Modelling and Optimisation of Water Melon Seed Protein Isolate Coag-flocculation of Nworie River Water

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Abstract:- **Treatment of surface water by coagulation/flocculation was investigated in this research using protein isolate of water melon seed known as Water Melon Coagulant (WMC) with the aim of removing turbidity and colour in the water sample. Bench-scale nephelometric jar tests were performed to remove turbidity and colour from the water sample collected from Nworie River (NR) in Owerri, Imo state, Nigeria. Process factors were initially varied to investigate their effects on the coagulation/flocculation process adopting one-factor-at-a-time approach. Thereafter, the experiment was designed within a narrower region of search for optimality of the process variables. Response Surface Methodology (RSM) was employed in the experimental design, adopting the rotatable Central Composite Design (CCD) option. ANOVA results showed that turbidity and colour removal efficiencies in WMC-in-NR system are well represented by quadratic models. The turbidity removal efficiency model yielded p-value of 0.0001 at 5 % significance level, coefficient of determination, R^2 of 0.9563 and adjusted R^2 of 0.9126. The adequate precision, representing the signal-to-noise ratio was found to be 14.976, sufficiently above the benchmark of 4. This implies that the quadratic model can be used within the range of variables in the design space. The coefficient of variance which indicates the ratio of the standard error of estimate to the mean value of the observed model was reasonably low at 2.79 %. This value is well below the required maximum of 10 %, clearly pointing to the reproducibility of the models. For colour removal efficiency model, the indices used for the judgement were p-value of 0.0001 as obtained, R^2 of 0.9879, adjusted R^2 of 0.9759, signal-to-noise ratio of 35.692 and coefficient of variance of 2.10. Process optimization results gave optimal process parameters values of 250 mg/l dosage, pH of 7.26 and 35 minutes settling time. At this point, the optimal turbidity and colour removal efficiencies were 94.87 % and 84.66 % respectively. It is concluded that while water melon-derived coagulant is very effective in the removal of turbidity and colour from surface water, the process at room temperature is described by a quadratic model.**

Keywords: **water melon, coagulant, Nworie River, turbidity, colour.**

I. INTRODUCTION

Nigeria is blessed with many industries ranging from brewing to soft drinks production and from beverage production to paints, pharmaceuticals, soaps and detergents, oil and gas, agrochemicals, food, distillery fermentation, etc (Ibrahim *et al*, 2012). These industries have tapped largely from the country's abundant water resources for their day-to-day industrial production processes. This was made possible by the presence of many rivers and streams traversing the length and breadth of the country as well as the near pure aquifer with which the country is blessed. These factories either source raw water from the rivers or use the rivers as open sewers for their effluents (WHO/UNEP, 1997). Raw water from surface sources (rivers and streams) undergoes various stages of treatment to conform to the World Health Organisation's (WHO's) standard for drinking water quality, likewise raw water from the aquifer (borehole water). Effluents from such factories are equally treated to detoxify them prior to disposal.

Many factories in Nigeria are sited near rivers because they source raw water from such rivers. Examples of such are the Nigerian Bottling Company (NBC) plant sited on the bank of river Benue in Makurdi, Benue State, the SABMiller brewing and beverage company located on the bank of river Niger in Onitsha, Anambra State, etc. Owerri, the Imo State capital, is densely populated (AC-Chukwuocha *et al*, 2017). The city boasts of large number of commuters in transit due to its centralized location between the business-centre Southeast and the oil-rich Niger delta regions of the country. Perhaps, this explains why Owerri city and its very numerous and expensive hotels are always beehives of activities, irrespective of the time of the day or season of the year. The town is also naturally endowed with intra-city rivers – the Nworie River, and the Otamiri River. These rivers' banks are very good sites for factories, more so as the city is strategically located. The rivers, especially Nworie River, serve as a veritable source of water for drinking and other domestic uses for the teeming population living on their watershed (Onyekuru *et al,* 2014).

However, the waters from Otamiri River and Nworie River are unsafe for drinking and they require appropriate treatment before human consumption (Okoro *et al*, 2016).

Coagulation/flocculation is a combined unit-process/unit-operation employed over the years as a pre-treatment step in water treatment practice (Anagwu *et al*, 2016). Conventional coagulants such as aluminium sulphate, iron (11) chloride and polyaluminium chloride (PAC) have been applied in water treatment with sludge disposal problems and the risk of certain neurological diseases such as Alzheimer's disease (McLachlan, 1995). Many polymeric coagulants have also been applied in some instances with very high cost implications. In recent times, plant and animal based coagulants have been proposed by researchers. Such coagulants include *Moringa oleifera* (Ndabingesere and Narasiah, 1998), snail shell (Ani *et al*, 2009), *Afzelier africana* (Babayemi *et al*, 2013), *Mucuna pruriens* (Menkiti *et al*, 2010; Menkiti and Onukwuli, 2011a), *Afzelier bella* (Menkiti and Onukwuli, 2011b), Chitosan (Mohammad *et al*, 2009), periwinkle shell (Menkiti *et al*, 2009), *Telfairia occidentalis* (Ugonabo *et al*, 2016), Gypsum spp. (Babayemi and Onukwuli, 2015), Water melon (Muhammed *et al*, 2015), *Aloe vera* leaf gel (Nougbode *et al*, 2016), etc.

Water melon, a relatively less known coagulant but very abundant in Nigeria has been selected in this research with improved method of preparation and used to carry out bench-scale tests on the coagulation/flocculation of Nworie River water sample. The water melon coagulant used in this research is known as water melon protein isolate or water melon coagulant (WMC).

