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OPTIMIZATION OF CONGO RED (CR) DYE ADSORPTION FROM AQUEOUS SOLUTION ONTO RICE HUSK (RH) BIOSORBENT USING RESPONSE SURFACE METHODOLOGY (RSM)

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Abstract

In this study, Rice husk (RH) a renewable agricultural by product was utilized as biosorbent for the removal of Congo Red (CR) dye from aqueous solution. Fourier transform infrared spectroscopy (FTIR) and Brunauer-Emmett-Teller (BET) analysis were used to characterized the adsorbent. Batch Adsorption experiments were designed and conducted with the aid of Statistical Box-Benkhen Design (BBD) in other to investigate the effects of contact time, adsorbent dosage and pH on Congo Red (CR) removal. Adsorption of Congo Red (CR) dye onto RH was best described by a quadratic model equation, and analysis of variance revealed the significance of the model equation. Response surface methodology (RSM) was used to optimize the conditions of Congo Red (CR) dye adsorption onto RH biosorbent. The predicted optimum values of the process variables for Congo red (CR) removal were found to be at pH of 2.0, contact time of 10 minutes and adsorbent dosage of 0.539 g.

Keywords: Congo Red (CR) dye, Rice Husk (RH), Adsorption, Box-Benkhen Design(BBD), Optimization.

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The experimental percentage adsorption of Congo Red (CR) obtained under the predicted optimum conditions was 98.97 %, which is very close to the predicted value of 100 % and thus validates the developed model. Adsorption capacity of the biosorbent (RH) was found to be 3.95 mg/g. The research generally revealed that Rice husk (RH), a renewable agricultural by product could be utilized as a promising adsorbent in the removal of the Congo Red (CR) dye from aqueous solution

Introduction

The release of large volume of water into water bodies containing synthetic dye stuff from various industries such as textile, paper, printing, cosmetics and pharmaceutical poses significant threat to both human and aquatic living organisms (Bamroongwongdee *et al*.,2019; Roy and Mondal, 2017)). Congo red (CR) (4-aminonaphthalene-1-sulphonicacid) is a benzidine based and an anionic diazo dye used commonly in textile, paper and printing industries. This synthetic dye is water soluble and not easily biodegradable or photodegradable because of its structural stability (Yakubu *et al*., 2024; Yunus and Nuhu, 2020; Abdulmalik *et al*., 2020). The removal of these toxic dyes is very essential before their eventual discharge into water bodies (Isah *et al*., 2022). Several physical, chemical and microbial methods, including membrane separation, ion exchange, biological degradation, electrochemical techniques, chemical oxidation and adsorption have been employed to remove Congo red (CR) and other dyes from wastewaters (Yunus and Nuhu, 2020; Gupta *et al*., 2015; Khaniabadi *et al*., 2017).However each technology has its own inherent limitations, such as high cost, complexity, high energy input and sludge generation. Among these technologies, adsorption has been found to be simple, effective and economical (Hamza *et al*., 2019; Ajoge, 2020). Adsorption process is one of the physical treatment methods, where by adsorbate molecules or ions accumulated onto the surface of an adsorbent via physical or chemical bond. (Isah *et al*., 2022; Mustapha *et al*., 2019). In adsorption process, activated carbon (AC) has been reported as one of the most effective adsorbent used for the removal of many pollutants (organic and inorganic), including dyes and other colored compounds. However, production of activated carbon by carbonizing and activating the organic substances from the proper materials is relatively costly, and thus requires the search for alternatives and low-cost adsorbents (Rehman *et al*., 2018; Hamza *et al*., 2019; Sivakumar, 2015). A low-cost adsorbent should be inexpensive materials and does not require many processing and can be found in the environment naturally in abundance or produced as a by-product or a waste from an industry or agriculture (Mustapha *et al*., 2019; Sivakumar, 2015). Hence there is a growing demand to find low cost and efficient adsorbents to remove dyes from

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aqueous solution. In this study, Rice husk (RH) a biomas and a renewable agricultural by product would be utilized as a potential biosorbent in the removal of Congo red (CR) dye from aqueous solution.

Materials and Method

Preparation of Adsorbent

The adsorbent (Rice husk), which is a by-product of a local rice milling was obtained from Station market Rice mill, Kakuri, Kaduna, Nigeria. Impurities removed, washed thoroughly with distilled water, dried and pulverized to powdered form using pestle and mortar. It was then sieved with 100µm sieve and stored in a well cleaned and dried container.

Preparation of the Adsorbate

Congo red (CR) dye adsorbate analytical grade was obtained from Steeve-moore chemical store Samaru, Zaria, Kaduna, Nigeria. A stock solution of 1000 mg/L of Congo Red (CR) was prepared by dissolving 1g of CR powder with distilled water in a 1 litre volumetric flask stirred and making it up to the mark. Other lower concentrations were prepared from the stock solution by serial dilutions.

