Nigerian Research Journal of Engineering and Environmental Sciences 9(1) 2024 pp. 235-248
p ISSN: 2635-3342; e ISSN: 2635-3350

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Development and Application of a Bio-Coagulant using Plantain Pseudo Stem Extract for Crude Oil-Field Produced Water Treatment

***Odisu, T. and Basikoro, A.**

Department of Chemical Engineering, Federal University of Petroleum Resources, Effurun, Nigeria
*odisu.teddy@fupre.edu.ng

http://doi.org/10.5281/zenodo.12599674

ARTICLE INFORMATION

Article history:
Received 17 Apr. 2024
Revised 01 May. 2024
Accepted 09 May. 2024
Available online 30 Jun. 2024

Keywords:
Bio-coagulant
Plantain-pseudo-stem-extract
Produced-water
Total suspended solids
Total dissolved solids
ANOVA

ABSTRACT

One factor contributing to the high cost of crude oil production in Nigeria is produce water handling. This is because of regulatory requirements for produced water disposal. Application of imported water clarifier chemicals have become a prominent approach in water treatment, leading to huge capital flight and poor local capacity development. Therefore, this work investigates the optimization of coagulation efficacy of Musa paradisiaca (plantain) pseudo stem juice as natural coagulant, a substitute for aluminium Sulphate (Alum). The water sample from a flow station was obtained for the evaluation of the efficacy of the coagulants. Response Surface Methodology was used to optimize the process using Design Expert Version 10. Factors considered were; coagulant dosage (mg/L), retention time (min), and pH with seventeen experimental runs generated using Box-Behnken Design method. The parameters analyzed were EC, TSS, TDS and Turbidity. Jar test laboratory scale studies were performed, and the result analyzed statistically to study the effects of the factors on coagulation. The coagulation efficacy was achieved at pH 6 with percentage removal of 77%, dosage of 7.5mg/L after 60 minutes and 97% performance as a coagulant aid with Alum. The raw water sample was characterized by conducting preliminary test to ascertain the initial concentration of the parameters. Analysis of variance (ANOVA) was used to evaluate the significance of the model and the variables. Plantain pseudo stem juice showed tremendous potential as a bio-coagulant for water treatment and could be applied in the pre-treatment stage.

1. INTRODUCTION

In the process of crude oil exploitation and production, water is usually produced alongside the oil either as free water or emulsion. This water which is commonly referred to as produced-water needs to be rendered fit for disposal. This is because, besides crude oil, produced water commonly contain dissolved and suspended solids as well as other impurities which would obviously make the water unfit for immediate disposal (Akhter et al., 2021). Produced water can be disposed directly into water bodies, use for water-flooding and re-injection operations. When this water is disposed untreated, it can pollute water bodies or clog the pores of reservoirs depending on the disposal route. Steps are therefore required to ensure that the water is treated so as to meet environmental and regulatory standards for water disposal. Some steps that are usually employed in the treatment of produced water include – separation of oil components with the application of chemical demulsifiers, mechanical separation of suspended solids and the application of water clarifiers like coagulants.

Coagulation in water treatment operations helps to clarify water by agglomerating small particles into larger, settleable masses which can then be separated from the water by gravity-settling. The mode of operations of coagulants is by neutralizing the negative charges on suspended particles, then forming larger, heavier flocs (Alazaiza et al., 2022)**,** just as the particles alter the physico-chemical properties of the water. These coagulants can either be primary coagulants which helps to add density to slowly settling flocs or increase the toughness and prevent the particles from collapsing in subsequent processes, or they can be coagulant aids (Singh and Mahanta, 2022). They are mainly categorized as organic and inorganic coagulants (Yahya et al., 2020). Chemical-based coagulants like $AlCl_3$, $FeCl_3$, and poly aluminium chloride (PAC) are used in water treatment but have limitations like low-temperature ineffectiveness, generating large sludge volumes, high procurement costs, and negative impacts on human health and the environment. On the other hand, eco-friendly natural coagulants offer benefits like renewability, biodegradability, nontoxicity, and cost-effectiveness. They are locally available, sustainable, safe, and can be extracted from various sources like animals, microorganisms, and plants.

Numerous studies have highlighted the outstanding efficacy of natural coagulant/flocculants (NC/Fs) in water treatment and their potential for effectively purifying industrial wastewaters attributed to their varied intrinsic features. These attributes encompass long polymer chains, significant cationic charges, and efficient settling capabilities with a substantial capacity for associating large aggregates (Deepa et al., 2022). These studies have explored the application of plant-based coagulants in industrial wastewater treatment, yielding promising outcomes. Specifically, tannin-based coagulants were scrutinized for treating high-range turbidity surface water. The findings revealed that tannins help to achieve a remarkable 98% turbidity removal and 100% color removal at an optimal dose of 19 $mg \cdot l^{-1}$, with no pH variation (De Oliveirra et al., 2022). Additionally, the study highlighted that the use of tannins led to enhanced settleability and reduced sludge production compared to the utilization of chemical coagulants. In one study, Moringa oleifera seed extract was used as a bio-coagulant for the treatment of industrial paint wastewater, and the results showed that it was effective in reducing turbidity by 99.9% under optimal condition with coagulant dose of 2.5ml, in 5mins at a steering speed of 210.5rpm (Madjene et al., 2023). Similarly, Dao et al., 2021, investigated the use of natural coagulant obtained from Cassia fistula seeds extract for the treatment of wastewater from a textile dyeing industry. The results showed that the coagulant was effective in color removal with 93.8%. The use of a natural coagulant obtained from tamarind seeds extract for the treatment of drimarene dark red (DDR) synthetic wastewater was also investigated and the results showed that the tamarind seed extract-based coagulant was effective in reducing DDR turbidity with a maximum removal efficiency of 84.60% at pH 3 and dosage 3g/l respectively (Kristianto et al., 2019)