II. MATERIALS AND METHODS

2.1 Water Sample

The raw water used in this research was collected from the federal medical centre axis of Nworie River (NR) which traverses Owerri metropolis. The sample was collected and taken to the laboratory for characterisation and coagulation/flocculation experiments.

2.2 Preparation of Coagulant

Water melon fruits were sourced from Eke Onunwa market in Owerri metropolis, Imo State of Nigeria. The left over seeds of water melon after consumption were collected, hulled and sun-dried for two weeks. Thereafter, the seeds were milled to powdered form using a high speed laboratory electric blender and packed in an air-tight container. Oil was extracted from the powdered seed using the method reported by Muhammad *et al* (2015). When the extraction was complete, the cake was heated to 70^{o}C to evaporate residual n-hexane until constant weight was attained, and then sieved. The fine particles were then soaked in distilled water and diluted to form suspension. The suspension was heated to 50^{o}C and placed on a magnetic stirrer for 30 minutes at high speed and allowed to stand for 24 hours to effectively solubilize the proteins. Protein isolation from the solution to form protein concentrate (WMC) was then carried out adopting the salting out method, as reported by Martinez-Maqueda *et al* (2013), and stored at room temperature. This was used as the water melon coagulant

2.3 Coagulation-flocculation

Jar tests were carried out based on standard bench-scale nephelometry (WST, 2003; AWWA, 2005). The dependent variables in the experiments were turbidity and colour removal efficiencies while pH, coagulant dosage and settling time were the independent variables. The experiments were conducted at room temperature. The coagulation-flocculation experiments were carried out using a magnetic stirrer (model CMS-01, M/s. Contech Instruments Ltd) with two (2) minutes of rapid mixing (100 rpm) immediately followed by slow mixing of thirty (30) minutes at 40 rpm. The settling was conducted for 45 minutes prior to experimental design. In the course of the settling, the yields were determined by withdrawing samples with pipette from 2 cm depth after every 5 minutes and analysing same for turbidity and colour.

The turbidimeter, model no WZS – 185, was calibrated with solution of known turbidity with minimum and maximum turbidities of 3 NTU and 10,000 NTU respectively selected for calibration. After calibration, water sample was analysed by inserting the test tube containing it in the space provided for it in the turbidimeter. The pH meter PHS-3C was used to measure water pH. The instrument was first calibrated with solution of known pH. Three-point calibration method was employed, with three buffers of pH 4.0, 7.0 and 9.0 at room temperature selected for the calibration. The sample was constantly stirred until a stable pH was obtained before reading was taken. Initial turbidity and pH were kept constant for each run. 0.1N and 1N NaOH or 0.1N and 1N H_2S0_4 were used for pH control. Percentage of turbidity removal (response variable or yield) was calculated with the formula:

$$\text{Turbidity removal, } Y_1\,(\%) = \frac{T_r - T_t}{T_r} \times 100 \qquad (1)$$

Where:

T_r and T_t are the turbidities of raw water and treated water respectively.

The colour of water was determined by colorimetric platinum cobalt method using multi-parameter bench photometer, model HI83200.

Percentage of colour removal (response variable or yield) was calculated with the formula:

$$\text{Colour removal, } Y_2\,(\%) = \frac{C_r - C_t}{C_r} \times 100 \qquad (2)$$

Where: C_r and C_t are the colours of raw water and treated water respectively.

2.4 Experimental Design and Data Analysis

Design Expert software version 11 (Stat-Ease, Inc., USA) was used to design the experiment. The rotatable central composite design (CCD) matrix was adopted for the Response Surface Methodology (RSM). The CCD, introduced by Box and

Wilson in 1951, has stood the test of time in fitting quadratic surfaces, which normally works well for the process optimisation (Montgomery, 1985).

In the rotatable CCD, a total of 20 experiments – corresponding to 2^3 full factorial design at two factor levels (coded to the usual ± 1 notation), six axial points (star points) with coordinates $(+\alpha, 0, 0), (0, +\alpha, 0), (0, 0, +\alpha), (-\alpha, 0, 0), (0, -\alpha, 0), (0, 0, -\alpha)$, and six replicates at the centre point each with coordinate (0, 0, 0) superimposed on one another – were conducted. While the star points verify the nonlinear suspected curvature, the replicates at the centre point verify variations in the middle of the plan and serve as a tool for proper measurement of the degree of precision. The value of α for rotatability is a function of the number of points in the factorial region of the design (cubical in this case) and is given by equation 3:

$$\alpha = (N_F)^{\frac{1}{4}} \qquad (3)$$

Where:

N_F is the number of points in the cubical region of the design. Since $N_F = 2^m$ where m is the number of factors, equation 3 gives the value of α as $(2^3)^{\frac{1}{4}} = 1.682$, as indicated by the Design Expert software. Choice of base level and variation interval for each factor was based on one-factor-at-a-time (OFAT) experiments conducted prior to the design. The base levels of the factors are 300 mg/l, 7.0 and 45 minutes respectively for coagulant dosage, pH and settling time. Their variation intervals are respectively 50 mg/l, 1.5 and 10 minutes. The full factorial CCD matrix codes for the experiments are indicated in table 1.