The dilution formula is given as:

$$C_1V_1 = C_2V_2 \quad (1)$$

Where:

V_1 = Volume of stock solution

C_1 = Concentration of stock solution

V_2 = Final volume of new solution

C_2 = Final concentration of new solution

Adsorption Experiments

Batch adsorption experiments were carried out in 250ml beaker by mixing 100ml of Congo Red (CR) solution of the desired concentration with the required amount of the adsorbent (Rice husk) as determined using Box-Behnken design (BBD) of experiment. The pH of the Congo Red (CR) dye solutions were adjusted using either NaOH or HCl solution. The mixture was stirred thoroughly with a magnetic stirrer at temperature of 301.15K and 350 rpm for desired contact time. The mixture was then rapidly filtered using vacuum pump filter and the resulting supernatant was analyzed using UV-visible spectrophotometer at maximum absorption wavelength in other to determine the amount of CR remaining in the solution. The same procedure was repeated for other runs from the design of

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experiment presented in table 2. The percentage removal of Congo red (CR) dye was calculated using the relation in equation 2.

$$\text{Percentage Removal (CR)} = \frac{C_o - C_t}{C_o} \times 100 \quad (2)$$

$$qe = \frac{C_o - C_e}{m} \times V \quad (3)$$

Where; C_o and C_t represent initial and final concentrations of CR (mg/L) respectively.
q_e is the equilibrium adsorption capacity (mg/g), Ce is the equilibrium concentration (mg/L), V is the volume of the solution and m is the mass (g) of the adsorbent.

Design of Adsorption Experiments

Box-Behnken Design (BBD) was used in this work to generate the experimental design matrix. Three process parameters; contact time, solution pH and adsorbent dosage were chosen as the independent variables while the percentage of dye (CR) removed was the dependent response variable. The independent variables, the experimental ranges and levels for CR removal are presented in Table 1

Table 1: Experimental factors and levels of investigated variables

Independent Variables	Symbols	Levels		
		Low	Central	High
		-1	0	+1
Time (min)	A	10	45	80
Adsorbent Dosage (g)	B	0.5	0.75	1
pH	C	2	6	10

The process parameters (factors) and their ranges, as well as the output responses (CR removal efficiency) for both modelling and correlation studies are selected based on the literatures reviewed. The relationship between the output responses (CR removal) and the input process variables (time, adsorbent dosage and pH) are defined using RSM modelling approach. The RSM analysis software selected for implementing the methodology was the Box-Behnken Design (BBD) of experiment using Design Expert 12 software package. The experimental design matrix (BBD) for the three factors were generated using Design Expert 12 software package as shown Table 2.

Results and Discussion

The results of the experimental design for the input factors (time, adsorbent dosage and pH) and the experimental response variable (percentage CR removal) are presented in Table 2.

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Table 2.: Box-Behnken Design (BBD) matrix with experimental responses for Congo red (CR) dye adsorption onto Rice husk (RH).

Std	Run	A: Time (min)	B: Adsorbent dose (g)	C: pH	Removal efficiency (%)
5	1	10	0.75	6	68.01
7	2	45	0.50	6	73.32
11	3	45	0.75	6	75.75
9	4	45	0.75	2	97.06
8	5	45	1.00	6	66.75
12	6	45	0.75	6	75.72
2	7	80	0.50	10	57.55
1	8	80	1.00	2	98.78
4	9	10	0.5	2	98.59
14	10	45	0.75	6	75.61
10	11	45	0.75	2	96.98
13	12	45	0.75	6	74.98
3	13	10	1.00	10	66.52
15	14	45	0.75	6	76.07
6	15	80	0.75	10	68.60

A quadratic regression model was selected in approximation of the response variable (CR removal efficiency). The t-distribution, coefficients and p-values for the experimental results were obtained and the sum of squares as well as the F-distribution were also determined. The 95% confidence level was used for the statistical calculations. while p-value was also used to established the statistical significance of the model and the parameters. Furthermore, the effect of interaction between the input variable were established.

Analysis of Variance (ANOVA)

Statistical analysis of the optimization study of CR adsorption on rice husk (RH) bio sorbent was carried out using ANOVA to evaluate the optimization factor and check the adequacy of the empirical model. The statistical significance of the factors and the model were validated using p-value, Lack-of-Fit, regression coefficient value, R^2, Adjusted R^2 and Predicted R^2. The significance of the individual model coefficients was evaluated using the p-values, which is a means of assessing the interaction strength and effect of each parameter as well as the model F-value were used to test the validity of the model. If the p-value is < 0.05, then the factor and/or model is statistically significant at the 95% confidence level, while p-value is > 0.05 is not significant (Montgomery, 2013). The results

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of ANOVA for fitting the quadratic response surface model by a mean square method are summarized in Table 3

Table 3: ANOVA for Congo Red (CR) adsorption onto Rice husk (RH)

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remark
Model	2486.45	9	276.27	8.35	0.0154	Significant
A-Time	64.98	1	64.98	1.96	0.0059	
B-Adsorbent dose	21.58	1	21.58	0.6525	0.0155	
C-pH	1.50	1	1.50	0.0452	0.0100	
AB	552.17	1	552.17	16.70	0.0095	
AC	16.42	1	16.42	0.4965	0.0012	
BC	0.0155	1	0.0155	0.0005	0.0836	
A^2	2.07	1	2.07	0.0627	0.8123	
B^2	54.42	1	54.42	1.65	0.2558	
C^2	1069.42	1	1069.42	32.33	0.0023	
Residual	165.37	5	33.07			
Lack of Fit	59.24	1	59.24	2.23	0.2094	Not significant
Pure Error	106.13	4	26.53			
Cor Total	2651.82	14				