This present study is therefore focused on the application of plantain pseudo stem extract as bio-coagulant either as stand-alone or blended with natural alum in the treatment of produced water with the aim of reducing its turbidity arising from either dissolved or suspended solids or both. The choice of plantain pseudo stem extract is borne out of the need to seek value for this very abundant agricultural waste available in the South and North Central of Nigeria as well as other parts of the World.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

In developing the bio-coagulant from plantain pseudo-stem, the following materials and equipment were used. These include plantain pseudo stem, obtained from local farms around Warri, sulfuric acid (H_2SO_4), 1M, sodium Hydroxide NaOH, 1M, ethanol, absolute, distilled water. The equipment that were used include OEM LG oven with specification number of DHG-9023A, high speed Kenwood mixer, filter made of muslin cloth and mesh size of 100-200, graduated 500ml glass cylinder made by Jino Tech, glass beakers of 600ml capacity by Bur Tech, electronic balance with specification JJ224BC, and made by G&G, mechanical stirrer, with specification PE – 8300, and made by Ecohim Ltd, digital Turbidity meter by Labtech, pH meter with specification EZ9908, and made by Yinmik, electrical conductivity meter with specification EZ9908, and made by Yinmik, micro-pipette with specification 1210, and made by Liquid Handling Systems, evaporation disk with specification CE-EVAP200, and made by SKU and glass fibre filter, with specification GF 9, made by Whatman.

2.2. Sample Collection

2.2.1. Plantain pseudo stem collection and preparation of pith juice

Matured plantain stems (*Musa paradisiaca*) were collected from a local plantain plantation in Warri, Nigeria, and their piths were washed, cleaned, and sliced into small pieces and then weighed using an electronic balance (Gopika and Kani, 2016). The coagulant was extracted according to the method described by (Owoicho et al., 2021), by mixing 100g of sliced plantain pith with distilled water, filtered, and the juice collected. The juice was stored in a 1litre white gallon, precipitated with ethanol, and dried in an oven at 60℃ (see Figure 1). The coagulation experiment using the extract was conducted the same day.

(a) (b) (c)

Figure 1: Extraction process of the plant-based coagulant (a) a sample of the plantain pseudo stem (b) plantain pseudo stem juice plus ethanol (c) extracted mucilage from the juice

2.2.2. Collection of produced water sample

Produced water sample from a crude oil production facility (flow station) near Warri, Nigeria was collected in relatively sufficient quantity and preserved in a container for analysis and treatment. Preliminary tests were conducted to determine the initial values of parameters like salinity, turbidity, pH, temperature, and total solids.

2.3. Optimization of Coagulation Process

The response surface methodology (RSM) was utilized to optimize the removal efficiency of selected responses using a three-factor and three-level pattern design. The potential design factors considered were, Coagulant dose, pH and retention time with the range of values in Table 2. The results were analyzed using Design Expert ® 10 software, with 17 experimental runs generated using the Box Behnken design as shown in Table 3.

Table 2: Level and range of independent variables

Variable	Symbol	Coded variable levels	
		-1	+1
Dosage (mg/L)	A	5	10
Retention time (mins)	B	30	60
pH	C	6	8

Table 3: Experimental runs generated using the Box Behnken design method

Run	Factor 1	Factor 2	Factor 3
	A: Dosage (mg)	B: Retention time (min)	C: pH
1	7.5	30	6
2	7.5	60	8
3	7.5	45	7
4	10	30	7
5	7.5	45	7
6	5	45	6
7	7.5	60	6
8	10	60	7
9	10	45	8
10	7.5	30	8
11	7.5	45	7
12	5	60	7
13	5	30	7
14	7.5	45	7
15	10	45	6
16	7.5	45	7
17	5	45	8

2.4. Coagulation Jar Test Using Produced Bio-Coagulant

The study involved adding 300 ml of raw water to each beaker (used to replicate the jar test kit) and dosed with the bio coagulant with the respective dosage according to design expert specifications using a calibrated micropipette. After dosing each beaker content with the bio-coagulant, the mixture was stirred at 200 rpm for 5 minutes, then reduced to 100 rpm for 15 minutes. The flocculated particles sat for 30 minutes, 45 minutes, and 60 minutes depending on which is applicable in line with the design specification. The supernatant was then decanted to determine EC, TS, and turbidity (see Figure 2). The pH and concentration of produced water samples were adjusted using sodium hydroxide or sulfuric acid. Similar to negative and positive controls (El Bouaidi et al., 2022).

(a) (b) (c)

Figure 2: Coagulation jar test experimental procedure describing (a) 300 ml of the raw water transferred to a beaker (b) stirring the mixture of the coagulant and the water sample using a mechanical stirrer (c) clarified water sample

2.5. Coagulation Jar Test using 100% Alum as Coagulant

Alum was sourced from a local market in Effurun, delta state and subsequently broken down into crystals and crushed into smooth powdered form using a mortar and a pestle. The powdered alum (10 g) was measured on the weighing balance and mixed with 100ml distilled water and stirred with the aid of a magnetic stirrer in the laboratory similar to Akuboh et al., 2022 (Figure 3). Each beaker containing the raw water sample as described earlier was dosed with increasing concentration of the alum as coagulant ranging from 5-10 mg/l and a pH varying at 6-8 with retention time of 30, 45 and 60 mins.