Table 1: Full factorial 2^3 rotatable CCD matrix codes for the experiments

Run	Coefficient Effect	F_0	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	Responses	
		X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	X_1^2	X_2^2	X_3^2	Y_1	Y_2
1	$a_1b_1c_1$	+1	-1	-1	-1	+1	+1	+1	+1	+1	+1		
2	$a_2b_1c_1$	+1	+1	-1	-1	-1	-1	+1	+1	+1	+1		
3	$a_1b_2c_1$	+1	-1	+1	-1	-1	+1	-1	+1	+1	+1		
4	$a_2b_2c_1$	+1	+1	+1	-1	+1	-1	-1	+1	+1	+1		
5	$a_1b_1c_2$	+1	-1	-1	+1	+1	-1	-1	+1	+1	+1		
6	$a_2b_1c_2$	+1	+1	-1	+1	-1	+1	-1	+1	+1	+1		
7	$a_1b_2c_2$	+1	-1	+1	+1	-1	-1	+1	+1	+1	+1		
8	$a_2b_2c_2$	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1		
9	a*b*c*	+1	$+\alpha$	0	0	0	0	0	0	0	0		
10	a*b*c*	+1	0	$+\alpha$	0	0	0	0	0	0	0		
11	a*b*c*	+1	0	0	$+\alpha$	0	0	0	0	0	0		
12	a*b*c*	+1	$-\alpha$	0	0	0	0	0	0	0	0		
13	a*b*c*	+1	0	$-\alpha$	0	0	0	0	0	0	0		
14	a*b*c*	+1	0	0	$-\alpha$	0	0	0	0	0	0		
15	$a^0b^0c^0$	+1	0	0	0	0	0	0	0	0	0		
16	$a^0b^0c^0$	+1	0	0	0	0	0	0	0	0	0		
17	$a^0b^0c^0$	+1	0	0	0	0	0	0	0	0	0		
18	$a^0b^0c^0$	+1	0	0	0	0	0	0	0	0	0		
19	$a^0b^0c^0$	+1	0	0	0	0	0	0	0	0	0		
20	$a^0b^0c^0$	+1	0	0	0	0	0	0	0	0	0		

Key: $a_ib_ic_i$ = coefficient effect of coordinates at point i (factorial point) where $i = 1, 2$,
$a^*b^*c^*$ = coefficient effect of coordinates at an axial or star point where $\alpha = 1.682$ for rotatability

$a^0b^0c^0$ = coefficient effect of coordinates at centre point.

The response variables, Y_1 and Y_2 were fitted into the generic second-order polynomial equation 4:

$$y = b_o + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_i^2 + \sum_{i}^{i<j} \sum_{j} b_{ij} X_i X_j \qquad 4$$

Where, y is the yield or response variable (dependent variable), X_i, and X_j the independent variables, b_o, b_i, b_{ii} and b_{ij} are the fictitious term (offset term), the i^{th} linear coefficient, the quadratic coefficient and the ij^{th} interaction coefficient, respectively. Three-way analyses of variances (ANOVA) were employed to analyse the models. The qualities of the suggested models and the selection of model terms were based on the following statistical tools provided by the Design Expert software: diagnostic plots of the predicted versus actual values, lack of fit, coefficients of determination, R^2, adjusted R^2, *F*-values, *p*-values at 5% significance level, signal-to-noise ratios and coefficients of variances.

III. RESULTS AND DISCUSSION

3.1 Physiochemical characteristics of NR

The physiochemical characteristics of NR were determined and presented in table 2. The table shows that while turbidity of the NR is high at 85 NTU, the colour is equally high at 405 PCU.

Table 2: Physiochemical Characteristics of the NR

S/N	Parameter	WHO (2006, 2011)	FEPA (Ekanem *et al*, 2016)	A (NR)
1	Temperature (ºC)	25	<40	30.2
2	pH	6.5 – 8.5	6 – 9	6.22
3	Conductivity (µs/cm)	8-10,000	1000	107
4	TDS (mg/l)	–	2000	69.55
5	TSS (mg/l)	30	30	130.45
6	TS (mg/l)	500	–	200
7	Total chloride(mg/l)	≤ 250	600	3.0
8	Turbidity (NTU)	< 5.0	–	85.0
9	Colour (PCU)	≤ 15	–	405
10	Phosphate (PO_4^{3-}) (mg/l)	6.5	5.0	39.0
11	Phosphorus (mg/l)	6.5	–	13.0
12	P. pentoxide (P_2O_5) (mg/l)	6.5	–	29.0
13	Nitrate (mg/l)	50	20	41.3
14	Nitrite-nitrogen (mg/l)	0.9	–	12.2
15	BOD (mg/l)	5	50	186.67
16	COD (mg/l)	10	100	1760
17	Lead (mg/l)	0.01 (A, T)	<1	0.043
18	Iron (mg/l)	0.3	20	0.412
19	Copper (mg/l)	2	1.5	0.814
20	Zinc (mg/l)	≤ 3.0	<1.0	0.569
21	Chromium (mg/l)	0.05 (P)	0.05	0.1
22	Arsenic (mg/l)	0.01 (A, T)	–	$5x10^{-7}$

A: provisional guideline value because calculated guideline value is below the achievable quantification level; **P:** provisional guideline value because of uncertainties in the health database; **T:**provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

3.2 Contaminants Removal Efficiency Profiles

Figure 1 through 6 show selected contaminants profiles for NR treated with the WMC at room temperature. These plots which were obtained from OFAT experiments show that the highest turbidity and colour removals were obtained between 200 – 300 mg/l dosage and pH of 6 – 10 after 45 minutes settling time. These results provide an insight to the narrow region for optimality search. Thus, in the designed experiment, the optimisation target was set to search within these boundaries.

