

Saccharum officinarum Bio-coagulant for Palm Oil Mill Effluent Treatment

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Abstract

The coagulation process has become a common treatment method in water and wastewater treatment but not in palm oil mill effluent (POME) treatment. POME is known to have a high level of COD and turbidity and prior studies showed that the modified coagulation process using bio-coagulant may be feasible to remove primarily the COD and turbidity of the POME. In this study, an extract of *Saccharum officinarum* or bagasse is used as a source of bio-coagulant for the removal of COD and turbidity from POME at optimized coagulant dosage, pH, and contact time. The optimization was carried out via response surface analysis. This analysis stipulated that the application of *Saccharum officinarum* extract removed turbidity of more than 95%, COD of more than 65.0% with coagulation activity of 67.4% at optimum 50 mg/L coagulant dosage, pH 8, and slow mixing for 30 minutes. Henceforth, this study concludes the suitability of *Saccharum officinarum* as a bio-coagulant to primarily remove organic and solid pollutants during POME pre-treatment.

1. Introduction

Palm oil mills in Malaysia currently use an open ponding system that runs on a biological treatment process. This method is preferable due to low initial capital expenditure and low operating costs (Lee et al. 2019). However, it requires a large amount of area, which results in a longer hydraulic retention time (Ng and Cheng 2015; Syamimi Zaidi et al. 2022). The implementation of the coagulation process as a pre-treatment can potentially reduce the drawbacks. Alum or even known as alumina sulphate is a common chemical coagulant that is used in the coagulation process. However, the use of chemical coagulants contributes to more sludge, which necessitates additional cost and space for sludge treatment and disposal (Lee et al. 2019; Zaidi et al. 2019a; Amran et al. 2021). The application of green waste in water and wastewater treatment is not an old technology (Loh et al. 2021, 2022). Natural coagulants can likely lessen the impact of chemical coagulants (Chaibakhsh et al. 2014). Previous research demonstrates that employing natural coagulants can effectively remove various contaminants, with removal rates surpassing 70%, including turbidity (Zaidi et al. 2019b), total suspended solids (TSS), colour (Jagaba et al. 2017), and COD (Zaidi et al. 2022).

In the coagulation process, the operating conditions such as coagulant dosage and pH determine its performance for water and wastewater treatment (Bahrodin et al. 2021). Existing studies on the application of bagasse as a natural coagulant for water and wastewater treatment mainly focus on the effect of optimum condition individually through the One-Factor-at-a-Time method (OFAT) (Chitra and Muruganandam 2019; Amran et al. 2022). However, this method is outdated and does not show any interaction effects between operating conditions (Shak and Wu 2014; Adesina et al. 2019). Currently, the application of Response Surface Methodology (RSM) which involves the design, analysis, and modelling of experiments manages to attract the attention of many researchers to be applied in various fields (Priyatharishini et al. 2019). Therefore, this study was conducted to identify the potential of *Saccharum officinarum* as a natural coagulant for palm oil mill effluent (POME) treatment by optimizing the coagulant dosage, pH, and contact time.

2. Materials and Methods

2.1 Preparation of Natural Coagulant

This study was carried out using the stem of *Saccharum officinarum* (bagasse) as a source of natural coagulant. Bagasse used in this study was collected from vendors around Taman Universiti, Skudai, Johor. Preparation of bagasse as a natural coagulant was done according to Bahrodin et al. (Bahrodin et al. 2022) involves the grinding, sieving, and base extraction process using sodium hydroxide (NaOH).

2.2 Collection and Characterization of POME

Palm oil mill effluent (POME) used in this study was collected from an actively operated palm oil mill located at Felda Taib Andak, Kulai, Johor. This palm oil mill uses an open ponding system for the treatment process. Upon collection, POME was stored in a cold room to ensure its freshness. The collected POME was characterized by its physical and chemical properties. Table 1 shows the initial characteristics of POME collected from the anaerobic pond.

Table 1
Initial properties of the collected POME
from the anaerobic pond

Composition	Unit	Value
pH	-	8.4 ± 0.1
Turbidity	NTU	1662 ± 65.5
TSS	mg/L	988 ± 41.5
COD	mg/L	2010 ± 169.2
NH ₄ -N	mg/L	250.7 ± 14
Nitrate	mg/L	30 ± 7.8
Phosphate	mg/L	555.7 ± 23.8

2.3 Jar Test

The coagulation process was carried out using a jar test. 200 mL of POME that had been thoroughly mixed was poured into a 250 mL beaker. Bagasse extract as a natural coagulant with various dosages was added into each of the beakers followed by a rapid mix for 1 minute at 200 rpm. After 1 minute, the mixing speed was reduced to 80 rpm with a varied contact time. After a certain time of slow mixing, the solution was left for the sedimentation process for 30 minutes. To prevent disturbing the settled flocs,

water samples for turbidity removal, COD removal, and coagulation activity were taken from the surface and were measured immediately.

2.4 Coagulation Performance

Turbidity removal and coagulation activity were determined by identifying the before and after turbidity content using a turbidity meter (Milwaukee turbidimeter). COD content in the POME was analysed based on the USEPA Reactor Digestion Method (Method 8000). COD removal of the POME after the coagulation process can be determined using Eq. (2). For the coagulation activity, the turbidity content of POME without the addition of coagulant was determined and labelled as turbidity blank. The coagulation activity can be computed using Eq. (3).

$$\text{Turbidity removal (\%)} = ((\text{Turbidity}_{\text{Before}} - \text{Turbidity}_{\text{After}}) / \text{Turbidity}_{\text{Before}}) \times 100 \quad (1)$$

$$\text{COD removal (\%)} = ((\text{COD}_{\text{Before}} - \text{COD}_{\text{After}}) / \text{COD}_{\text{Before}}) \times 100 \quad (2)$$

$$\text{Coagulation activity (\%)} = ((\text{Turbidity}_{\text{Blank}} - \text{Turbidity}_{\text{After}}) / \text{Turbidity}_{\text{Blank}}) \times 100 \quad (3)$$

2.5 Experimental Design via Response Surface Methodology

The dosage of the coagulant, the solution's pH, and the contact time of slow mixing were optimized using the Response Surface Methodology (RSM) via Central Composite Design (CCD) in the Design Expert software. The dependent variables were predicted using Eq. (4).

The CCD analysis was made up of duplicates of 2^3 factorial designs, supplemented with a duplicate of six (6) axial points and six (6) central points; 34 tests were performed at random. The high and low values were chosen after examining the literature and performing preliminary trials. Table 2 shows the levels of operating conditions in the CCD. Analysis of Variance (ANOVA) was used to evaluate the effect of coagulant dosage, pH, and contact time on turbidity removal, COD removal, and coagulation activity. The order of statistical significance, as well as the model's hierarchy criterion, were utilized to decide whether the terms would remain in the prediction models or not. Following the development of the prediction models, three-dimensional (3D) response surface plots were created to show and investigate the impact of the operating conditions and interactions.