(a) (b)

Figure 3: Showing (a) a crystal of alum alongside a mortar and pestle (b) a sample of the test carried out using just alum

2.6. Coagulation Jar Test using a Blend of Alum and Plantain Pseudo-Stem- Based Coagulant

Jar tests were next conducted with a blend of alum solution and plantain pseudo-stem- based coagulant in ratios of 90%:10%, 70%:30%, 50%:50%, 30%:70%, 10%:90% respectively and at varying dose rates to further optimize the process as shown in Figure 4.

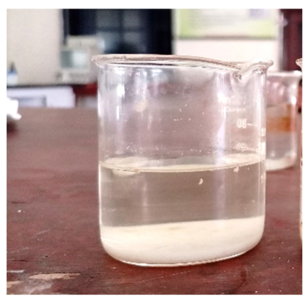


Figure 4: A sample of the test carried out using a combination of Alum and the produced coagulant.

2.7. Evaluation of Parameters

The turbidity was measured using a portable turbidity meter in nephelometric turbidity units (NTU). The meter was calibrated with a reference sample and the intensity of light scattered by the sample was read off. The percentage decrease in total turbidity was calculated using Equation 1. The process ensured precision, accuracy, and reproducibility in analytical results.

$$\text{Turbidity \% removal} = \frac{A-B}{A} \times 100 \quad (1)$$

Where A is turbidity of raw wastewater (NTU), B is turbidity after treatment (NTU).

The pH was measured using a digital pH meter. The pH value of the samples after each treatment was read off and same recorded.

A vacuum filtration apparatus and evaporation disk method was used to measure total suspended solids (TSS). The disks were dried at 100–105°C for one hour, cooled, and weighted. The water sample was then filtered through a glass fibre filter. The residue dried at same temperature range and weighed. The percentage of total suspended solids removal was determined by Equation 2.

$$\text{Total suspended solid \% removal} = \frac{A-B}{C} \times 100 \quad (2)$$

where A is weight of the disk + solids (g), B is weight of empty disk (g), C is volume of sample (ml).

The total dissolved solids was measured using a TDS meter in milligram per liter (mg/l).

Electrical conductivity (EC) was measured using conductivity meter in micro siemens per centimeter (ms/cm).

3. RESULTS AND DISCUSSION

3.1. Analysis of Preliminary Sample

Table 3 shows the characterization results obtained from the preliminary test conducted on the sample of produced water, before the coagulation process. The test was carried out as earlier stated and the results presented herein. Some of the physico-chemical water quality parameters investigated include pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS) and total suspended solids (TSS). From the result in Table 3, the raw water sample was found to be moderately alkaline with a pH of 10.53 signifying the presence of more hydroxyl (OH^-) ions. With a turbidity of 224NTU indicating a significant level of suspended particles in the water, TDS of 366 mg/l and a low EC of 9.4 ms/cm indicating low levels of dissolved salts or ions in the water.

Table 3: Characterization results of the raw produced-water

Parameters	pH	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	Electrical conductivity (mS/Cm)
Raw H_2O readings	10.53	224	366	100	9.4

3.2. Coagulation Jar Test Results

Jar Test was conducted at the optimum coagulant dose of 10 mg/L and a lower dose of 5 mg/L for the purpose of comparison for each coagulant used.

3.2.1. Jar Tests using the plantain pseudo stem-based coagulant

Following the experimental procedure earlier described, jar test was carried out for 17 runs generated by to design expert's specification using 100% of the plantain pseudo stem-based coagulant and the results tabulated in Table 4. From the experimental results shown in Table 4, the highest turbidity removal efficiency was 77.152% (at dosage = 7.5mg/l, retention time = 60 min, and pH = 6), while the least removal efficiency was 64.955% (at dosage =10, retention time = 45 min, and pH = 8). Though the result showed that the turbidity of the water treated with plantain pseudo stem extract is still above the World Health Organization and Nigerian Standard for Drinking Water Quality (W.H.O and NSDWQ respectively) permissible limit as found in (NIS, 2015) by 47.441NTU, enhanced treatment processes of filtration and disinfection is expected to bring the turbidity value to acceptable range in a conventional treatment facility. The results obtained are in line with those of Owoicho et al., 2021, who also verified the same range of pH and retention time in their study using banana pseudo stem extract. The results in Table 4 suggest that a dose of 5mg/l of the bio-coagulant would lead to a significant decrease in the turbidity of the water resulting in a percentage turbidity removal between 65-75%. This could be attributed to the hydroxyl (-OH) groups in the plantain pseudo stem extract, which enhanced polymer adsorption on contaminant particles and facilitated bridging actions between pollutants (Nath et al., 2021). It can therefore be concluded that a dose of 5mg/l is sufficient for turbidity adsorption, significantly enhancing removal efficiency. Also, at 7.5 mg/l, turbidity removal efficiency stabilized at 77%, prompting its selection for further investigation. Additionally, the relationship between coagulant dosage and Total Suspended Solids (TSS) showed that decreasing TSS values would be as a result of neutralization of negative charges on suspended particles. The measured Total Dissolved Solids (TDS) showed distinctive difference indicating reduction in the cloudiness of the water as particles agglomerated and formed settleable flocs. Higher dosage concentrations corresponded to increased TSS removal and reduced Electrical Conductivity (EC).