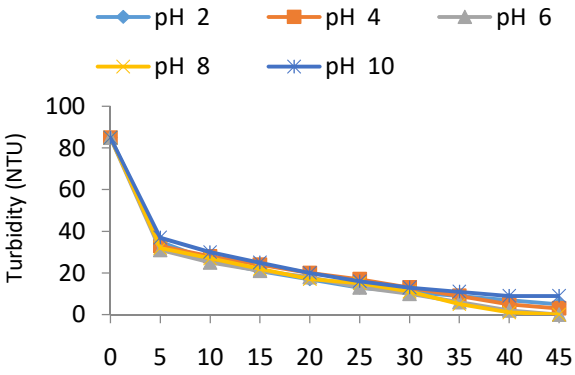

Figure 1: Turbidity versus time for WMC dose of 300mg/lit in NR at room temperature

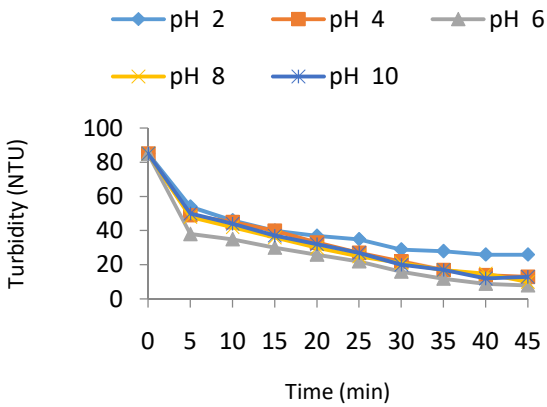

Figure 2: Turbidity versus time for WMC dose of 200mg/lit in NR at room temperature

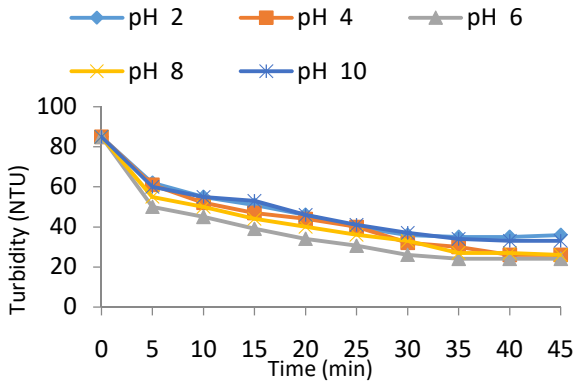

Figure 3: Turbidity versus time for WMC dose of 100mg/lit in NR at room temperature

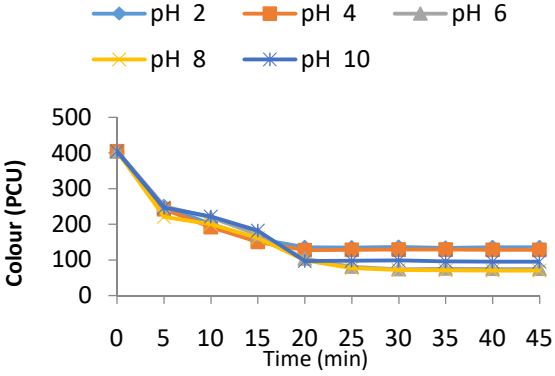

Figure 4: Colour versus time at WMC dose of 300mg/lit in NR at room temperature

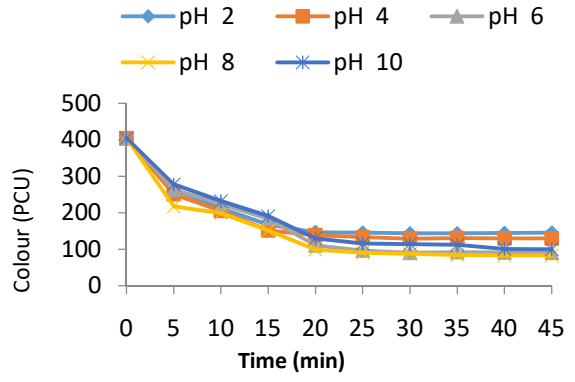

Figure 5: Colour versus time at WMC dose of 200mg/lit in NR at room temperature

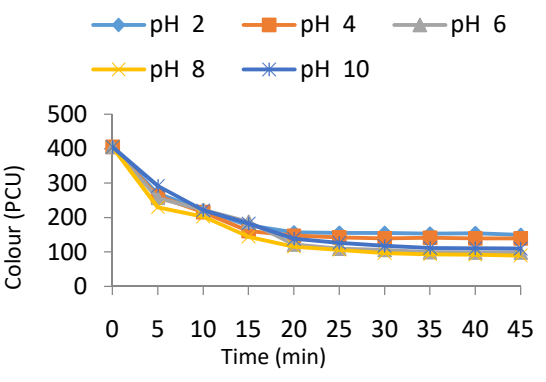

Figure 6: Colour versus time at WMC dose of 100mg/lit in NR at room temperature

3.3 Statistical analysis

The ANOVA tool provided by the Design Expert software was used to carry out the analyses of variances. The results of the three-way ANOVA – depicted by *p*-values less than 0.05 at 5% significance level, *F*-values less than F-table (Menkiti *et al,* 2012) and coefficient of determination (R^2) values nearing unity (Ghafari *et al,* 2009) – are a pointer to the significances as well as the adequacies of the proposed models. For turbidity removal efficiency studies, the ANOVA table 3 indicates that coagulant dosage exhibits the most main effect with p-value of 0.0001 while pH exhibit the least main

effect with p-value of 0.0441. This compares favourably with the results of Babayemi and Onukwuli (2015) who concluded that pH exhibited the least effect whereas coagulant dosage has the most influence. However, unlike the assertion of dropping pH in the final model as held by Babayemi and Onukwuli (2015), the parameter of pH (X_2) is still retained in the model since its p-value is less than the 0.05 benchmark, but its quadratic effect (X_2^2) with p-value higher than 0.05 may be excluded in the final model without having any major effect on the accuracy of the model. Other insignificant terms in the final model are those of interactions of coagulant dosage and pH (X_1X_2) and pH and settling time (X_2X_3). Accordingly, these terms have also been eliminated from the final model.