Table 3. shows a model F-value of 8.35 with a corresponding p-value of <0.0154, an indication that the model is quite significant (p-value < 0.05) and that there is only a 1.54% chance that a model F-values this large could occur due to noise in the experimental data (Gelman, 2013; Montgomery, 2013; Maqsood and Ibrahim, 2015). The model terms of the quadratic model are A (Time), B (adsorbent dosage), C (pH), AB, AC, BC, A^2, B^2 and C^2. It can be seen that A,B,C,AB,AC and C^2 are significant model terms with p-values < 0.05, indicating that the combination of adsorption time and adsorbent dosage as well as the quadratic term of pH have significant effect on the CR removal efficiency. However, the individual model term BC, A^2 and B^2 do not have significant effect on the response variable as their p-values are greater than 0.05. Additionally, the Lack-of-Fit criteria was also used to evaluate the validity of the optimization study. From Table 3, the model Lack-of-Fit F-value was 2.23 with a p-value of 0.2094 (p>0.05), implies the Lack of Fit is not significant relative to the pure error. Suggesting that there is only a 20.94% chance that a Lack of Fit F-value this large could occur due to noise. The non-significant lack of fit suggested that the optimization model of CR removal is good. (Maqsood and Ibrahim, 2015; Jia *et al*., 2018; Ajoge, 2020).

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Response Surface Model (RSM)

The relationship between the response variable (CR removal efficiency) and the independent factors that affects CR removal efficiency were investigated using the quadratic regression model with a 2-way linear-linear interaction. The coefficients of regression model that describe the CR removal efficiency in terms of coded factors are presented in Table 4.

Table 4: Model coefficient in terms of coded factor

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	73.00	1	2.47	66.64	79.37	
A-Time	-4.03	1	2.88	-11.42	3.36	2.00
B-Adsorbent dose	-2.32	1	2.88	-9.71	5.07	2.00
C-pH	-0.6116	1	2.88	-8.00	6.78	2.00
AB	16.62	1	4.07	6.16	27.07	2.00
AC	-2.87	1	4.07	-13.32	7.59	2.00
BC	-0.0880	1	4.07	-10.54	10.37	2.00
A^2	-0.5184	1	2.07	-5.84	4.80	1.00
B^2	-2.66	1	2.07	-7.98	2.67	1.00
C^2	11.77	1	2.07	6.45	17.10	1.00
R^2	0.9989					
Adjusted R^2	0.9974					
Predicted R^2	0.9954					
Adequacy Precision	90.971					

Table 4 presents the regression model coefficient of the response variable (CR removal efficiency) in terms of coded factors. The coefficients estimated represents the expected change in response per unit change in factor value when all remaining factors are held constant. The regression model in term of coded factors shown in Table 4 is as expressed in equation 4

$$CR\ Removal = 73 - 4.03A - 2.32B - 0.612C + 16.62AB - 2.87AC - 0.088BC + 11.77C^2 \quad (4)$$

The regression model for Congo Red (CR) removal efficiency in terms of coded factors (equation 4) is suitable for predicting the relative effect of the factors at any given level (the high level of +1 and low level of – 1). However, equation 4 is not suitable for

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predictions of response, percentage CR removal in actual terms. Hence, the regression model for CR removal efficiency in terms of actual factor is expressed as equation 5.

$$CR\ Removal\ =\ 145.9719 - 1.3785X_1 - 30.4741X_2 - 7.9965X_3 + 1.899X_1X_2 - 0.0205X_1X_3 - 0.088X_2X_3 - 0.0004{X_1}^2 - 42.4948{X_2}^2 + 0.7359{X_3}^2 \quad (5)$$

Note: X_1 = time, X_2 = adsorbent dosage and X_3 = pH

The regression model in terms of actual factors as represented in equation 5 is suitable for predicting the response, CR removal efficiency for any given levels of each factor in its actual terms with the levels specified in their original units for individual factor. However, equation 5 is not suitable for determining the relative effect of the factors on CR removal. This is because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space. The fitness and validity of the regression model with experimental response was evaluated using the regression coefficient, R^2 and Adjusted-R^2. Regression coefficient, R^2, is a measure of how close the experimental responses are to the fitted model and lies between 0 and 1, such that, the closer the R^2 value is to 1, the better the model prediction (Jia *et al*., 2018). The obtained regression coefficients, R^2 and Adjusted-R^2 values of the fitted regression model are 0.9376 and 0.8254 respectively. This shows that the 93.76% of the experimental data are well captured and describable by the regression model. The Adjusted R^2 value of 0.8354 indicates reasonable agreement with the Predicted R^2 value as the difference is less than 0.2 which further shows that there is good agreement between the experimental and predicted CR removal (Montgomery, 2013; Adepoju and Olawale, 2015; Hamza *et al*., 2019). The high R^2 values obtained in this study suggests that the quadratic model of the BBD adequately describe the experimental data and suitable for predicting the response, CR removal efficiency. This is because, a model that adequately described an experimental data is expected to have R^2 values close to 1 (Montgomery, 2013). Also, adequacy precision which measures the signal to noise ratio was used to assess the goodness of the fitted model with a ratio greater than 4 being desirable (Montgomery, 2013). Table 4. shows adequacy precision of 90.971 which indicates an adequate signal and confirms that this model can be used to navigate the design space. The goodness of the fitted model was further demonstrated by the plot of the predicted response CR removal against actual experimental response denoted by the colored point all lies very close to the diagonal line representing the predicted response in Figure 1b. This indicates the validity and goodness of the fitted regression model for predicting the response CR removal (Ajoge, 2020; Kumar *et al.*, 2017; Bazezew *et al*., 2022). Additionally, the deficiency or discrepancy in the

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performance of the fitted model to the experimental data was further evaluated using normal plot of residuals (Figure 1a). The normal probability plot shows organized and cluster points with "S" shape that are close to the diagonal line in Figure 1a, suggesting the homogeneity of the error discrepancies and the independent style of the residuals which signifies that the errors are normally distributed and independent of each other (Qiu *et al.*, 2014).

