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Adsorption of Textile Reactive Dye by Palm Shell Activated Carbon: Response Surface Methodology

Siti Maryam Rusly and Shaliza Ibrahim

***Abstract*—**The adsorption of simulated aqueous solution containing textile remazol reactive dye, namely Red 3BS by palm shell activated carbon (PSAC) as adsorbent was carried out using Response Surface Methodology (RSM). A Box-Behnken design in three most important operating variables; initial dye concentration, dosage of adsorbent and speed of impeller was employed for experimental design and optimization of results. The significance of independent variables and their interactions were tested by means of the analysis of variance (ANOVA) with 95% confidence limits. Model indicated that with the increasing of dosage and speed give the result of removal up to 90% with the capacity uptake more than 7 mg/g. High regression coefficient between the variables and the response (R-Sq = 93.9%) showed of good evaluation of experimental data by polynomial regression model.

***Keywords*—**Adsorption, Box-Behnken Design, Palm Shell Activated Carbon, Red 3BS, RSM.

I. INTRODUCTION

TEXTILE industries using synthetic dyes discharge large amounts of coloured effluents resulting from dyes remaining in the water stream due to difficult to treat because of poor biodegradation. Colored wastewater not only affects transparency and aesthetic aspect, but also because of their negative impacts on water ecosystems and human health since most of these dyes is potentially toxic and carcinogenic.

The existing technologies for dye-containing effluents are being undertaken by physical and chemical methods such as adsorption, coagulation, precipitation, filtration, oxidative process and membrane separation. Adsorption process is one of the most efficient methods of removal dye which also provides attractive alternative treatment, especially if the adsorbent is readily available and economical. Activated carbon is the widely used as adsorbent for decolorized color from textile effluents due to its high capacity for organic matter.

The application of response surface methodology (RSM) in treatment can result in improved adsorption process. RSM is a combination of mathematical and statistical techniques that are useful for modeling and evaluate the problem with numerous significance variables influencing the response even in the presence of complex interactions. The main objective is to determine the optimum response in addition to reduce the number of experiment.

In the present study, three levels, three-factorial Box-Behnken experimental designs was applied to analyze and investigate process parameters affecting the adsorption of textile dye Reactive Red 3BS by palm shell activated carbon.

S. M. Rusly is with the Department of Civil, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia (e-mail: simr_277@yahoo.com).

S. Ibrahim is with the Department of Civil, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia (e-mail: shaliza@um.edu.my).

II. MATERIALS AND METHODS

A. Adsorbent

Palm shell activated carbon (PSAC) obtained from Bravo Sdn. Bhd., Sarawak. It was kept in air tight container at room temperature.

B. Chemicals

The textile dye Reactive Red 3BS (C.I Reactive Red 239) was obtained from textile factory in Kelantan.

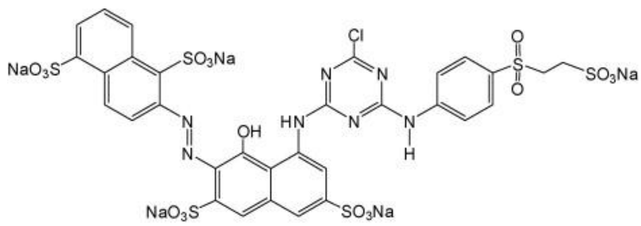

Fig. 1 Chemical structure of Reactive Red 3BS dye

C. Batch Adsorption Experiment

The simulated dye solution of Red 3BS of 100, 200 and 300 mg/L was prepared by dissolving 0.3 g, 0.6 g and 0.9g respectively in 3 litres in distilled water. Each experiment was carried out at room temperature with a certain amount of adsorbent was added to 3 litres of simulated dye solution in a cylindrical tank and mixing it by using 6 blade upward impeller for certain speed for 4 hours. The samples were filtered and placed in small container to be analyzed by spectrophotometer (Spectroquant® Pharo 100, Merck) at a maximum wavelength 540 nm. The efficiency and capacity of dye removal was defined as (2) and (3).

$$Efficiency\ (\%) = \left(\frac{C_i - C_e}{C_i}\right) x100 \qquad (2)$$

$$Capacity\,(mg/g) = \frac{C_i - C_f}{m} \qquad (3)$$

where, C_i = initial concentration(mg/L), C_f = final concentration (mg/L) and m = concentration of adsorbent (g/L).