Similarly, in studying colour removal efficiency, it can be seen from ANOVA table 4 that coagulant dosage and settling time (p-values < 0.0001) exhibit the most main effect whereas pH (p-value 0.0006) exhibits the least main effect. However, the quadratic effect of each of the parameters of dosage, pH and settling time are all significant with p-values less than the 0.05 benchmark. Thus, they are retained in the final model. But the interaction effect of the coagulant dosage and pH are insignificant and are thus dropped in the final model. The R^2 values nearing unity in each case indicate high dependence levels and correlations between the predicted and observed/actual values of the responses (Sharma *et al,* 2009). High R^2 values obtained from the ANOVA – 0.9563 for turbidity removal efficiency study and 0.9879 for colour removal efficiency study – validate the CCD models and DOE procedures; thus, the experiments are reproducible. The adjusted R^2 values are a little bit displaced from the R^2 values, a situation which, according to Menkiti *et al,* (2012), is a necessity. Turbidity and colour removal efficiency studies have adjusted R^2 values of 0.9126 and 0.9759 respectively. The adequate precision values – representing signal-to-noise ratio for the responses – is in each case sufficiently greater than 4, indicating that the quadratic model equation can be used to navigate the design space. The adequate precision values for turbidity and colour studies are respectively 14.976 and 35.692. The coefficient of variance (CV in %) which represents the ratio of the standard error of estimate to the mean value of the observed model was found to be less than 10% in each case, confirming the reproducibility of the models (Ahmadi *et al, 2005*) and indicating that the precision and reliability of the experiments are good. The CV for turbidity and colour studies are 2.79% and 2.10% respectively. Diagnostic plots (figure 7 and 8) of the predicted versus actual values were employed to verify the suitability of the model and provide useful agreement between the experimental data and the values obtained from the models. The ANOVA results are presented in tables 3 and 4 while the models in terms of coded factors are given as equations 5 and 6. Y_1,Y_2, stand for turbidity removal efficiency and colour removal efficiency respectively.

Table 3 ANOVA for Response Surface Quadratic model (turbidity removal efficiency for WMC-treated NR)

Source	Sum ofSquares	Coefficient Estimate	df	Standard Error	MeanSquare	F-Value	p-value Prob> F		R^2	Ratios
Model	1338.11		9		148.68	21.88	< 0.0001	*Significant*		
Intercept		99.82	1	1.07						
A-X1	*356.76*	-5.11	*1*		*356.76*	*52.51*	*< 0.0001*			
B-X2	*345.01*	0.50	*1*		*345.01*	*51.00*	*0.0441*			
C-X3	*264.95*	4.40	*1*		*264.95*	*39.00*	*0.0002*			
AB	*1.08*	-0.37	*1*		*1.08*	*0.16*	*0.6993*			
AC	*64.37*	2.84	*1*		*64.37*	*9.47*	*0.0132*			
BC	*2.27*	0.53	*1*		*2.27*	*0.33*	*0.5776*			
A^2	*616.93*	-6.55	*1*		*616.93*	*90.80*	*< 0.0001*			
B^2	*22.16*	-1.24	*1*		*22.16*	*3.26*	*0.1044*			
C^2	*55.79*	-1.97	*1*		*55.79*	*8.21*	*0.0186*			
Residual	61.15		9		6.79					
Lack of Fit	*61.15*		*5*		*12.23*			*Not significant*		
Pure Error	*0.000*		*4*		*0.000*					
R^2									0.9563	
Adjusted R^2									0.9126	
Predicted R^2									0.8202	
Adequate precision > 4										14.976
C.V.(%)<10 %										2.79

The final equation in terms of coded factors is:

$$Y_1 = +99.82 - 5.11X_1 + 0.50X_2 + 4.40X_3 + 2.84X_1X_3 - 6.55X_1^2 - 1.97X_3^2 \quad (5)$$

Table 4: ANOVA for Response Surface Quadratic model (colour removal efficiency for WMC-treated NR)

Table 4(a)

Source	**Sum of Squares**	Coefficient Estimate	**df**	**Standard Error**	**Mean Square**	**F-Value**	**p-value Prob> F**		R^2	Ratios
Model	1963.76		9		218.20	81.95	< 0.0001	*Significant*		
intercept		82.73	1	0.67						
A-X1	*794.76*	-7.63	*1*		*794.76*	*298.49*	*< 0.0001*			
B-X2	*71.93*	2.29	*1*		*71.93*	*27.01*	*0.0006*			
C-X3	*273.50*	4.48	*1*		*273.50*	*102.72*	*< 0.0001*			
AB	*4.35*	-7.63	*1*		*4.35*	*1.63*	*0.2331*			
AC	*56.41*	2.66	*1*		*56.41*	*21.19*	*0.0013*			
BC	*27.34*	1.85	*1*		*27.34*	*10.27*	*0.0108*			
A^2	*524.02*	-0.74	*1*		*524.02*	*196.81*	*< 0.0001*			
B^2	*138.21*	-3.10	*1*	- 3.10	*138.21*	*51.91*	*< 0.0001*			
C^2	*60.01*	2.04	*1*		*60.01*	*22.54*	*0.0010*			
Residual	23.96		9		2.66					
Lack of Fit	*23.96*		*5*		*4.79*			*Not significant*		
Pure Error	*0.000*		*4*		*0.000*					
R^2									0.9879	
Adjusted R^2									0.9759	
Predicted R^2									0.8702	
Adequate precision > 4										35.692
C.V.(%)<10%										2.10