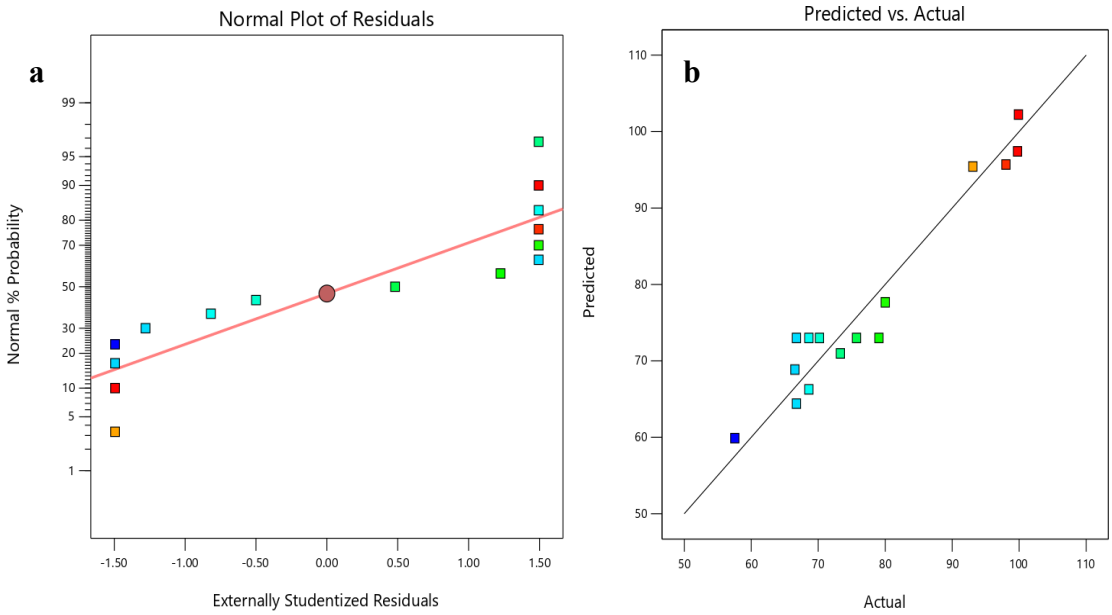


Figure 1: Diagnostics plot of model: (a) Normal probability of residuals, and (b) Predicted vs Actual plot of response

Response Surface Analysis

The simultaneous interaction among the factors and the response CR removal were evaluated using 3D response surface and contour plots in other to explore the relationship between the factors that produce desirable response value. The effect of time and adsorbent dosage on CR removal by RH bio adsorbent is presented in Figure 2 . Figure 2 showed that the CR removal increases with increase in time from 10 – 80 min and adsorbent dosage from 0.5 – 1 g to reach a maximum CR removal of almost 100%. The high CR removal obtained is attributed to relatively large surface area and the presence of a large number of active sorption sites available per unit mass of adsorbents for the retention of CR and the prolonged adsorption time, which allows for maximum CR adsorption by the RH bio sorbent (El-Zahhar and Al-Hazmi, 2015; Momina *et al.*, 2018).Therefore, the interaction between time and adsorbent dosage have significant effect on CR removal efficiency which conforms with results presented in Table 3.

