Fit	12.80	1	12.80	1.20	0.3873	not significant
Pure Error	21.29	2	10.65			
Cor Total	1023.04	12				

Mathematical Modelling

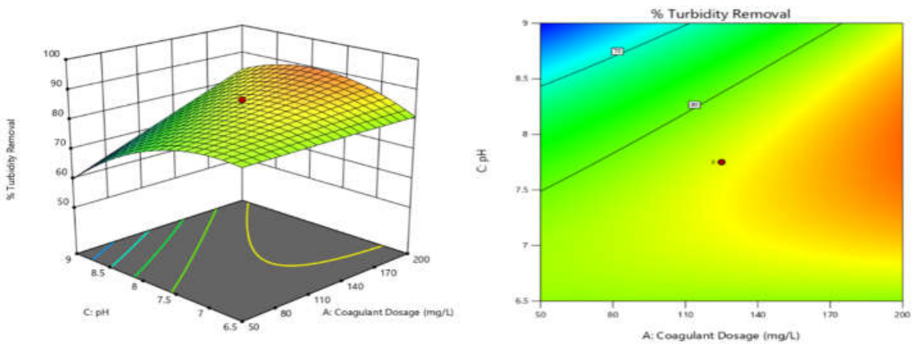
A quadratic regression model was developed using RSM to describe the relationship between coagulant dosage (A), stirring speed (B), and pH (C) with turbidity removal efficiency. The resulting model equation is:

$$\% \, Turbidity \, Removal = +84.18 + 5.93A + 1.36B - 4.69C - 7.91AB + 6.08AC + 6.87BC - 0.1847A^2 - 6.88B^2 - 7.37C^2$$

Among the variables, coagulant dosage and stirring speed had the strongest positive linear effect, while pH showed a negative influence. The interaction between dosage and stirring speed (AB) negatively impacted removal, suggesting excessive values may hinder performance. In contrast, AC and BC interactions were synergistic, enhancing efficiency. These findings indicate the need for a balanced combination of parameters to achieve optimal turbidity removal.

Response Surface Analysis

Graphical analysis using 3D response surface and 2D contour plots in Figure 1 showed that coagulant dosage and stirring speed significantly affected turbidity removal ($p < 0.05$). Removal efficiency increased with both variables, reaching 87–90% at 150–170 mg/L and 170–200 rpm, but only 50–70% at 50–80 mg/L and 100–130 rpm due to inadequate floc formation and mixing. These trends align with El Gaayda et al. (2022), who reported reduced removal at lower operational parameters. Coagulant dosage controls the availability of active compounds for colloid destabilisation, where underdosing causes incomplete floc formation and overdosing risks charge reversal or excess sludge (Dassanayake et al., 2022; Saritha et al., 2019). Stirring speed influences mixing: rapid mixing distributes coagulant and promotes collisions, while gentle flocculation mixing supports floc growth; overmixing breaks fragile flocs, reducing performance (Yu et al., 2011).



(a) (b)

Figure 1.: Coagulant Dosage vs pH (a) 3D Response Surface Plot; (b) 2D Contour Plot

Optimization and Validation of Model Prediction

The optimized conditions in Table 2 show a dosage comparable to the 130 mg/L reported by Muda et al. (2020) for municipal wastewater treatment with natural coagulants. The stirring speed matches the 180–200 rpm range noted by Ahmad et al. (2022), while the slightly alkaline pH aligns with the 7–8 range reported by Nweke et al. (2022). These findings are consistent with parameters proven effective in related natural coagulant studies.

Table 2. Optimum condition for maximum turbidity removal

Parameter	Suggested Value
Coagulant Dosage (mg/L)	125
Stirring Speed (rpm)	175
pH	7.75

A validation experiment under the predicted optimal conditions achieved 87.78% turbidity removal, compared to the model's prediction of 84.18%, giving a 4.27% error as shown in Table 6. This discrepancy, well within the acceptable limit of 5 percent, demonstrates the high accuracy and reliability of the RSM model, confirming its validity and practical utility for optimizing natural coagulant performance in wastewater treatment (Kiew et al., 2013).

CONCLUSION

Carica papaya seed extract showed strong potential as a natural coagulant for turbidity removal. Using RSM, optimal conditions were identified at 125 mg/L dosage, 175 rpm stirring speed, and pH 7.75, achieving maximum turbidity reduction. A predictive quadratic model was developed to describe variable interactions, with strong statistical validation (ANOVA, residual and response plots, and high R^2). Laboratory tests under optimal conditions closely matched model predictions, with only 4.27% error, confirming the model's reliability. This study highlights RSM as an efficient, cost-effective tool for applying natural coagulants in wastewater treatment.

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