The final equation in terms of coded factors is:

$$Y_2 = +82.73 - 7.63X_1 + 2.29X_2 + 4.48X_3 + 2.66X_1X_3 + 1.85X_2X_3 - 0.74X_1^2 - 3.10X_2^2 + 2.04X_3^2 \quad (6)$$

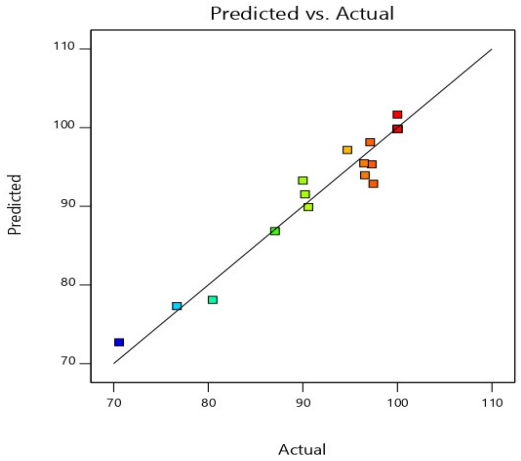

Fig. 7: diagnostic plot of turbidity removal eff. for WMC-in-NR

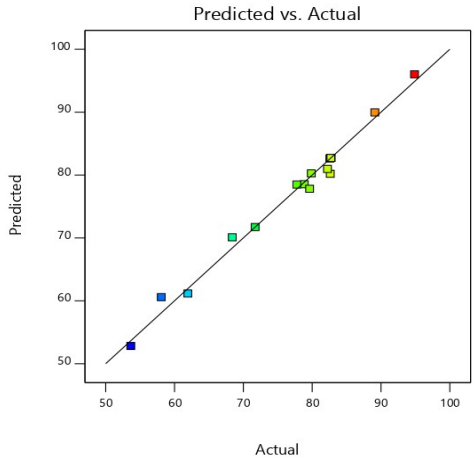

Fig. 8: diagnostic plot of colour removal eff. for WMC-in-NR

3.4 Process Optimisation

Optimisation of the process was carried out with the following optimisation set goals:

- X_1: Minimise the dosage to economise coagulants, thereby saving cost
- X_2: Operate at pH range of 6.0 – 10.0, the observed optimal region of pH
- X_3: Minimize settling time to boost turnover per day
- Y_1: Target turbidity removal efficiency of 98 %. This is above the minimum of 94.10 % that will give the WHO standard turbidity of 5.0 NTU for portable water.
- Y_2: Target colour removal efficiency goal of 98 %. This is well above the maximum of 82 % obtained from the OFAT experiment.

The results obtained from process optimisation are presented in 3D surface and contour plots of figures 9 through14. These graphs depict two measure information: optimal values of the response variables and the interaction effects of the cardinal coag-flocculation coordinates. The contour plots are shown as figures 15 through 20. In these figures, A, B and C represent the independent variables (X_1, X_2 and X_3). The numerical optimisation results show that under the optimisation set goals and targets, optimal process parameters for the WMC-in-NR system were 250 mg/l dosage, pH of 7.26 and settling time of 35 minutes. At this point, the optimal turbidity and colour removal efficiencies were found to be 94.87.000% and 84.66 % respectively.