Table 2
Levels of operating condition in the CCD

Operating Conditions	Level of Operating Conditions				
	- α	-1	0	+1	$+\alpha$
Coagulant Dosage	26.3	50	125	200	223.7
pH	4.5	5	6.5	8	8.5
Contact time	20.5	30	60	90	99.5

$$Y = \beta_0 + \sum_{i=1}^n \beta_i X_i + \sum_{i=1}^n \beta_{ii} x_i^2 + \sum_{i=1}^n \sum_{j=i+1}^n \beta_{ij} x_i x_j + \epsilon \quad (4)$$

where,

Y = Predicted responses (turbidity removal and coagulation activity)

β_0 = Constant coefficient

β_i = Linear coefficient

β_{ii} = Quadratic coefficient

β_{ij} = Interactive coefficient

$x_i x_j$ = Influenced factors

ϵ = Random error

3. Results and Discussion

3.1 Statistical Analysis

RSM was carried out to optimize the selected operating conditions (coagulant dosage, pH, and contact time). 34 experimental runs from the central composite design with various coagulant dosage, pH, and contact time was carried out to identify its effect on turbidity removal, COD removal, and coagulation activity. All experimental runs were analysed by Analysis of variance (ANOVA) to identify the correlation between the operating factors by using the p -value. Results from the ANOVA analysis are shown in Table 3.

Table 3
Analysis of variance (ANOVA) for the response surface quadratic model

Term	Turbidity removal		COD removal		Coagulation activity	
	p-value	F-value	p-value	F-value	p-value	F-value
Model	< 0.0001	19.19	< 0.0001	14.97	< 0.0001	22.49
A: Coagulant dosage	0.1929	1.82	< 0.0001	28.86	0.5943	0.2930
B: pH	0.0039	10.68	< 0.0001	46.22	0.0006	16.54
C: Contact time	0.1126	2.75	0.2337	1.49	0.9613	0.0024
A x B	< 0.0001	30.75	0.0002	19.05	0.0003	19.56
A x C	0.0002	21.66	0.0425	4.59	< 0.0001	34.60
B x C	0.0017	13.19	0.3316	0.9820	0.0008	15.38
A x A	0.4856	0.50	0.0482	4.34	0.1919	1.82
B x B	< 0.0001	33.85	0.0006	15.58	< 0.0001	65.79
C x C	< 0.0001	55.23	0.0028	11.10	< 0.0001	33.97
A x B x C	0.1929	1.82	-		0.0441	4.62
A x A x B	0.1155	2.71			< 0.0001	74.32
A x A x C	0.0001	23.38			0.2153	1.64
A x B x B	0.0689	3.70			0.9365	0.0065
Lack of fit (LOF)	0.0003	19.58	0.3145	1.07	0.0048	10.19
R ² value	0.93		0.89		0.94	
Adjusted R ²	0.88		0.82		0.89	
Predicted R ²	0.77		0.74		0.82	

Identification of the suitability of the model generated can be seen through the F-value of the response, lack of fit (LOF) value, and R² value of the operating conditions. Based on Table 3, the model F-value of the response is big enough that there is only a 0.01% chance that it could occur due to noise. Lack of fit (LOF) F-value of COD removal is not significant relative to the pure error. There is a 31.45% chance that a LOF value this large could occur due to noise. Meanwhile, for turbidity removal and coagulation activity, the LOF F-value is significant. There is only a 0.03% and 0.48% chance for the F-value of turbidity removal and coagulation activity this large could occur due to noise. A significant lack of fit is not preferable as it indicates that the model is not fit. However, there are a few studies such as Cheraghipour and Pakshir (Cheraghipour and Pakshir 2021) and Tamoradi et al. (Tamoradi et al. 2021) that used the generated

model despite the significant LOF F-value, and it still shows good findings. Therefore, the generated model is still usable.

In a model, R-Squared (R^2 or the coefficient of determination) is a statistical metric that measures how well the data fit the model. Based on Table 3, the R^2 value of the turbidity removal model, COD removal model, and coagulation activity model are close to 1.0 which indicates they fit the model. Normal probability plots as shown in Fig. 1 further shows the plots distribute along the normal distribution line. Based on this value, it indicates that 7.42%, 11.03%, and 6.4% of the variability in the turbidity removal, COD removal, and coagulation activity cannot be explained by the model which is very low thus, it shows that the data did fit the model. Besides that, the predicted R^2 of turbidity removal, COD removal, and coagulation activity is in reasonable agreement with the adjusted R^2 as the difference between both is less than 0.2.

The generated model can be further justified its adequacy through the plots of predicted versus actual values as shown in Fig. 2. Based on the plots, shows that the actual values are distributed fairly close along the $y = x$ line and have linear behaviour. This result illustrates the strong performance of the generated model and demonstrates satisfactory agreement between actual data and data from the created models (Banch et al. 2019; Chua et al. 2019). Therefore, the effect of coagulant dosage, pH, and contact time on turbidity removal, COD removal, and coagulation activity was modelled using a second-order model as given in Eq. (5)–(7).

$$\text{Turbidity removal (\%)} = 131.46 - 0.31A - 11.52B - 0.14C + 0.05AB + 0.0016AC - 0.025BC + 0.001A^2 + 1.06B^2 + 0.0018C^2 \quad (5)$$

$$\text{COD removal (\%)} = 56.36 + 0.2A - 3.45B + 0.078C - 0.059AB - 0.00088AC - 0.049BC + 0.00029A^2 + 0.85B^2 + 0.0002C^2 \quad (6)$$

$$\text{Coagulation activity (\%)} = -64.22 + 4.80A - 20.09B + 0.43C - 0.73AB - 0.0045AC - 0.229BC - 0.026A^2 + 5.76B^2 + 0.01C^2 \quad (7)$$

3.2 Response Surface: Effect of *Saccharum officinarum* on Coagulation Performance

The 3D surface graph plots created from the models were used to further evaluate and understand the influence and interactions between coagulant dosage, pH, and contact time towards turbidity removal, COD removal, and coagulation activity. The plots were created using a function of two operating conditions at a time while maintaining the other factor. The 3D surface graph plots for turbidity removal, COD removal, and coagulation activity are shown in Fig. 3, Fig. 4, and Fig. 5 respectively.