Table 4: Results obtained from the treated raw water using plantain pseudo stem-based extract

Run	A: Dosage (mg/l)	B: retention time (min)	C: pH	%Turbidity (NTU)	% TDS (mg/l)	% TSS (mg/l)	% Electrical Conductivity (mS/cm)
1	7.5	45	7	65.268	41.967	94.3	90.85
2	5	60	7	75.196	24.153	97	72.128
3	10	30	7	72.411	44.973	97	54.894
4	7.5	45	7	65.268	41.967	94.3	90.85
5	10	45	8	64.955	56.175	100	86.383
6	7.5	45	7	65.268	41.967	94.3	90.85
7	7.5	45	7	65.268	41.967	94.3	90.85
8	7.5	45	7	65.268	41.967	94.3	90.85
9	7.5	30	8	66.625	40.910	85.8	83.191
10	7.5	60	8	68.687	42.194	4	78.936
11	5	45	8	66.804	32.705	3	91.809
12	7.5	30	6	72.679	50.273	98.4	17.340
13	7.5	60	6	77.152	30.027	94.3	96.170
14	5	45	6	70.893	35.792	85.9	92.128
15	10	60	7	73.192	53.123	98.57	96.809
16	5	30	7	67.304	44.825	87	78.723
17	10	45	6	75.670	47.760	95.65	35.745

The study also highlights that turbidity removal efficiency is influenced by the water pH levels, which affect ion concentrations and cationic acids in the mucilage extract. When the water becomes alkaline (pH above 7), removal efficiency decreases due to the presence of hydroxyl ions. However, the most effective turbidity removal occurs within the pH range of 6 to 7, considered to be slightly acidic/ basic as in the cases of Run 2, Run 13, and Run 17 having removal efficiencies of 75.196 %, 77.152%, and 75.670 % respectively attributed to increased absorption ability of the mucilage extract in the presence of hydrogen ions. Optimal removal efficiency was observed at pH 6 for turbidity, pH 8 for Total Dissolved Solids (TDS), pH 6 for Total Suspended Solids (TSS), and pH 7 for Electrical Conductivity (EC). Consequently, a pH level of 7 was selected to investigate the impact of mucilage dose and contact time. Another key outcome of this study is the importance of residence time in water treatment processes like adsorption. It was observed that turbidity removal significantly increased, reaching around 65 NTU or 77% turbidity removal was achieved after 60 minutes of contact time. This corroborates the position that longer retention times facilitate greater agglomeration and settling of flocs. Therefore, providing adequate retention time is crucial to allow particles to settle effectively due to gravity. The mixing phase is also crucial in the coagulation process. Mixing has to be in two modes – rapid and followed by a slower one. Rapid mixing at 200 rpm for 5 minutes was found to enhance interactions between coagulants and suspended particles, facilitating the formation of microflocs. Conversely, slower mixing at 100 rpm for 15 minutes promoted the aggregation of these microflocs into larger, more substantial flocs. Longer mixing times ensure even distribution of coagulants throughout the wastewater, allowing particles sufficient time to become unstable and clump together.

3.3. Summary of the Removal Efficiencies of Each Coagulant

Jar tests were conducted using the produced bio-coagulant as a bio- coagulant, aluminum sulphate (alum) as a chemical coagulant and a combination of both coagulants to further test the effectiveness of the produced bio-coagulant as a coagulant aid. The summary of the results obtained from the laboratory investigation is presented in Figure 5.

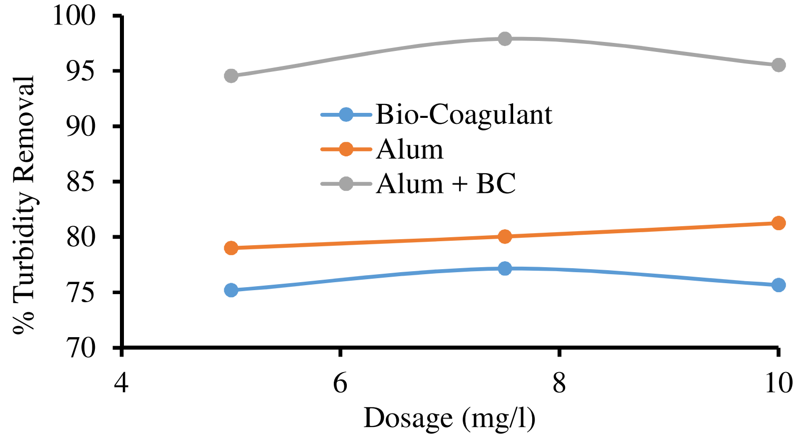


Figure 5: Summary of turbidity removal efficiencies

The initial turbidity of the raw water was 224 NTU as stated in Table 3, while the least turbidity overall, from Figure 1 stands at 4.70 NTU indicating a 97.9% removal efficiency at a pH of 7 using 70% Alum and 30% bio- coagulant after 60 mins of retention time. A 94.554% turbidity removal was also achieved using 50% each of both coagulants at same pH and retention time. This shows that the use of the bio-coagulants mixed with alum, would result to improved inter-particle bridging mechanism and would enhance the growth of the floc by at least thrice compared to the use of just synthetic chemicals due to the ability of polymeric chains to stretch and get attached to as several colloids as possible (Bahrodin et al., 2021). Using the bio-coagulant alone, a removal efficiency of 75.196%, 77.152%, and 75.67% were achieved at doses of 5 mg/l, 7.5 mg/l and 10 mg/l respectively. The World Health Organization (W.H.O.) and Nigerian Standard for Drinking Water Quality (NSDWQ) acceptable maximum standard for drinking water is 5 NTU (NIS, 2015), this indicates that the mixed coagulant reduced the initial turbidity of the raw water by 47.66 times to 4.7NTU.