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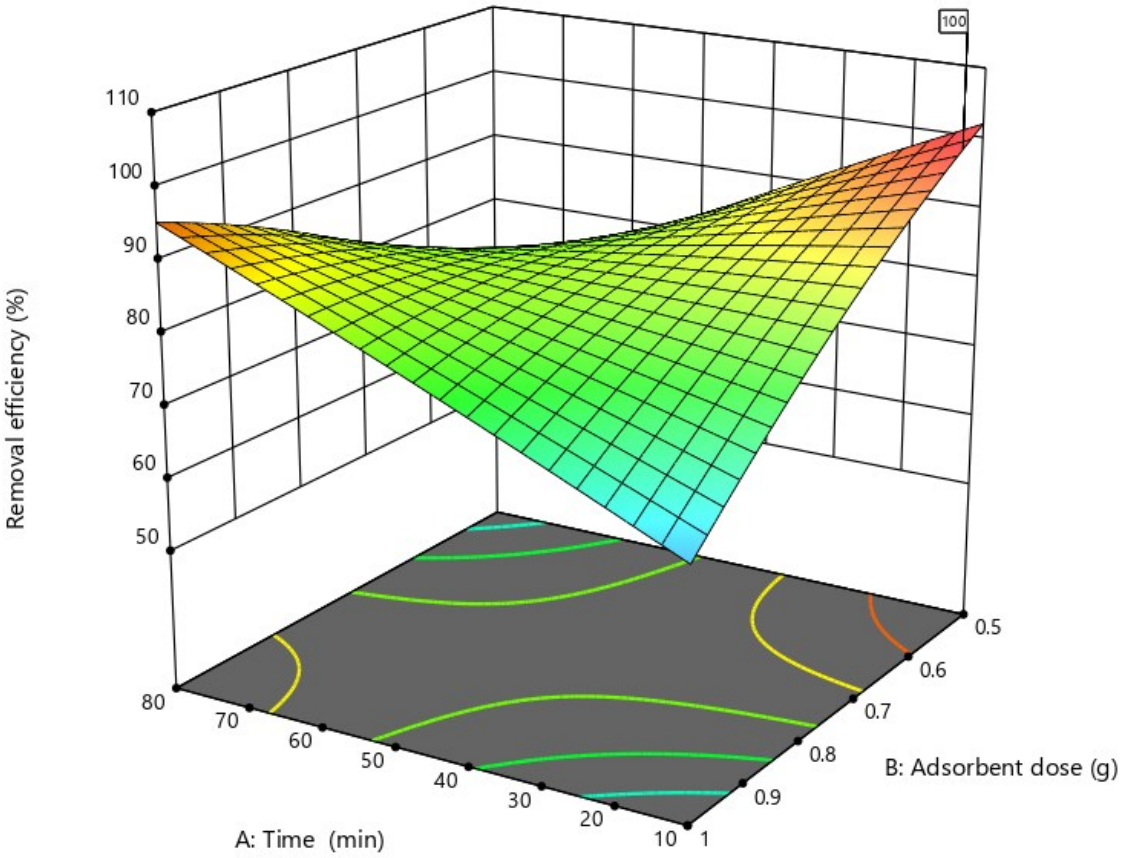


Figure 2: 3D Response surface plot for the effect of time and adsorbent dosage on Congo red (CR) dye removal from aqueous solution

The effect of time and pH on CR removal is presented in Figure 3. Figure 3 showed that CR removal is highest at low adsorption time of 10 min and at acidic environment (pH of 2) to reach a maximum CR removal of almost 100%. This shows that the pH of the adsorption environment impacts the removal of CR at lower adsorption time. The high percentage of CR removal at low adsorption time and pH could be attributed to protonation of adsorbent surface and low mass transfer resistance during adhesion of the adsorbate molecules onto the adsorbent. The protonation of the adsorbent surface at low pH, results in strong electrostatic attraction between the positively charged adsorbent surface (RH) and anionic CR molecules. Whereas the lowest CR removal occurs towards adsorption time of 80 min, which suggest possible desorption of the CR back into the solution due to saturation of active sorption sites at prolonged adsorption time (Bamroongwongdee *et al*., 2019). Hence, combination of time and pH have relatively significant effect on CR removal and conforms with the ANOVA result in Table 3.

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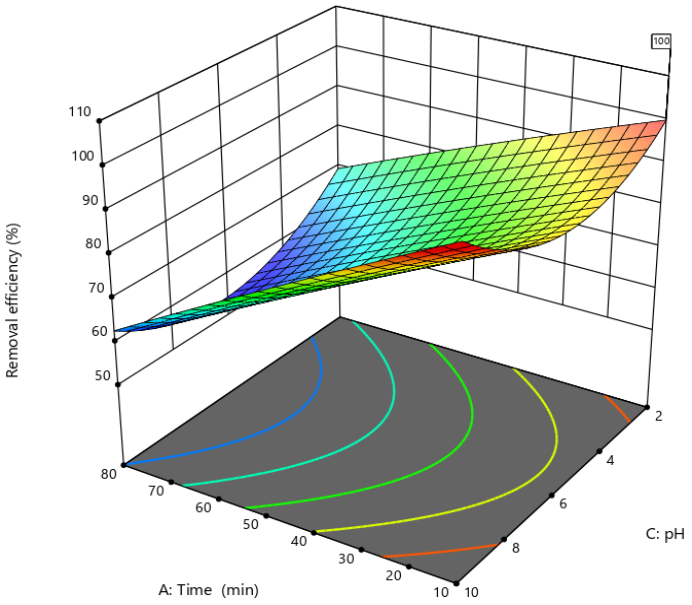


Figure 3: 3D Surface plot for the effect of time and pH on Congo red (CR) dye removal

The 3D response surface plot of the effect of adsorbent dosage and pH on CR removal is presented in Figure 4. Similarly, Figure 4 showed that CR removal is highest at low adsorbent dosage of 0.5 g and at pH of 2 for acidic environment and low CR removal at pH of 10 for basic environment .The high CR removal at low pH environment and low adsorbent dosage could be attributed to electrostatic attraction and presence of Silanol and Si-O functional groups on the adsorbent surface. (Sivakumar, 2015; Dafalla *et al*., 2010; Hamza *et al*., 2019).