3.2.1 Effect of Coagulant Dosage

Coagulant dosage is one of the most important operating conditions in the coagulation process to optimize the removal of pollutants and is most studied by researchers worldwide. To study the effect of coagulant dosage on the removal of turbidity and COD and coagulation activity, the coagulant dosage was varied from 50 mg/L to 200 mg/L. Based on Fig. 3(a, b), coagulant dosage is a significant operating condition that could increase turbidity removal. The plot shows that 50 mg/L is the optimum coagulant dosage for turbidity removal and increasing the coagulant dosage will only worsen the turbidity removal. The finding from this study is aligned with Tong et al. (Tong et al. 2021) which used *Moringa oleifera* for fish farm wastewater. Both studies show that a lower coagulant dosage is preferable and as the dosage increases, it will reduce turbidity removal. Coagulant dosage less than the optimum dosage is known as underdosing where the coagulant is insufficient to cater to the pollutants. Meanwhile, increasing the coagulant dosage beyond the optimum coagulant dosage will only cause overdosage. During overdosage, too many coagulants but insufficient pollutants could react with the coagulant. Eventually, both underdosing and overdosage will only cause the pollutants to repel each other instead of attracting each other, thus worsening the turbidity removal (Adesina et al. 2019; Nouj et al. 2022).

Based on Fig. 4(a, b), increasing the coagulant dosage from 50 mg/L to 200 mg/L reduces the removal of COD. This finding is in line with the findings by Shan et al. (Shan et al. 2017) and Fard et al. (Besharati Fard et al. 2021). Shan et al. (Shan et al. 2017) used *Moringa oleifera* for the treatment of wastewater from industrial estates and landfill. Meanwhile, Fard et al. (Besharati Fard et al. 2021) used *Lallemantia mucilage* for the treatment of saline oily wastewater. Both studies show the higher the coagulant dosage used in the coagulation process, the lower the COD removal. However, the study by Khader et al. (Khader et al. 2018) shows otherwise as increasing coagulant dosage improves the COD removal. The study by Shan et al. (Shan et al. 2017) and Fard et al. (Besharati Fard et al. 2021) extracts the natural coagulant prior to application using either alkali or ethanol while the study by Khader et al. (Khader et al. 2018) did not extract the coagulant. According to Shan et al. (Shan et al. 2017), the solvent used could probably reduce COD removal. Anyhow, sources of natural coagulants such as bagasse, *Moringa oleifera*, and mucilage contain their organic compound (Simin et al. 2022). The extraction process that was carried out not only extract the active coagulant agent but also manage to extract the organic compound as well which contribute to increasing COD content as a higher coagulant dosage was used. The advantage from this is that very low coagulant dosage is sufficient for optimum removal of COD unlike others that require higher coagulant dosage.

Figure 5 (a) and Fig. 5 (b) show the effect of coagulant dosage on coagulation activity. Based on these figures, coagulant dosage is significant for coagulation activity. The purpose of carrying out coagulation activity (%) is to identify the removal of pollutants in POME treatment is either due to the coagulation process or not. Lower coagulant dosage will show high coagulation activity. These plots show that the removal of COD is due to the coagulation process.

3.2.2 Effect of pH

Besides coagulant dosage, pH also plays an important role in improving the coagulation process as it could significantly affect the responsible coagulation mechanism. To identify the effect of pH by using

bagasse as a natural coagulant for the treatment of POME, the pH was varied from pH 5 to pH 8. Based on Fig. 3(a, c), Fig. 4(a, c), and Fig. 5(a, c), pH is a significant operating condition upon improving all three responses, turbidity removal, COD removal, and coagulation activity. Compared to coagulant dosage, pH is a more significant operating condition. All plots show that turbidity removal, COD removal, and coagulation activity is highest at pH 8. From pH 5, the higher the pH, the higher the turbidity removal, COD removal, and coagulation activity. This finding is similar to findings by Rifi et al. (Rifi et al. 2022) that use *Moringa oleifera* for the treatment of olive oil mill wastewater as well as Desta and Bote (Desta and Bote 2021) that also used *Moringa oleifera* seeds but for the treatment of domestic wastewater. Both studies showed that pH 8 as optimum pH for most effective pollutant's removal.

The coagulation mechanism of natural coagulants can be either interparticle bridging or charge neutralization. According to Bahrodin et al. (Bahrodin et al. 2022), the coagulation mechanism of *Saccharum officinarum* is interparticle bridging and not charge neutralization. Interparticle bridging relies on the polymeric chain that extends and attaches to pollutants or colloids and forms a complex structure of coagulant-colloid-coagulant. Bahrodin et al. (Bahrodin et al. 2022) have also identified the active coagulant agent of *Saccharum officinarum* is an extremely high polysaccharide content and according to the FT-IR analysis, the carboxyl group is part of the functional group. Guo et al. (Guo et al. 2017) state that the carboxyl group (-COOH) is the functional group that makes the polysaccharide acidic. At lower temperatures, the pollutants will have similar pH as the natural coagulant thus, both will repel each other. At higher pH, removal will also increase probably due to the availability of more adsorption sites from the polymeric chain (Shak and Wu 2014; Choy et al. 2015). This is because, at slightly alkali conditions, ionization of -COOH can occur and produce -COO⁻ group and -OH group. As a result, the -OH group will increase thus, causing intramolecular electrostatic repulsion which will enhance the uncoiling and extension of the polymeric chain (Lüring et al. 2020; Aziz et al. 2021). This will result in more adsorption sites available and a more complex structure can be formed for the removal of pollutants. However, further, increasing the pH will only extensively uncoil and stretch the polymeric chain which will wrap the pollutants instead of only attaching them. Similarly charged colloids will be produced and will only repel each other. The optimum pH of pH 8 agrees with the statement by Yin (Yin 2010) and Bratby (Bratby 2015) that identifying the natural coagulant based on the plant is best to be used at a pH range of 7 to 10. It is also worth noting that at pH 8, the coagulation activity is also high indicating that the removal of turbidity and COD is due to the coagulation and not from other reactions.

3.2.3 Effect of Mixing Contact Time

Besides coagulant dosage and pH, contact time during slow mixing can also affect the coagulation process but the least study focuses on this operating condition. To study the effect of contact time on turbidity removal, COD removal, and coagulation activity, the contact time was varied from 30 minutes to 90 minutes. Based on Fig. 3(b,c), Fig. 4(b,c), and Fig. 5(b,c), contact time during slow mixing is a significant operating condition but not as significant as pH as some of the condition is insignificant. However, based on these plots, a shorter contact time is preferable and results in higher turbidity removal, COD removal, and coagulation activity compared to a longer contact time. The finding from this study is

similar to the findings by Choong Lek et al. (Choong Lek et al. 2018) that used *Cicer arietinum* as a natural coagulant for the treatment of POME as well as Kusuma et al. (Kusuma et al. 2021) used *Ipomoea batatas* for water treatment. All studies show shorter contact time shows better coagulation performance.