3.4. Modelling, Optimization and Statistical Analysis using RSM

Modelling and optimization are of great importance in any process as it improves the yield. The optimization process includes the following step; conducting statistically designed of experiments, estimation of the coefficients in a mathematical model, prediction of the response and checking the model adequacy.

3.4.1. Determination of appropriate models

The study used various regression analysis methods to identify the most significant model for a response variable. To find the most statistically significant model and the model that best captures the connection between the inputs and the response, analysis of linear interaction, two factor interaction, and quadratic models were conducted. The quadratic model best described the turbidity, total suspended solids (TSS), and electrical conductivity responses, while the two-factor interaction model showed a significant effect on total dissolved solids (TDS). All significant models had a p-value less than 0.05 and maximized R^2, indicating their importance in the analysis.

3.4.2. Fit summary statistics

The fit summary statistics summarize the calculated statistical and empirical (test) results for all distributions to fit the selected model. It analyses the relationship between independent variables and response through regression analysis. The quadratic model with significant terms and P-values less than 0.05 is statistically significant, providing a confidence level greater than 99.5 % (Tripathi et al., 2009) as shown in Table 5. The RSM model was validated using a correlation coefficient (R^2 `value), with an R^2 score ranging from 0.7852 – 0.9983, indicating high agreement between experimental results and the expected values, indicating the model's suitability for correlating with the experiment data. With p-values ranging from < 0.0001- 0.05, the model terms are statistically significant.

Table 5: Model summary fit statistics for water parameters

Parameter	Source	Sequential p-value	Adjusted R^2	Predicted R^2	
Turbidity	Quadratic	< 0.0001	0.9983	0.9878	Suggested
TDS	2FI	< 0.0001	0.9660	0.8909	Suggested
TSS	Quadratic	0.0112	0.7852	-0.5038	Suggested
EC	Quadratic	0.0590	0.8052	-0.3636	Suggested

3.4.3. Final equation as a function of actual factors

The final regression model equation in a fit summary statistics provides valuable information about the relationship between the independent variables (predictors) and the dependent variable (response) in the regression analysis. The equation summarizes how well the model fits the observed data and how changes in the independent variables are associated with changes in the dependent variable, allowing for predictions and insights into the data. The equation allows the prediction of the value of the dependent variable for given values of the independent variables. By plugging in specific values for the predictors, you can estimate the corresponding value of the response variable. The final regression models, in terms of their coded and actual factors, are presented as follows:

$$\text{Turbidity} = -151.18375 - 1.58950A + 2.21175B + 47.08750C + 0.106200AB + 1.48400AC + 0.052667BC - 0.950200A^2 - 0.040883B^2 - 3.72125C^2$$

$$\text{TDS} = -+1321.41221 - 49.51350A - 15.45308B - 86.95500C + 0.707267AB + 4.21000AC +1.31333BC$$

$$\text{TSS} = +2002.83500 - 39.59400A - 3.65942B - 543.16625C + 0.062867AB + 0.675000AC + 1.29500BC + 2.05160A^2 - 0.058511B^2 + 36.84000C^2$$

$$\text{TSS} = +77.69750 + 4.14950A - 1.19825B - 17.28750C - 0.030400AB - 0.479000AC + 0.130167BC + 0.057200A^2 + 0.004767B^2 + 0.990000C^2$$

Where; A represents dosage, B is retention time and C is pH

The coefficients of the independent variables in the equation represent the magnitude and direction of their effect on the dependent variable. Positive coefficients indicate a positive relationship, while negative coefficients indicate a negative relationship. The magnitude of the coefficient indicates the strength of the relationship.

3.4.4. Analysis of variance

The analysis of variance (ANOVA) is crucial for confirming model adequacy, as it evaluates the significance of a model. The ANOVA for removal efficiency shows that the model involving all terms is significant, and the lack of fit is not significant. A low p-value of less than 0.05 indicates that the terms in the model significantly impacts the response (Dharma et al., 2016) as shown in Table 6. The model's predicted R^2 value as high as 0.9878 suggests a better response prediction. A negative Predicted R^2 implies that the overall mean may be a better predictor of the response than the current model. But with R^2 ranging from 0.9060-0.999, this indicates high agreement between the predicted and adjusted values. Having p-values less than 0.05, ranging from < 0.0001- 0.0053 shows that the model has a significant impact on the responses. The Adequate

Precision measures signal-to-noise ratio, and a ratio greater than 4 is desirable. Table 4 shows adequate precision values of a range of 9.494-88.6813. This indicates adequate signal for the models developed.