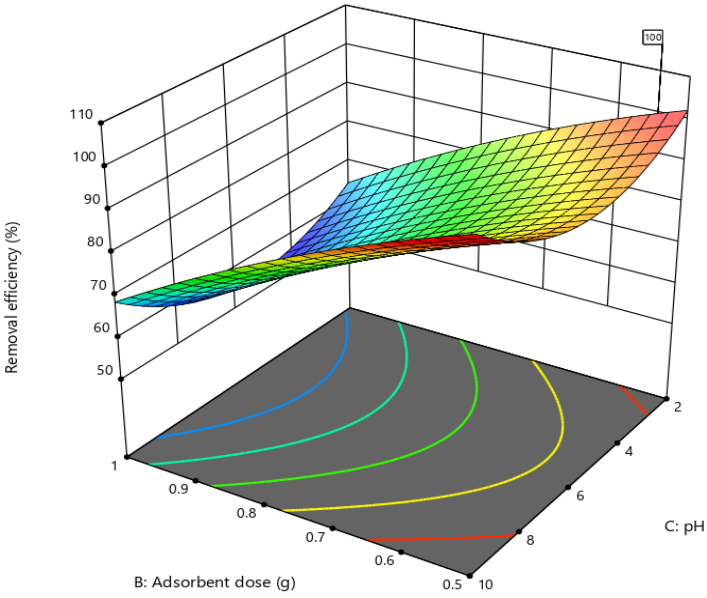


Figure 4: 3D Surface plot for the effect of adsorbent dosage and pH on Congo red (CR) dye removal

Optimization of Process Parameters

The primary objective of this optimization study is to find the best input factors that maximizes Congo red (CR) removal by RH bio sorbent. The optimization tool in Design Expert version 12 application package was utilized to determine the optimum factors values that maximizes CR removal using the desirability function with the setup constraint for time, pH and adsorbent dosage sets in range between the lower and upper limit considered in this study, while the goal for the response, CR removal was set to maximum. The best condition that maximizes CR removal by RH bio sorbent were at time of 10 min, adsorbent dosage of 0.539 g and pH

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environment of 2.0 at maximum desirability of 1 to give 100% CR removal. Meanwhile, 98.87% CR removal was achieved experimentally under the predicted optimum conditions. The good agreement observed between experimental percentage adsorption of CR and the predicted percentage adsorption validates the developed model. Figure 5 shows the ramp plots depicting the optimum conditions of adsorption process parameters and the response variable.

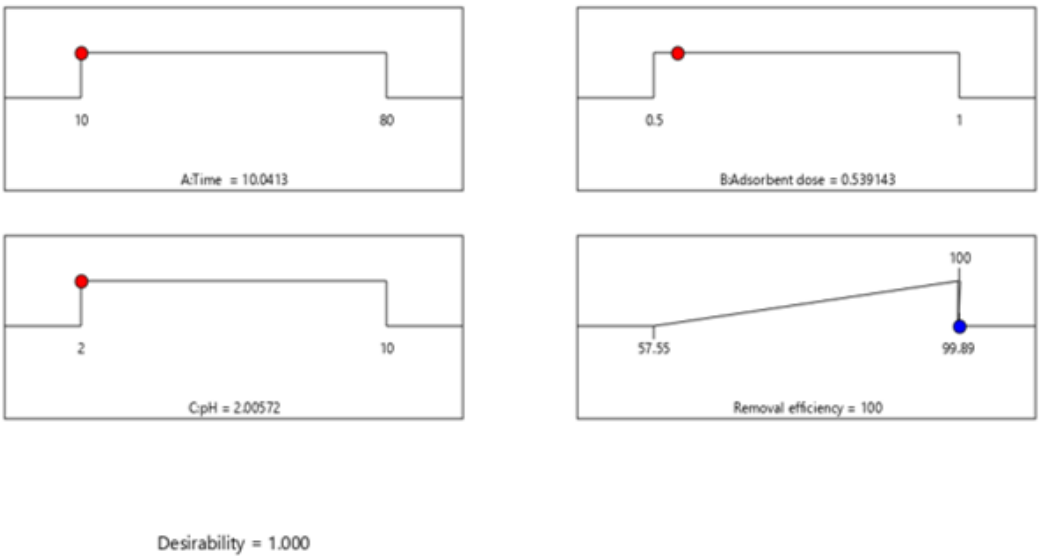


Figure 5: Optimization ramp plots of process parameters and response variable.

Brunauer-Emmett-Teller (BET) Analysis

The RH bio sorbent was characterized using BET analyzer to determine its surface properties such as surface area, pore volume and pore diameter. Table 5 present the results of the characterization of the RH bio sorbent using BET analysis.

Table 5: Results of BET analysis of the Rice husk (RH)

Parameters	Units	Value
Pore volume	cm^3/g	0.186
Average pore diameter	nm	2.122
Surface area	m^2/g	337.6

The rice husk has specific surface area of 337.6 m^2/g, pore volume of 0.186 cm^3/g and pore diameter of 2.122 nm. This BET surface characteristics shows that the rice husk adsorbent has a relatively good and better surface area suitable for adsorption processes. The pore

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diameter also indicates that the pore sites are suitable for adsorbing nano particles such as colors, as well as gaseous molecules.

Fourier Transforms Infrared Spectroscopy (FTIR) Analysis

The FTIR-analysis was used to investigate the functional groups present on the adsorbents that could be responsible for the dye removal. The FTIR spectra of the rice husk were analyzed to determine the vibration frequency changes in the functional groups within the range of 4000–400 cm^{-1} wave number shown in Figure 6.