Slow mixing is an essential step in the coagulation process to ensure the coagulant can react with pollutants and flocs can be formed. However, overmixing will cause more collisions between the flocs formed. The frequent collision between flocs will cause excessive mechanical shearing that can lead to floc breakage and lead to restabilization of the pollutants which will increase the concentration of the pollutants (Ramphal and Sibiya 2014; Ernest et al. 2017; Karam et al. 2021). Besides that, overmixing can also disturb the coagulation mechanism. The coagulation mechanism of *Saccharum officinarum* is interparticle bridging that relies on the polymeric chain for the formation of complex structures. According to Owodunni and Ismail (Owodunni and Ismail 2021), overmixing can break the polymeric chain and will hinder the formation of complex structures (flocs) that can settle via gravity. It is good that a shorter contact time is sufficient for the removal of turbidity and COD because extending the contact time not only can cause floc breakage but also require more energy which eventually will increase the total operating cost of the coagulation process (Choong Lek et al. 2018).

3.3 Identification of Optimum Operating Conditions and Validation of the Models

Based on the plots in Fig. 6, Fig. 7, and Fig. 8, optimum removal of turbidity and COD with high coagulation activity was obtained by using 50 mg/L coagulant dosage, slow mixed for 30 minutes with pH of wastewater maintained at pH 8. Optimum removal obtained from models was compared with the experimental response with the same operating condition to identify errors between the predicted and experimental response. Table 4 shows the comparison between experimental and predicted values with the same optimum operating conditions.

Table 4
Value comparison between experimental and predicted responses

Response	Experimental Response	Predicted Response	% Error
Turbidity removal (%)	95.7	95.0	0.75
COD removal (%)	62.9	66.8	3.86
Coagulation activity (%)	55.0	58.3	3.28

Based on Table 4, the error between the predicted response with the experimental response is between 0.7–4%. According to Priyatharishini and Mokhtar (Priyatharishini et al. 2019), the error should be less than 10% to validate that the experimental and predicted response is in good agreement. Error obtained from this finding which is less than 10% indicates that there are good agreements between the value

obtained from experimental and predicted. Joaquin et al. (Joaquin et al. 2022) state that an error of less than 10% is generally acceptable due to the nature of the experiment involving several fluctuating variables.

4. Conclusion

Coagulation-flocculation technique was used to demonstrate the efficiency of *Saccharum officinarum* (bagasse) as a possible natural coagulant for turbidity and COD removal from palm oil mill effluent (POME). Bagasse has been proven to offer promising treatment of wastewater with high COD content. A central composite design (CCD) was used to describe the treatment process using a second-order model. The operating condition that could affect the process such as coagulant dosage, pH and contact time during slow mixing was regulated to obtain optimum removal of turbidity and COD with high coagulation activity. The model validation report proved that the proposed model matched the experimental data with an R^2 value exceeding 85%. To obtain optimum turbidity removal and COD removal with high coagulation activity, the dosage of bagasse as a natural coagulant is 50 mg/L, pH of 8, and slow-mixed for 30 minutes. Findings from this study demonstrate that bagasse as a natural coagulant can be used for pre-treatment in POME to reduce both turbidity and COD content.

Declarations

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References

1. Adesina OA, Abdulkareem F, Yusuff AS, et al (2019) Response Surface Methodology Approach to Optimization of Process Parameter for Coagulation Process of Surface Water Using *Moringa Oleifera* Seed. S Afr J Chem Eng 28:. <https://doi.org/10.1016/j.sajce.2019.02.002>
2. Amran AH, Bahrodin MB, Zaidi NS, et al (2022) Turbid Water Treatment using Deshelled Carica Papaya Seed: Analysis via Factorial Design. Biointerface Res Appl Chem 12:7787–7795. <https://doi.org/10.33263/BRIAC126.77877795>
3. Amran AH, Zaidi NS, Syafiuddin A, et al (2021) Potential of carica papaya seed-derived bio-coagulant to remove turbidity from polluted water assessed through experimental and modeling-based study. Applied Sciences (Switzerland) 11:. <https://doi.org/10.3390/app11125715>
4. Aziz A, Agamuthu P, Hassan A, et al (2021) Green Coagulant from *Dillenia Indica* for Removal of Bis(2-ethylhexyl) Phthalate and Phenol, 4,4'-(1-methylethylidene)Bis- from Landfill Leachate. Environ Technol Innov 24:. <https://doi.org/10.1016/j.eti.2021.102061>

5. Bahrodin MB, Zaidi NS, Hussein N, et al (2021) Recent Advances on Coagulation-Based Treatment of Wastewater: Transition from Chemical to Natural Coagulant. *Curr Pollut Rep* 7:379–391. <https://doi.org/10.1007/s40726-021-00191-7>
6. Bahrodin MB, Zaidi NS, Kadier A, et al (2022) A Novel Natural Active Coagulant Agent Extracted from the Sugarcane Bagasse for Wastewater Treatment. *Applied Sciences (Switzerland)* 12:.. <https://doi.org/10.3390/app12167972>
7. Banch TJH, Hanafiah MM, Alkarkhi AFM, Amr SSA (2019) Factorial Design and Optimization of Landfill Leachate Treatment Using Tannin-Based Natural Coagulant. *Polymers (Basel)* 11:.. <https://doi.org/10.3390/polym11081349>
8. Besharati Fard M, Hamidi D, Alavi J, et al (2021) Saline oily wastewater treatment using *Lallemantia mucilago* as a natural coagulant: Kinetic study, process optimization, and modeling. *Ind Crops Prod* 163:.. <https://doi.org/10.1016/j.indcrop.2021.113326>
9. Bratby J (2015) *Coagulation and Flocculation in Water and Wastewater Treatment - Second Edition*, 2nd edn.
10. Chaibakhsh N, Ahmadi N, Zanjanchi MA (2014) Use of *Plantago Major L.* as a Natural Coagulant for Optimized Decolorization of Dye-Containing Wastewater. *Ind Crops Prod* 61:169–175. <https://doi.org/10.1016/j.indcrop.2014.06.056>
11. Cheraghipour E, Pakshir M (2021) Environmentally Friendly Magnetic Chitosan Nano-Biocomposite for Cu(II) Ions Adsorption and Magnetic Nano-Fluid Hyperthermia: CCD-RSM Design. *J Environ Chem Eng* 9:.. <https://doi.org/10.1016/j.jece.2020.104883>
12. Chitra D, Muruganandam L (2019) Performance of Natural Coagulants on Greywater Treatment. *Recent Innovations in Chemical Engineering (Formerly Recent Patents on Chemical Engineering)* 13:81–92. <https://doi.org/10.2174/2405520412666190911142553>
13. Choong Lek BL, Peter AP, Qi Chong KH, et al (2018) Treatment of Palm Oil Mill Effluent (POME) Using Chickpea (*Cicer Arietinum*) as a Natural Coagulant and Flocculant: Evaluation, Process Optimization and Characterization of Chickpea Powder. *J Environ Chem Eng* 6:6243–6255. <https://doi.org/10.1016/j.jece.2018.09.038>
14. Choy SY, Prasad KMN, Wu TY, Ramanan RN (2015) A Review on Common Vegetables and Legumes as Promising Plant-based Natural Coagulants in Water Clarification. *International Journal of Environmental Science and Technology* 12:367–390. <https://doi.org/10.1007/s13762-013-0446-2>
15. Chua SC, Malek MA, Chong FK, et al (2019) Red Lentil (*Lens Culinaris*) Extract as a Novel Natural Coagulant for Turbidity Reduction: An Evaluation, Characterization and Performance Optimization Study. *Water (Switzerland)* 11:.. <https://doi.org/10.3390/w11081686>
16. Desta WM, Bote ME (2021) Wastewater Treatment Using a Natural Coagulant (*Moringa Oleifera* Seeds): Optimization Through Response Surface Methodology. *Heliyon* 7:.. <https://doi.org/10.1016/j.heliyon.2021.e08451>
17. Ernest E, Onyeka O, David N, Blessing O (2017) Effects of pH, Dosage, Temperature and Mixing Speed on The Efficiency of Water Melon Seed in Removing the Turbidity and Colour of Atabong River,