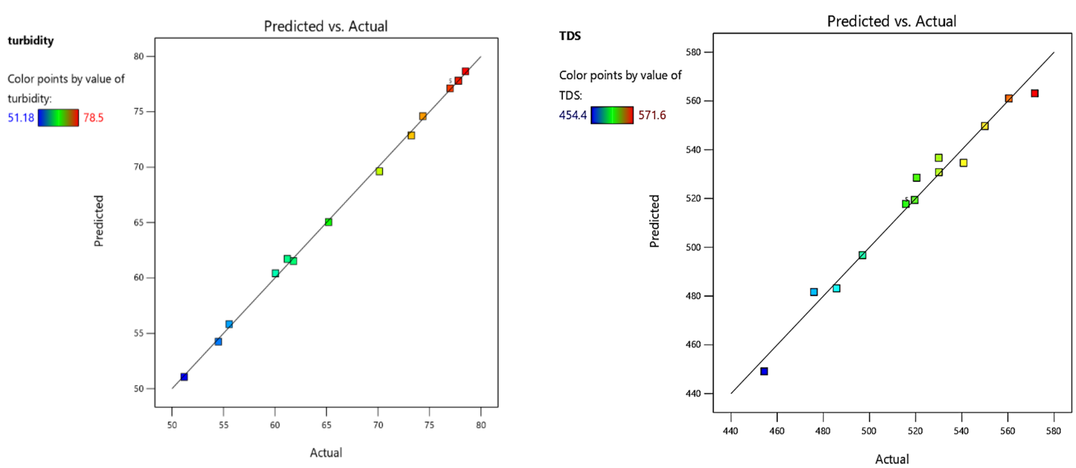
Table 6: ANOVA of parameter models

Source	Model				Remark
	Turbidity	TDS	TSS	EC	
Sum of Squares	1503.87	13504.99	19716.79	64.85	
Df	9	6	9	9	
Mean Square	167.10	2250.83	2190.75	7.21	
F-value	1015.50	76.81	7.50	8.35	
p-value	< 0.0001	< 0.0001	0.0073	0.0053	
R^2	0.9992	0.9788	0.9060	0.9148	
Adjusted R^2	0.9983	0.9660	0.7852	0.8052	significant
Predicted R^2	0.9878	0.8909	-0.5038	-0.3636	
Adeq. Precision	88.6813	32.8216	8.4447	9.4943	Desirable

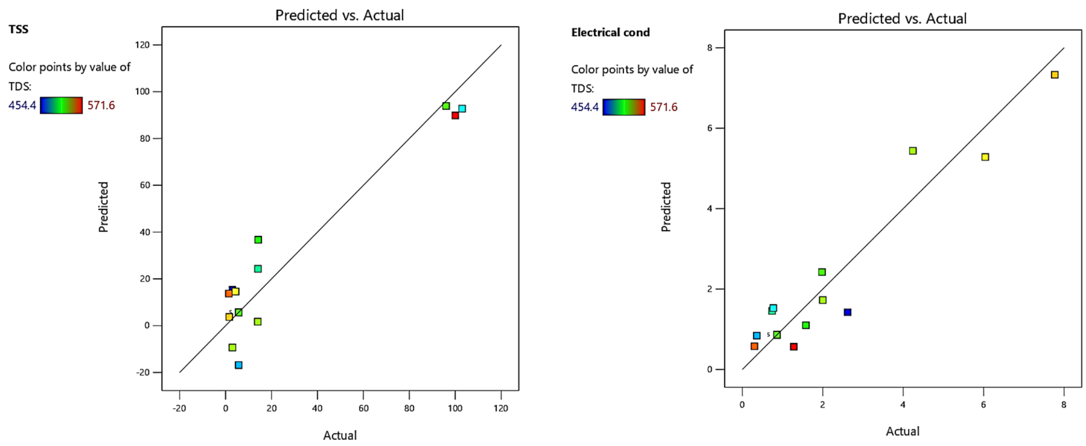
In a bid to further analyze and show the efficiency of the process developed, model graphical result description for removal efficiency were plotted. Figures 2 and 3 show contour maps and 3D rendering of the predicted response as a function of the experimental process parameter factors. They explain the effects of changing each factor while holding others constant. A steep slope in a factor shows that the removal efficiency is sensitive to the factor while a relatively flat line shows insensitivity to change in that particular factor.

3.4.5. Parity plots

For all responses, the actual and projected were displayed to assess the correlation between them. The data points are distributed close to the straight line, as seen in Figure 6 (a-d). This suggests further that the models for each response might be used as a major model for forecasting responses over the independent input variables.



(a) (b)

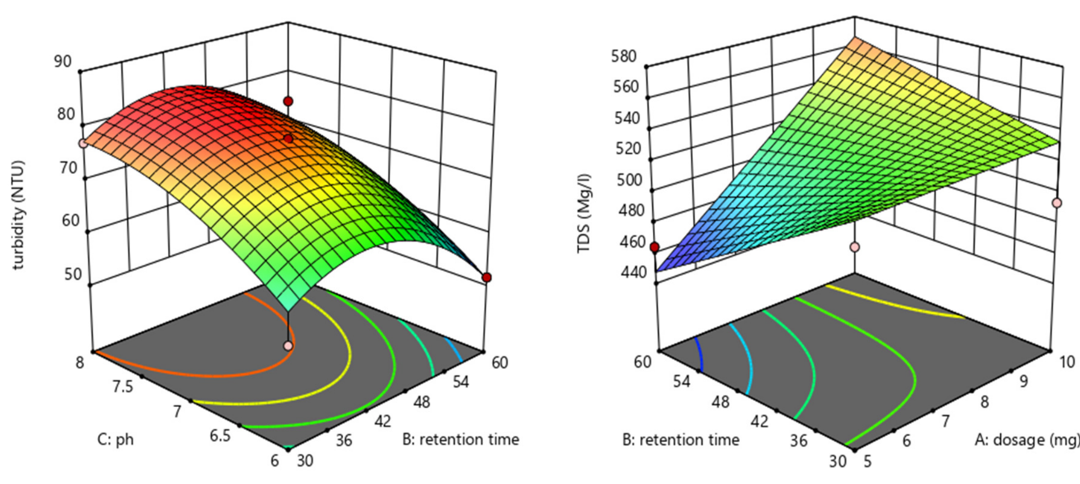


(c) (d)