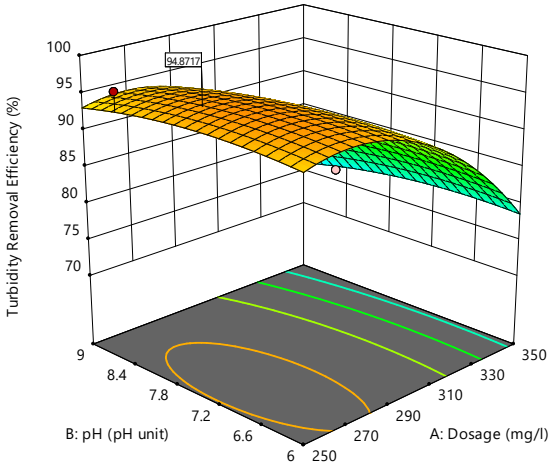

Fig. 9: 3D surface plot of interaction of A and B onY_1

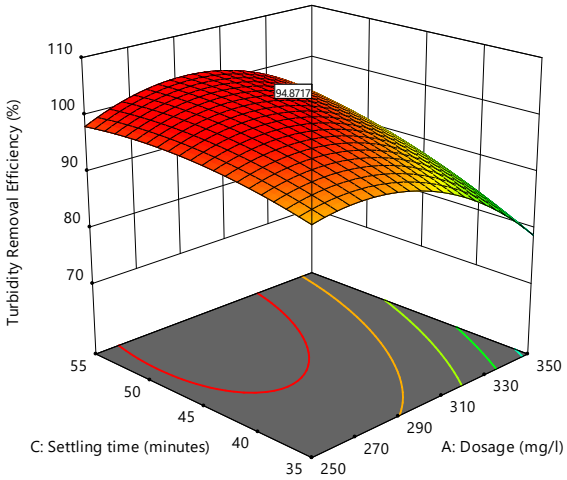

Fig. 10: 3D surface plot of interaction of A and C onY_1

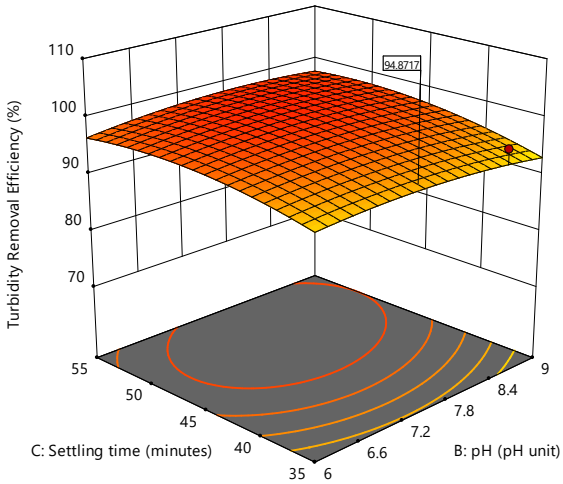

Fig. 11: 3D surface plot of interaction of A and B onY_1

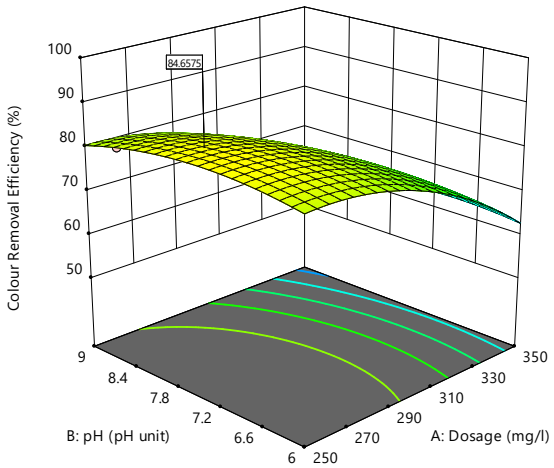

Fig. 12: 3D surface plot of interaction of A and C onY_2

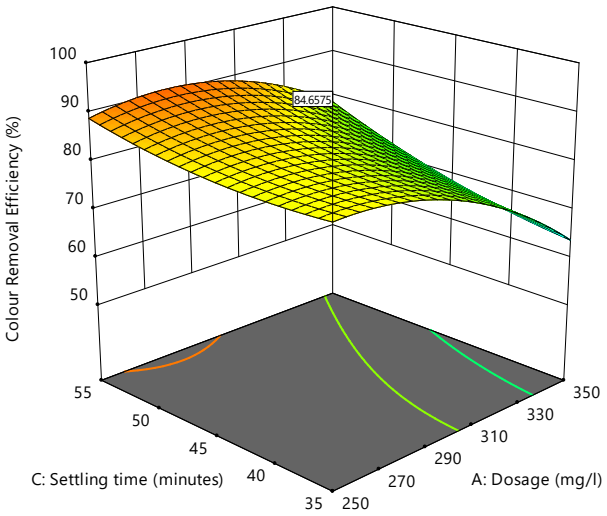

Fig. 13: 3D surface plot of interaction of A and B onY_2

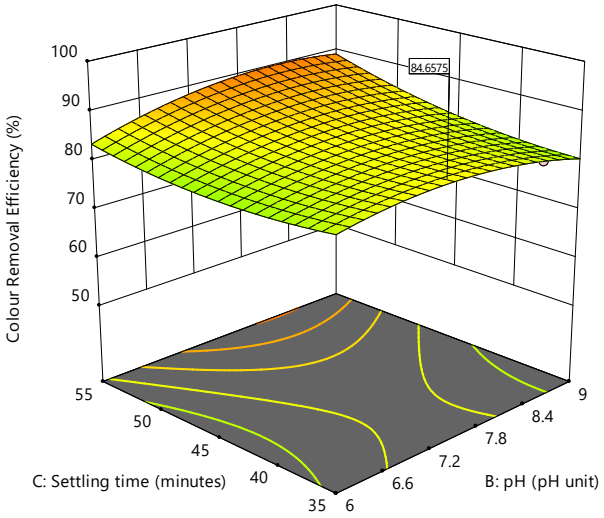

Fig. 14: 3D surface plot of interaction of A and C onY_2

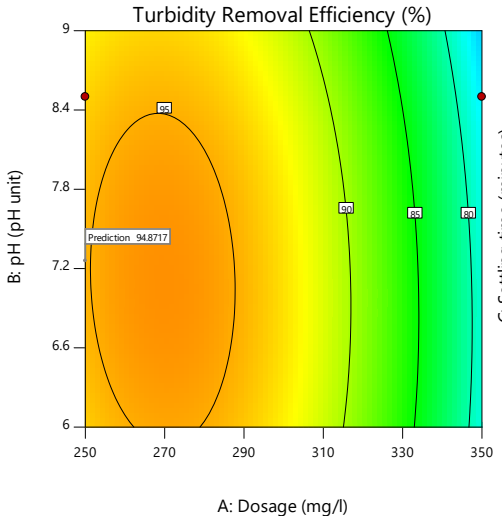

Fig. 15: Contour plot of interaction of A and B onY_1

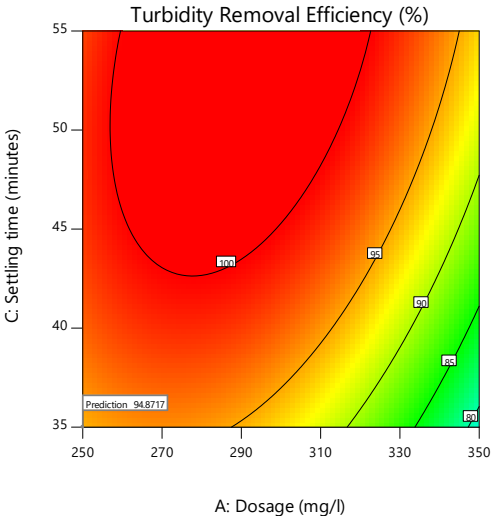

Fig. 16: Contour plot of interaction of A and C onY_1

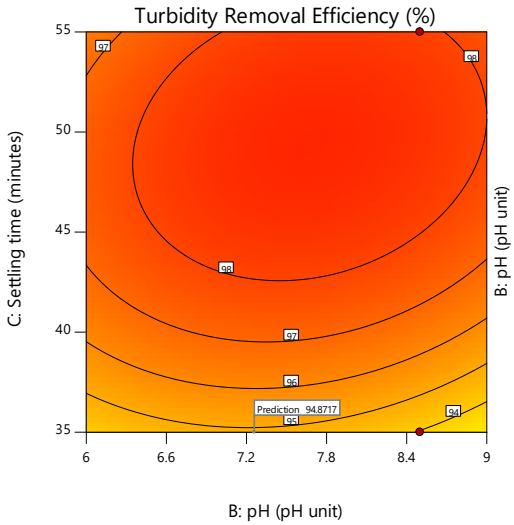

Fig. 17: Contour plot of interaction of A and B onY_1

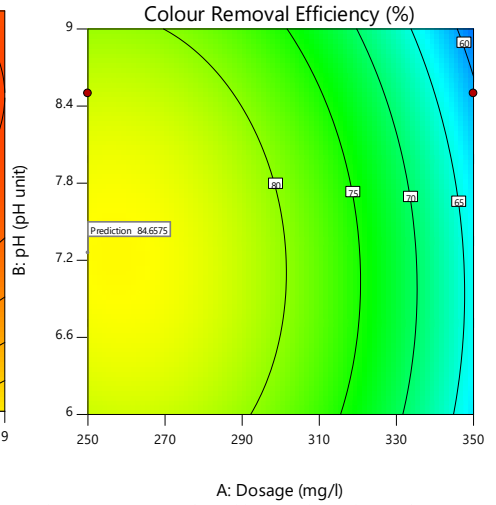

Fig. 18: Contour plot of interaction of A and C onY_2

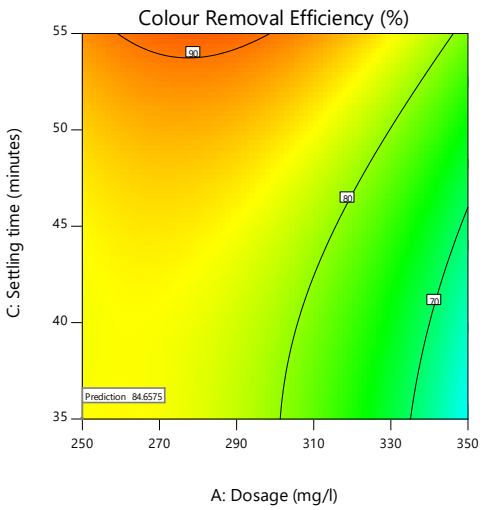

Fig. 19: Contour plot of interaction of A and B on Y_2

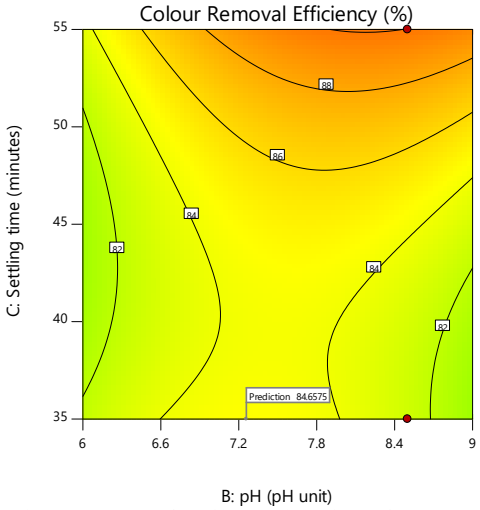

Fig. 20: Contour plot of interaction of A and C on Y_2

3.5 Confirmatory Tests

Confirmatory tests were carried out at the predicted parameter points and the results of the experiments tabulated against the predicted results as shown in table 5. These results validate the predictions by the models; thus the models truly represent the behaviour of the system studied.

Table 5: Experimental versus predicted response values the WMC-in-NIR system

Independent variables' optimal Levels			Responses' optimal levels			
X_1 (mg/l)	X_2 (pH unit)	X_3 (minutes)	Experimental Y_1(%)	Predicted Y_1 (%)	Experimental Y_2 (%)	Predicted Y_2 (%)
250	7.26	35	95.02	94.87	84.53	84.66

IV. CONCLUSION

Based on the physiochemical characteristics of the NR, it is concluded here that the river contains high levels of turbidity and colour. It is equally concluded that WMC is a useful plant-based coagulant effective for water treatment application. It is very effective in the coag-flocculation of the NR sample. The turbidity and colour removal efficiencies from the NR is described by quadratic models as indicated in this study. The optimal parameter levels are as presented in this research.

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