- Awka-Ibom State, Nigeria. International Journal of Advanced engineering, Management and Science 3:427–434. <https://doi.org/10.24001/ijaems.3.5.4>
18. Guo MQ, Hu X, Wang C, Ai L (2017) Polysaccharides: Structure and Solubility. In: Solubility of Polysaccharides. InTech
 19. Jagaba AH, Aziz A, Latiff A, et al (2017) Treatment of Palm Oil Mill Effluent (POME) by Coagulation-Flocculation using different Natural and Chemical Coagulants: A Review. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN 13:67–75. <https://doi.org/10.9790/1684-1306076775>
 20. Joaquin AA, Sivamani S, Gnanasundaram N (2022) Statistical experimental design and analysis of mixed natural-synthetic coagulants for the reduction of total suspended solids and turbidity in sewage wastewater treatment. Biomass Convers Biorefin. <https://doi.org/10.1007/s13399-022-02566-2>
 21. Karam A, Bakhoun ES, Zaher K (2021) Coagulation/flocculation process for textile mill effluent treatment: experimental and numerical perspectives. International Journal of Sustainable Engineering 14:983–995. <https://doi.org/10.1080/19397038.2020.1842547>
 22. Khader EH, Mohammed T, Mirghaffari N, Thj M (2018) Use of Natural Coagulants for Removal of COD, Oil and Turbidity from Produced Waters in the Petroleum Industry. Article in Journal of Petroleum & Environmental Biotechnology 9:3. <https://doi.org/10.4172/2157-7463.10003741>
 23. Kusuma HS, Amenaghawon AN, Darmokoesoemo H, et al (2021) Evaluation of extract of Ipomoea batatas leaves as a green coagulant–flocculant for turbid water treatment: Parametric modelling and optimization using response surface methodology and artificial neural networks. Environ Technol Innov 24:. <https://doi.org/10.1016/j.eti.2021.102005>
 24. Lee ZS, Chin SY, Lim JW, et al (2019) Treatment Technologies of Palm Oil Mill Effluent (POME) and Olive Mill Wastewater (OMW): A Brief Review. Environ Technol Innov 15:. <https://doi.org/10.1016/j.eti.2019.100377>
 25. Loh ZZ, Zaidi NS, Syafluddin A, et al (2021) Shifting from conventional to organic filter media in wastewater biofiltration treatment: A review. Applied Sciences (Switzerland) 11
 26. Loh ZZ, Zaidi NS, Yong EL, et al (2022) Current Status and Future Research Trends of Biofiltration in Wastewater Treatment: a Bibliometric Review. Curr Pollut Rep 8
 27. Lüring M, Kang L, Mucci M, et al (2020) Coagulation and Precipitation of Cyanobacterial Blooms. Ecol Eng 158:. <https://doi.org/10.1016/j.ecoleng.2020.106032>
 28. Ng KH, Cheng CK (2015) A Novel Photomineralization of POME Over UV-Responsive TiO₂ Photocatalyst: Kinetics of POME Degradation and Gaseous Product Formations. RSC Adv 5:53100–53110. <https://doi.org/10.1039/c5ra06922j>
 29. Nouj N, Hafid N, El Alem N, et al (2022) Valorization of β -Chitin Extraction Byproduct from Cuttlefish Bone and Its Application in Food Wastewater Treatment. Materials 15:. <https://doi.org/10.3390/ma15082803>