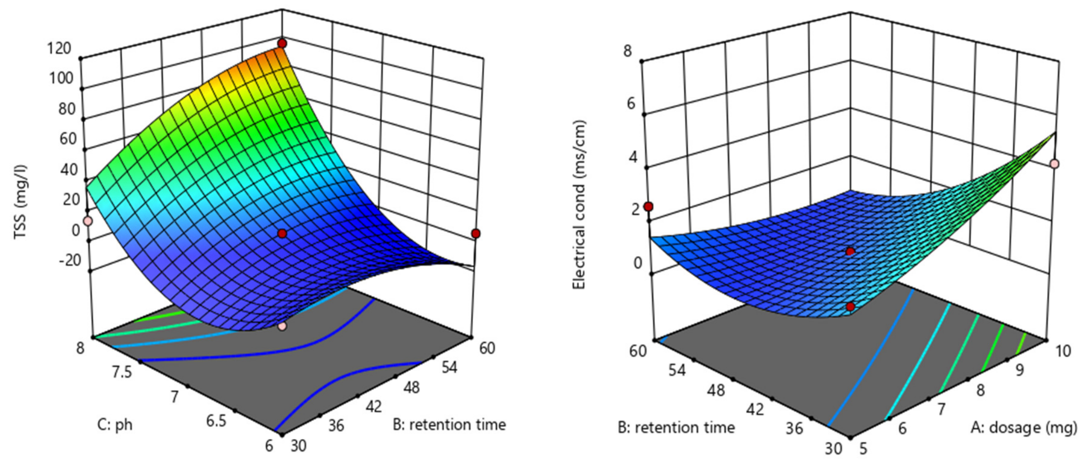
Figure 6 (a-d): Predicted versus experimental values plot for all responses

3.4.6. 3D Plots

The study used 3D response surface plots in Figure 7 (a-d) to represent the sensitivity of input variables to responses in a produced water treatment process. The plots showed that retention time and Ph (B and C respectively) had a steep slope, indicating they were sensitive and had a greater impact on the removal efficiency outcome. The effect of varying retention time and pH while keeping the dosage constant is shown in Fig 3a. The pH had the greatest effect on turbidity indicating a positive impact on the optimization process with a prediction of 82.4 NTU at 44.4 mins and 7.9 pH. The ANOVA analysis shows that the pH had the highest f-value, indicating that it was the most significant. According to Figure 3b, increasing the retention time and dosage resulted in a significant change in TDS, with a prediction of 564.113 mg/l at 9.93 mg of dosage and 59.49 mins of retention time while pH was kept constant. Figure 3c shows that pH and retention time have an effect on TSS, with a prediction of 89.28 at 59.20 mins and 7.96 pH. Finally, Fig. 3d shows that retention time and dosage have a visible effect on electrical conductivity while pH was kept constant, with the highest point being 5.13 ms/mc at 9.94 mg/l of dosage and 30.83 min.



(a) (b)



(c) (d)

Figure 7 (a-d): 3D Response surface plot for input variable response to show the interaction between factors

3.4.7. Optimization of the coagulation process

To accomplish a high percentage of coagulation, the experimental design's goal was to identify the ideal coagulation conditions. In order to optimize all responses, it is necessary to identify the ideal operating conditions and Table 7 shows the ideal conditions for all responses that will optimize the coagulation process. The Design Expert Software was used for numerical optimization in order to find a balance between these three factors. It was used to optimize the parameters with the goal response set at maximum values and the values of the variables (retention time, dosage, and pH.) set within the study's acceptable range. The best retention time, dosage, and pH values were 53.654 minutes, 10 mg/l, and 7. These circumstances resulted in a desirability rating of 92.8%.

Table 7: The optimum factors

Dosage (mg/l)	Retention time (min)	pH	Turbidity (NTU)	TDS (mg/l)	TSS (mg/l)	Electrical conductivity (mS/cm)	Desirability
10.000	53.654	7.000	75.063	575.601	103.289	0.645	0.928

4. CONCLUSION

Based on the results presented in this work, it can be concluded that plantain pseudo stem juice is an effective natural coagulant which can be used in produced-water treatment in its crude form. While the produced coagulant recorded turbidity removal efficiency of 77%, comparatively, the turbidity removal efficiency of Alum from the research was 81% respectively. This implies that alum is more effective than plantain pseudo stem extract but the turbidity removal efficiency of plantain pseudo stem is more than 70% which is also good, indicating it has potentials to serve as a bio-coagulant. Furthermore, a combination of alum and the produced coagulant reveals that the optimum dose of 10mg/l suffices for 70% Alum and 30% plantain pseudo stem extract as coagulants. The produced coagulant functions optimally and effectively in combination with alum rather than when acting alone. Therefore, plantain pseudo stem extract has the potential to cut down the volume of alum consumption for water clarification by at least 30%. Results from the analysis of variance indicated a significant difference ($p < 0.05$) within and between the final measurements.