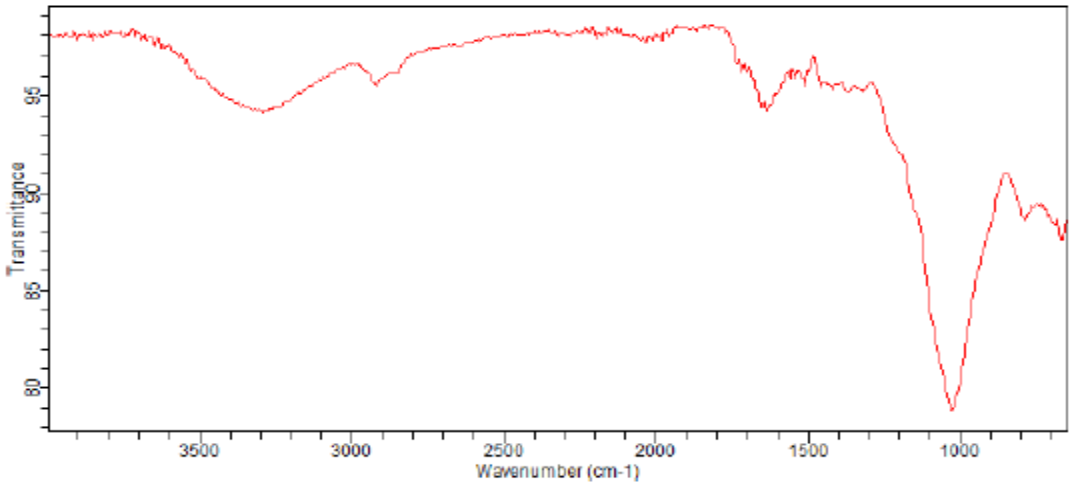


Figure 6: FTIR Analysis of Rice Husk (RH)

A close examination of the adsorbent surface, Rice husk biosorbent provides information regarding the surface functional groups involved in the sorption of the Congo red (CR) from solution. The FT-IR spectrum of Rice husk (RH) in the figure 6 shows several bands were observed which suggest that various functional groups could be responsible for binding of the CR. Absorption band observed at (1043.7 – 1170.4 cm^{-1}) corresponds to Si-O bending vibration stretching and absorption band at 790.2 cm^{-1} indicate the presence of Si-H and Si-OH group on the surface of the adsorbent. The presence of peak around (1617.70-1737.74 cm^{-1}) corresponds to -CO and -CHO stretching aromatic groups. (Dafalla *et al*., 2010). The Silanol functional group plays a vital role in the sorption process due to its acidic nature.

Conclusion

Rice husk (RH) bio sorbent was successfully prepared and characterized and found to have specific surface area of 337.6 m^2/g, pore volume, 0.186 cm^3/g and pore size of 2.122 nm. FTIR analysis of the adsorbent confirms the presence of Silica and Silanol functional

groups, which play vital role in the sorption process. Adsorption of Congo Red (CR) onto rice husk (RH) biosorbent was best described by a quadratic model equation and analysis of variance revealed the significance of the model equation. Response surface methodology (RSM) was used to optimize the conditions of Congo Red (CR) dye adsorption onto Rice husk. The optimum conditions of Congo red CR removal from aqueous solution were found to be at contact time of 10 minutes, pH of 2.0 and adsorbent dosage of 0.539 g. The experimental percentage removal of Conge red obtained under optimum predicted conditions is 98.97%, which is very close to the predicted value of 100%. Thus, the good agreement between the predicted and experimental values validates the developed model. Adsorption capacity of the biosorbent was found to be 3.95 mg/g. This study revealed that rice husk, a renewable agricultural by product could be utilized as a promising adsorbent in the removal Congo red (CR) dye and other colored pollutants from aqueous solution.

Recommendations

1. Further research should be carried out using other types of design of experiment.
2. Other renewable agricultural by products should explored as alternative biosorbent for the removal of the dye from aqueous solution

REFERENCES

Abdulmalik A.K., Natasha A., Muhammad N., (2020). A comparative study of the Adsorption of Congo Red dye on Rice husk, Rice husk char and chemically modified rice husk char from aqueous media, *Bull Chemical Society of Ethopia* ,34(1), 41 – 54.

Adepoju, T. F. and Olawale, O. (2015). Optimization and Predictive Capability of RSM Using Controllable Variables in Azadiracha Indica Oilseeds Extraction Process, International *Journal of Chemistry and Materials Research*, 3(1), 1-10.

Akpomie K.G, and Dawodu F.A. (2016). Acid modified montmorillonite for sorption of heavy metals from automobile effluent, *Beni-Suef University Journal of basic and applied sciences* doi: 10.1016/j.bjbas.2016.01.003.

Ajoge H.S (2020). Iron impregnated Rice husk ash adsorbent for cyanide removal from cassava processing effluent, *An MSc Dissertation,* Department of Chemical Engineering Ahmadu Bello University, Zaria, Nigeria.

Bamroongwongdee C., Suwannee S. and Kongsomsaksiri M., (2019). Adsorption of Congo red from aqueous solution by surfactant modified rice husk: kinetic Isotherm and thermodynamic analysis, *Songklanakarin Journal of Science and Tecchnology*, 41(5), 1076 – 1083.