30. Owodunni AA, Ismail S (2021) Revolutionary Technique for Sustainable Plant-Based Green Coagulants in Industrial Wastewater Treatment—A review. *Journal of Water Process Engineering* 42:. <https://doi.org/10.1016/j.jwpe.2021.102096>
31. Priyatharishini M, Mokhtar NM, Kristanti RA (2019) Study on the Effectiveness of Banana Peel Coagulant in Turbidity Reduction of Synthetic Wastewater. *INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGY AND SCIENCES (IJETS)* ISSN:2462–1269. <https://doi.org/10.15282/ijets.6.1.2019.1007>
32. Ramphal S, Sibiya MS (2014) Optimization of Time Requirement for Rapid Mixing During Coagulation Using a Photometric Dispersion Analyzer. *12th International Conference on Computing and Control for the Water Industry, CCWI2013* 70:1401–1410. <https://doi.org/10.1016/j.proeng.2014.02.155>
33. Rifi SK, Souabi S, El Fels L, et al (2022) Optimization of coagulation process for treatment of olive oil mill wastewater using *Moringa oleifera* as a natural coagulant, CCD combined with RSM for treatment optimization. *Process Safety and Environmental Protection* 162:406–418. <https://doi.org/10.1016/j.psep.2022.04.010>
34. Shak KPY, Wu TY (2014) Coagulation-Flocculation Treatment of High-Strength Agro-Industrial Wastewater Using Natural *Cassia Obtusifolia* Seed Gum: Treatment Efficiencies and Floccs Characterization. *Chemical Engineering Journal* 256:. <https://doi.org/10.1016/j.cej.2014.06.093>
35. Shan TC, Matar M Al, Makky EA, Ali EN (2017) The Use of *Moringa Oleifera* Seed as a Natural Coagulant for Wastewater Treatment and Heavy Metals Removal. *Appl Water Sci* 7:1369–1376. <https://doi.org/10.1007/s13201-016-0499-8>
36. Simin T, Davie-Martin CL, Petersen J, et al (2022) Impacts of Elevation on Plant Traits and Volatile Organic Compound Emissions in Deciduous Tundra Shrubs. *Science of the Total Environment* 837:. <https://doi.org/10.1016/j.scitotenv.2022.155783>
37. Syamimi Zaidi N, Syafiuddin A, Sillanpää M, et al (2022) Insights into the potential application of magnetic field in controlling sludge bulking and foaming: A review. *Bioresour Technol* 358
38. Tamoradi T, Kiasat AR, Veisi H, et al (2021) MgO Doped Magnetic Graphene Derivative as a Competent Heterogeneous Catalyst Producing Biofuels via Transesterification: Process Optimization through Response Surface Methodology (RSM). *J Environ Chem Eng* 9:. <https://doi.org/10.1016/j.jece.2021.106009>
39. Tong CY, Yusuf FHBC, Derek CJC (2021) Fish Farm Wastewater Treatment using *Moringa oleifera* Seed Powder as Natural Coagulant. In: *IOP Conference Series: Earth and Environmental Science*. IOP Publishing Ltd
40. Yin CY (2010) Emerging Usage of Plant-Based Coagulants for Water and wastewater Treatment. *Process Biochemistry* 45:1437–1444. <https://doi.org/10.1016/j.procbio.2010.05.030>
41. Zaidi N syamimi, Chin Ting W, Zhan Loh Z, et al (2022) Assessment and optimization of a natural coagulant (*Musa paradisiaca*) peels for domestic wastewater treatment. *Environmental and Toxicology Management* 2:. <https://doi.org/10.33086/etm.v2i1.2901>

42. Zaidi NS, Muda K, Abdul Rahman MA, et al (2019a) Effectiveness of Local Waste Materials as Organic-Based Coagulant in Treating Water. IOP Conf Ser Mater Sci Eng 636:.
<https://doi.org/10.1088/1757-899X/636/1/012007>
43. Zaidi NS, Muda K, Loan LW, et al (2019b) Potential of Fruit Peels in Becoming Natural Coagulant for Water Treatment. International Journal of Integrated Engineering 11:.
<https://doi.org/10.30880/ijie.2019.11.01.017>

Figures

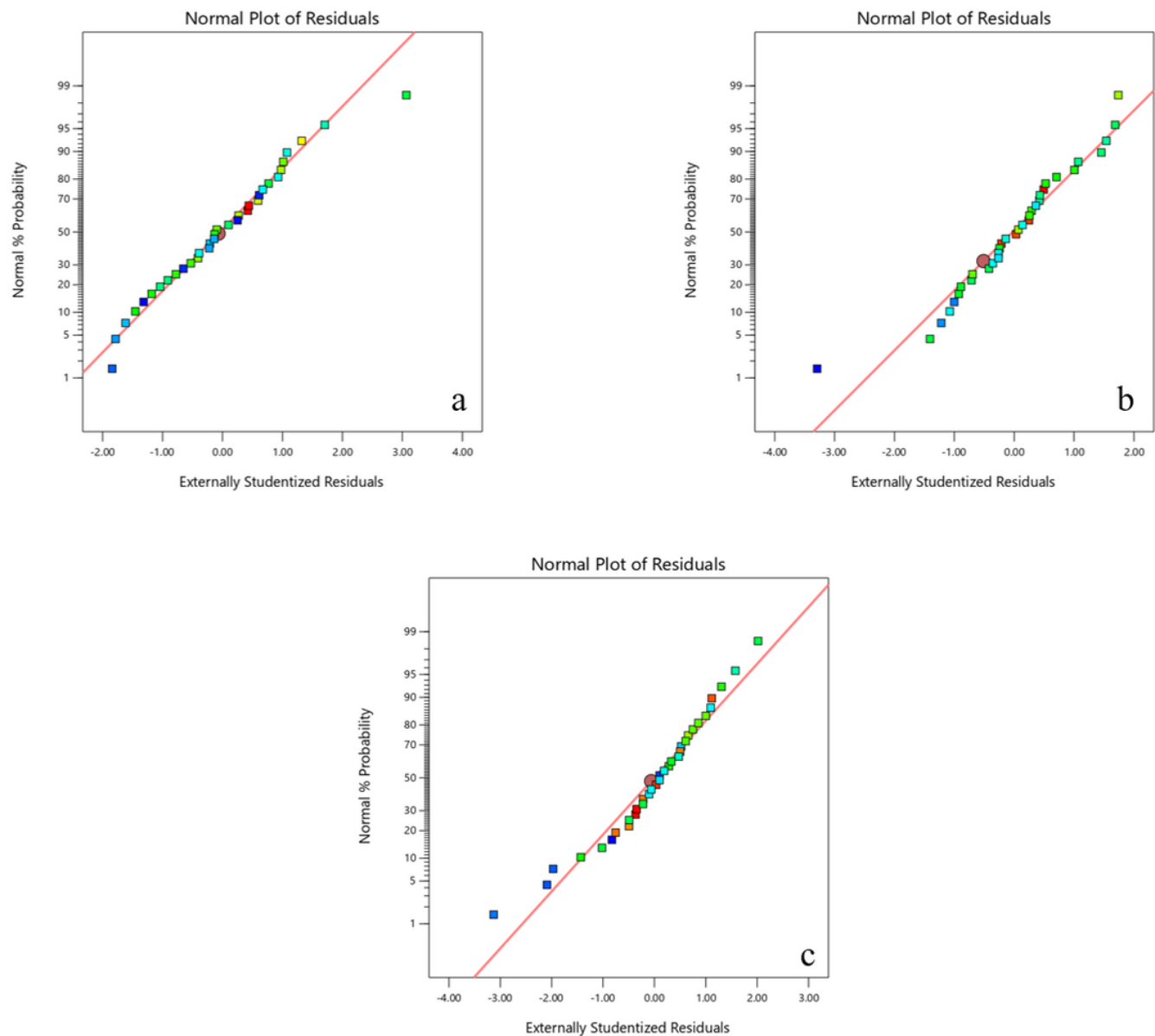


Figure 1
Normal probability plots for (a) Turbidity removal, (b) COD removal, and (c) Coagulation activity