5. ACKNOWLEDGEMENTS

We wish to acknowledge Mr. Solomon Obanowe of Darew Ventures Ltd, Warri, Nigeria for providing the produced water that was used in the course of the laboratory work.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Akhter, F., Soomro, S. A., Siddique, M. and Ahmed, M. (2021). Plant and non-plant based polymeric coagulants for wastewater treatment: A review. (F. Akhter, Ed.) Journal Kejuruteraan, 33(2), 175-181. https://doi.org/http://dx.doi.org/10.17576/jkukm-2021-33(2)-02

Akuboh, D. O., Saidu, M., Abdulkareem, A. S. and Busari, A. O. (2022). Assessing the potentials of a plant-based coagulant (Cyperus Esculentus Pulp) as alternative to alum in conventional water treatment process. *Arid Zone Journal of Engineering, Technology and Environment, 18*(3), 387-402. https://doi.org/file:///C:/user/Downloads/azojete143/www.azojete.com.ng

Alazaiza, M. Y., Albahnasawi, A., Ali, G. A., Bashir, M. J., Nassani, D. E., Maskari, T. A. and Abujazar, M. S. (2022). Application of natural coagulants for pharmaceutical removal from water and wastewater: A review. (L. Bulgariu, Ed.) *Water, 14*(2), 140. https://doi.org/https://doi.org/10.3390/w14020140

Bahrodin, M.B., Zaidi,N., Silanpaa, M., Prasetyo, D.D., and Syafiuddin,A, (2021). Recent advances on coagulation-based treatment of wastewater. Transitionfrom chemical to natural coagulants. (R.B. Hong, Ed), Current pollution reports, 7(3), 379-391

Dao, M.-T., Nguyen, V.-C.-N., Tran, T.-N., Nguyen, X.-D., Vo, D.-T., Nguyen, V.-K. and Hoang, L.-T.-T.-T. (2021). Pilot-scale study of real domestic textile wastewater treatment using cassia fistula seed-derived coagulant. (R. Rehman, Ed.) *Journal of Chemistry, 2021*(Special), 7608856. https://doi.org/https://doi.org/10.1155/2021/7608856

de Oliveira, C., Trevisan, V. and Skoronski, E. (2022). Application of tannin-based coagulant for high-range turbidity surface water clarification. *Journal of Water, Sanitation and Hygiene for Development, 12*(11), 803-815. https://doi.org/https://doi.org/10.2166/washdev.2022.120

Deepa, D., Keerthana, R., Kumar, R. P. and Suryaprakash, R. (2022). Primary Treatment of dairy wastewater using bio based natural coagualnts,. *Materials Today: Proceedings, 60*(1), 616-621. https://doi.org/https://doi.org/10.1016/j.matpr.2022.02.125

Dharma, S., Masjuki, H., Ong, H., Sebayang, A. and Silitonga. (2016). Optimization of biodiesel production process for mixed jatropha curcas ceiba pentandra biodiesel using response surface methodology. *Energy conversion and management, 115*(1), 178-190.

El Bouaidi, W., Libralato, G., Tazart, Z., Enaime, G., Douma, M., Ounas, A., Loudik, M. (2022). Nature-based coagulants for drinking water treatment: An. (J. He, Ed.) *Water Environment Research, 94*(8), e10782. https://doi.org/https://doi.org/10.1002/wer.10782

Gopika, G. L., and Kani, K. M. (2016). Accessing the suitability of using banana pith juice as a natural coagulant for textile wastewater treatment. *International Journal of Scientific and Engineering Research, 7*(4), 260-264. Retrieved July 21, 2023, from https://www.researchgate.net/profile/Mophin-Kani Kani/publication/303840022_Accessing_the_Suitability_of_Using_Banana_Pith_Juice_as_a_Natural_Coagulant_for_Textile_Wastewater_Treatment/links/5757847108ae05c1ec16d4be/Accessing-the-Suitability-of-Using-Bana

Kristianto, H., Handriono, C. W. and Soetedjo, J. N. (2019). Preliminary study on tamarindus indica seeds kernel as natural coagulant for color removal of synthetic textile wastewater, international conferenc on sustainable engineering and creative computing (ICSECC), 422-425

Madjene, F., Benhabiles, O., Boutra, A., Benchaib, M. and Bouchakour, I. (2023). Coagulation/Flocculation process using moringa oleifera bio-coagulant for industrial paint wastewater treatment: Optimization by D-optimal experimental design. (M. Abbaspour, Ed.) *International Journal Environmental Science and Technology, 20*(2), 12131–12140. https://doi.org/https://doi.org/10.1007/s13762-023-04808-w

Nath, A., Mishra, A. and Pande, P. P. (2021). A review natural polymeric coagulants in wastewater treatment. (D. B. Syed Arshad Hussain, Ed.) *Materials Today: Proceedings, 46*(14), 6113-6117. https://doi.org/https://doi.org/10.1016/j.matpr.2020.03.551

NIS, N. S. (2015). Nigerian Industrial Standard. *Nigerian standard for drinking water quality*, 1-28. https://doi.org/ICS 13.060.20

Owoicho, A., Shaibu-Imodagbe, E. M. and Sani, I. M. (2021). Optimization of coagulation efficacy of banana stem juice in water treatment. *Fudma Journal Of Sciences, 5*(4), 130-141. https://doi.org/https://doi.org/10.33003/fjs-2021-0504-735

Singh, K. and Mahanta, S. (2021, May 08). Sustainable urban water management strategies. (A. B. Girish Chadha, Ed.) *Water governance and management in India: issues and perspectives, 2*(2), 23-43. https://doi.org/https://doi.org/10.1007/978-981-16-1472-9_2

Tripathi, P., Srivastava, V. C. and Kumar, A. (2009, December 25). Optimization of an Azo dye batch adsorption parameters using Box–Behnken design. *Desalination, 249*(3), 1273-1279. https://doi.org/http://dx.doi.org/10.1016/j.desal.2009.03.010

Yahya, M.D., Muhammed, I.B., Obayomi, K.S., Olugbenga, A.G. and Abdullahi, U.B. (2020). Optimization of fixed bed column process for removal of Fe(li) and Pb(li) ions from thermal power plant effluent using Naoh-rice husk ash and spirogyra. Scientific African , 10(e00649).