Bazezew, A. M., Emire, S. A., Sisay, M. T. and Teshome P. G. (2022). Optimization of mucilage extraction from Ximenia americana seed using response surface methodology. *Heliyon*, 8, e08781: 1 – 8. https://doi.org/10.1016/j.heliyon.2022.e08781

Dafalla S.B, Mukhtar H, Shaharun M.S. (2010). Characterization of adsorbent developed from rice husk: effect of surface functional group on phenol adsorption, *Journal of applied sciences*, 10(12), 1060-1067.

El-Zahhar, A. A. and Al-Hazmi, G. A. (2015). Organically Modified Clay for Adsorption of Petroleum Hydrocarbon, *European Chemical Bulletin*, 4(2), 87-91

Gelman, A. (2013). P Value and Statistical Practice, *Epidemiology*, Vol. 24, Number 1, Departments of Statistics and Political Science, Columbia University, New York, 69 – 73.

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Gupta V.K., Khamparia S., Tyagi I., Jaspal D., and Malviya A. (2015). Decolorization of mixture of dyes, *Global Journal of Environmental Science and Management,* 1(1),71-94.

Hamza A., Alao M.A, Galadima M.S., (2019). Adsorption of Chromium (VI) onto Metakaolin: Isotherms, Modelling and Optimization, *Journal of science and technology,* 11(1), 45-54.

Isah U.I, Abdurraheem G., Ibrahim A., Muhammad S., Abdullahi M., (2022). Kinetics, equilibrium and thermodynamics studies of Direct Red 1 dye adsorption on groundnut shell based activated carbon, *Journal of materials and environmental science,* 13, 988 -1002.

Jia, L., Jianguo, W., Chunfai, L. and Feng, G. (2018). A Multi-Parameter Optimization Model for the Evaluation of Shale Gas Recovery Enhancement, *Energies*, 11(654). doi:10.3390/en11030654.

Khaniabadi Y.S., Mohammad M.J., Shegerd M., Sadeghi S., Saeedi S., and Basiri H. (2017). *Environmental Health Engineering and Management Journal,* 4(1), 29 – 35.doi:10.15171/EHEM.2017.05.

Kumar, S. N. A., Ritesh, S. K., Sharmila, G., and Muthukumaran, C. (2017). Extraction optimization and characterization of water-soluble red purple pigment from floral bracts of Bougainvillea glabra. *Arabian Journal of Chemistry*. 10, 2145–2150.

Kyzas G.Z, Lazaridis N.K, and Mitropolous A.C., (2012). Removal of dyes from aqueous solutions with untreated coffee residues as potential low cost adsorbents:Equilibrium, reuse and thermodynamic approach, Chemical Eng. J. 9(7), 148 – 159.

Maqsood, Z. and Ibrahim, M. (2015). The Significance of P-Value in Medical Research. *Journal of Allied Health Sciences*, Pakistan, 1(1),74-85.

Minitab Blog Editor, (2013). Regression Analysis: How Do I Interpret R-squared and Assess the Goodness-of-fit. Available from www.blog.minitab.com, accessed: 27/12/2019.

Momina, M., Mohammad S and Suzylawati, I. (2018). A review on Regeneration performance of clay-based adsorbents for the removal of industrial dyes. *Journal of royal society of chemistry*: 24571-24587.

Montgomery, D. C. (2013). *Design and Analysis of Experiments*. 8th edition, Hoboken, New Jersey: Wiley. ISBN 978-1119320937.

Mustapha S., Ndamitso M.N, Abdulkarim A.S, Tijjani J.O, Mohammed A.K, Shuaibu D.T (2019). Potential of Using kaolin as a natural Adsorbent for removal of pollutant from tannery waste water, *Heliyon Journal*,5, e02923.

Qiu, P., Cui, M., Kang, K., Park B., Son, Y., Khim, E., Jang, M. and Khim, J. (2014). Application of Box–Behnken design with response surface methodology for modeling and optimizing ultrasonic oxidation of arsenite with H_2O_2. *Central European Journal of Chemistry*. 12(2), 164 – 172. DOI: 10.2478/s11532-013-0360-y.

Pathania D., Sharma A., and Siddiqi Z.M, (2016). Removal of congo red dye from aqueous system using Phoenix dactylifera seeds. J. Mol Liq, 21(9), 59 – 67.

Rehman R., Manzoor I., and Mitu L., (2018). Isothermal study of Congo red dye biosorptive removal from water by Solanum tuberosum and pisum peels in economical way, *Bull Chemical Society of Ethopia,* 32, 213 – 223.

Roy T.K. and Mondal N.K, (2017). Biosorption of Congo red from aqueous solution onto burned root of Eichornia crassipes biomas, *Applied water Science,* 7(4), 1841 – 1854. Doi:10.1007/s13201-015-0358-z.

Sivakumar D, (2015). Hexavalent chromium removal in a tannery industry wastewater using rice husk silica, *Global J. Environ. Sci. Manage*., 1 (1): 27-40, DOI: 10.7508/gjesm.2015.01.003.

Yakubu R.O, Yaro M.N, Habibu S. and Nasir S., (2024). Efficient Removal of Congo Red Dye from Aqueous Solution using a Biosorbent derived from Phoenix Dactylifera Seeds: Exploring Kinetic and Thermodynamic Parameters, *Chemical Search Journal*, 15(1), 8 – 19.

Yunus M.M., and Nuhu A.H., (2020). Thermodynamic study of Congo red dye Adsorption using Rice husk Activated carbon, *International Journal of Research and scientific innovation.* 7(3), 124 – 128.

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