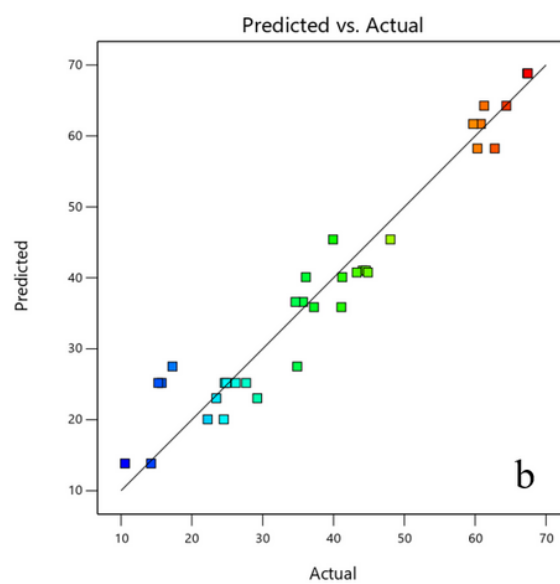
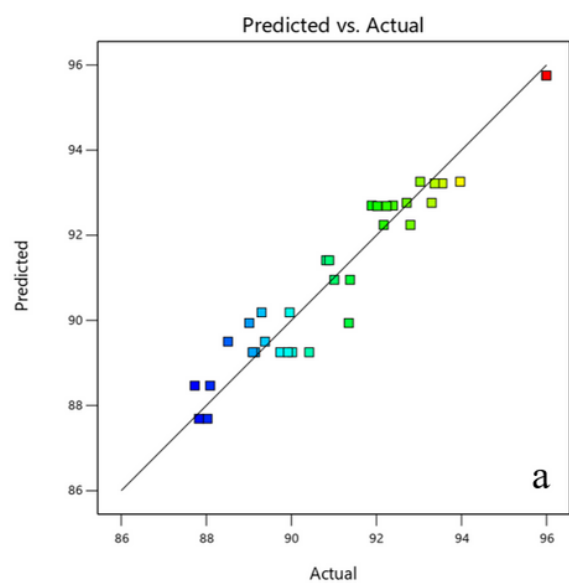


Figure 2

Plots of predicted versus actual values for (a) Turbidity removal, (b) Coagulation activity

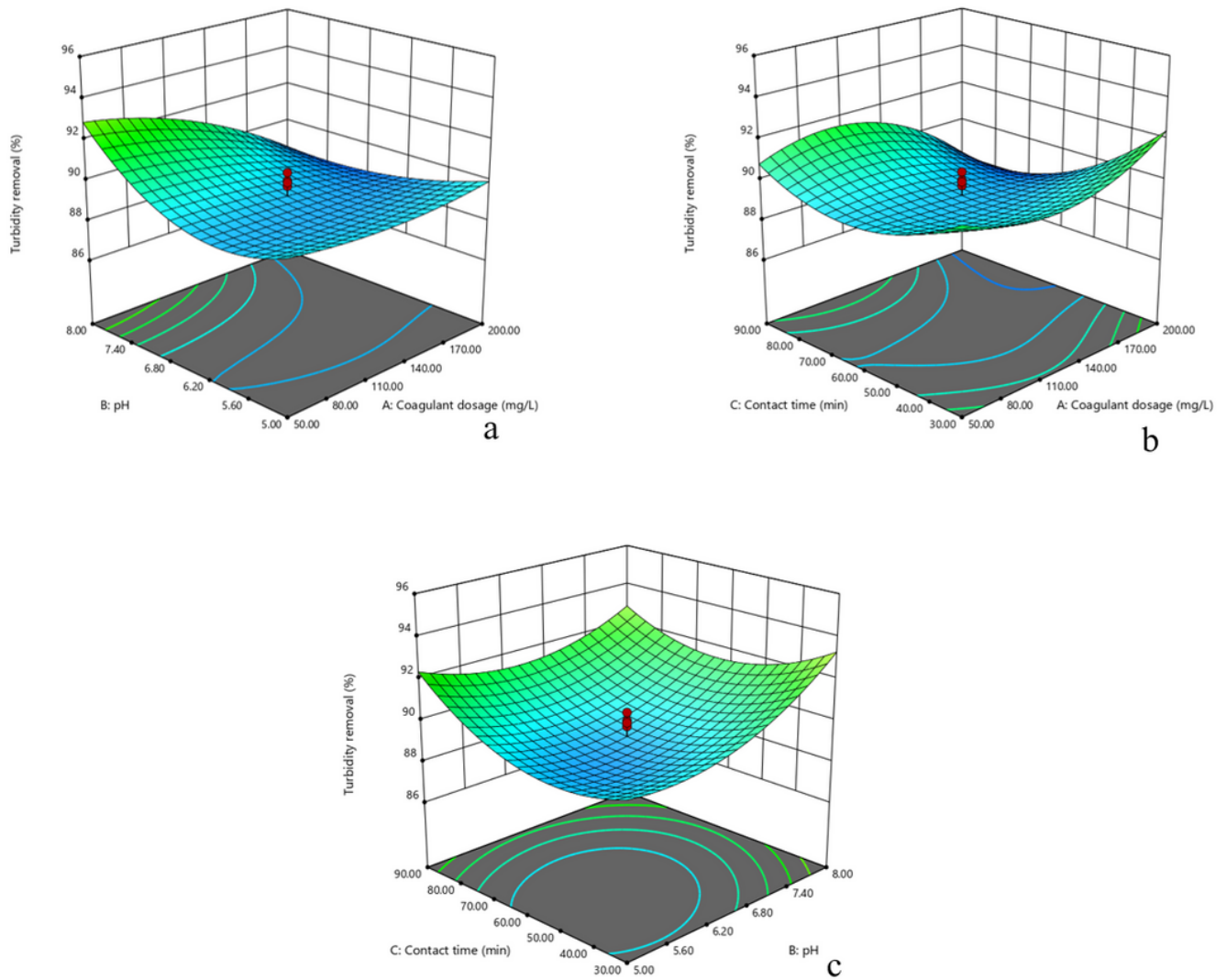


Figure 3

3D surface graph for turbidity removal (%) as a function of (a) Coagulant dosage and pH, (b) Coagulant dosage and contact time, and (c) pH and contact time.

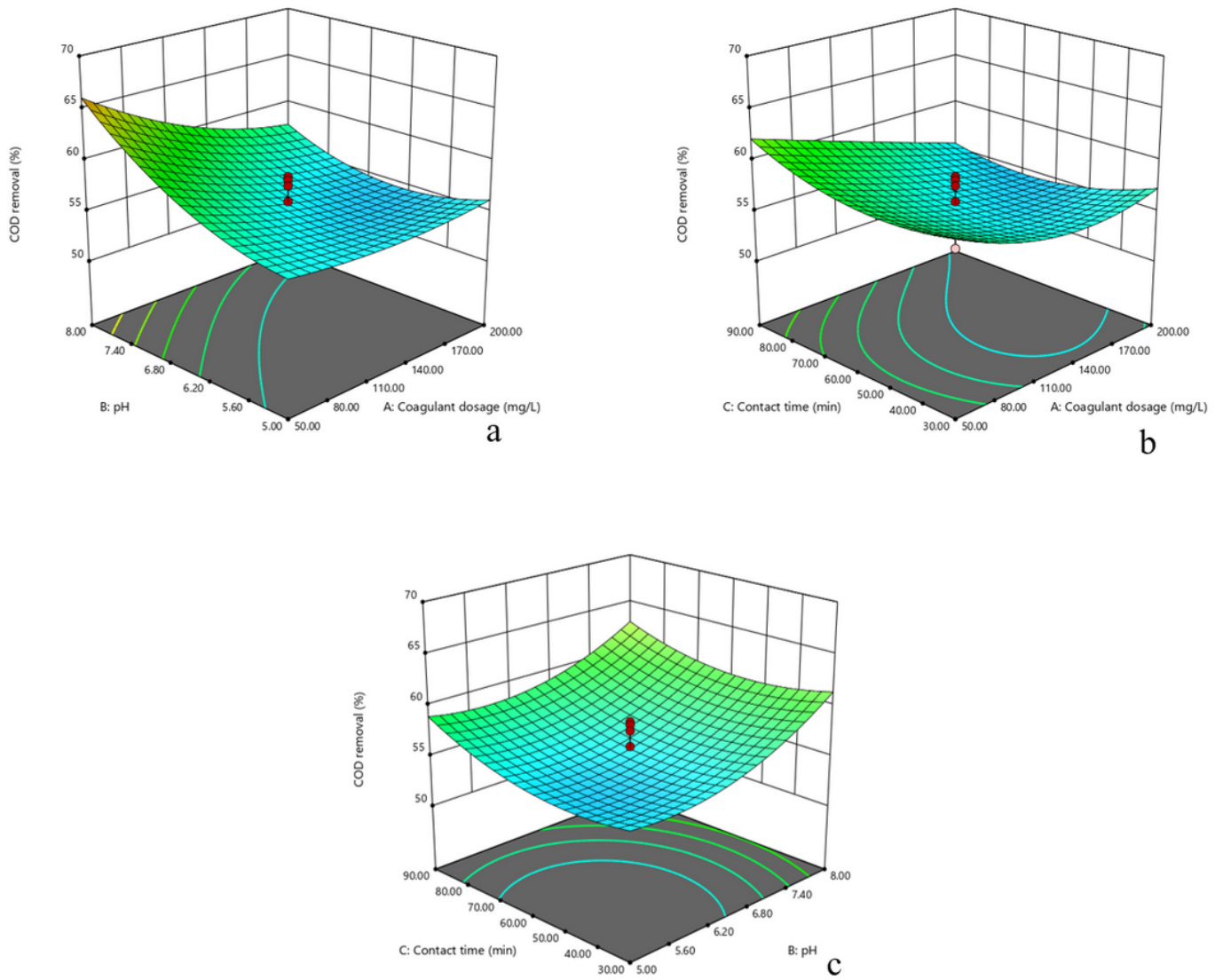


Figure 4

3D surface graph for COD removal (%) as a function of (a) Coagulant dosage and pH, (b) Coagulant dosage and contact time, and (c) pH and contact time

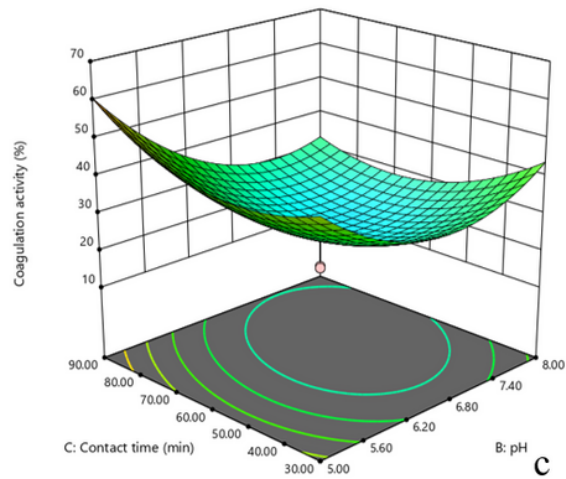
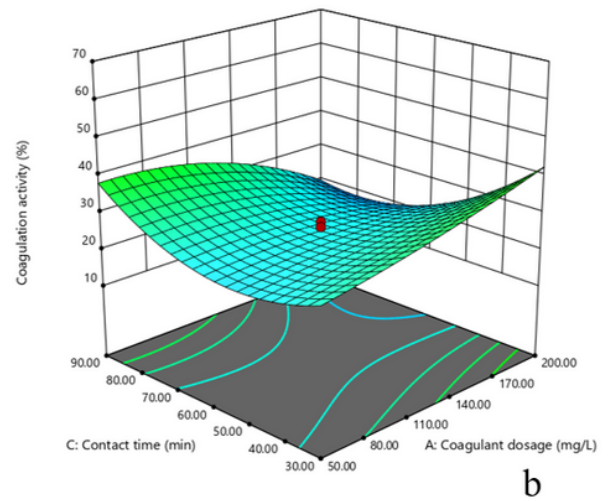
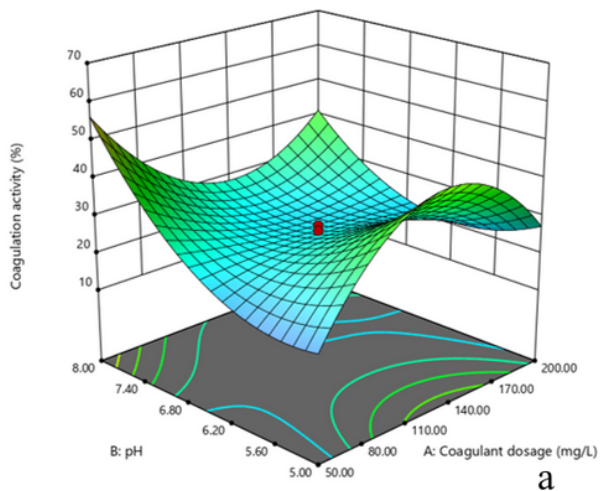


Figure 5

3D surface graph for coagulation activity (%) as a function of (a) Coagulant dosage and pH, (b) Coagulant dosage and contact time, and (c) pH and contact time