TABLE I
EXPERIMENTAL FACTORS AND LEVEL OF BBD

Code	Factors	Level		
		-1	0	1
A	Speed (rpm)	50	600	1150
B	Initial concentration (mg/L)	100	200	300
C	Adsorbent dosage	5	27.5	50

D. Experimental Design and Data Analysis

The three input parameters; initial dye concentration, dosage of adsorbent and speed of the impeller were varied and the factor levels were coded by Box-Behnken design (BBD) model as given in Table I.

The actual experimental design matrix which is a total 28 experiments have been designed by BBD is given in Table II. The main effects and contour plots of the factor were plotted in response surface and determined by fitting a second order polynomial equation, refer to (1), as well as by interpretation of analysis of variance (ANOVA). A variable was considered significant if the calculated probability value (p) was smaller than the significance level (0.05).

TABLE II
EXPERIMENTAL DESIGN

Run No	Factors		
	A rpm	B mg/L	C g/L
1	1150	200	5
2	50	200	50
3	600	100	5
4	1150	200	50
5	600	200	27.5
6	1150	300	27.5
7	600	100	50
8	50	100	27.5
9	600	200	27.5
10	600	300	50
11	600	200	27.5
12	1150	100	27.5
13	50	300	27.5
14	600	300	5
15	50	200	5

$$Y = b_0 + \sum b_i X_i + \sum b_{ii} X_i^2 + \sum b_{ij} X_i X_j \qquad (1)$$

The results of experimental design were studied and interpreted by MINITAB® 14 statistical software to estimate the response of dependent variable [9].

III. RESULTS AND DISCUSSION

A. Interaction and Contour Plots on Dye Adsorption

The interaction plot for the removal and capacity are shown in Figs. 2 and 3. It was observed from the figure that as dosage increases, dye removal efficiency increases which indicate of increasing active component in dosage, correspondingly increased the adsorption efficiency. However as speed increasing, the capacity also increasing due to the well mixing of adsorbent with the solution in the stirred tank but the capacity decreasing as the initial concentration of dye increasing.

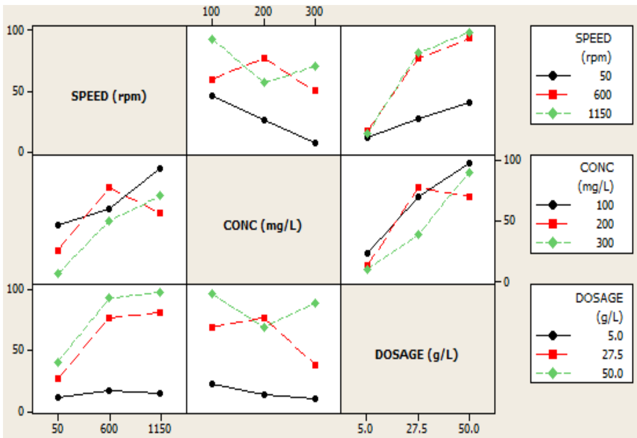

Fig. 2 Interaction plot for dye removal (%)

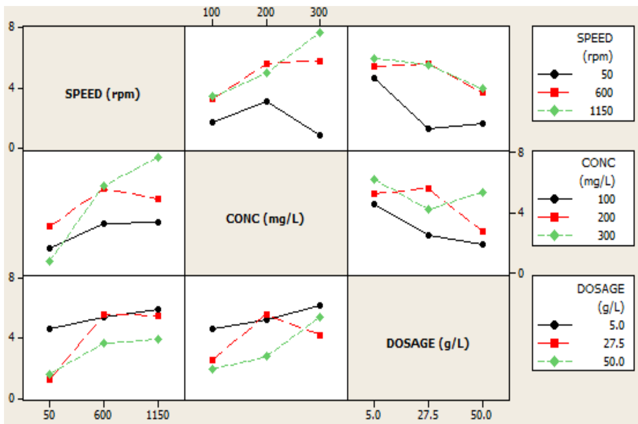

Fig. 3 Interaction plot for dye capacity uptake (mg/g)

The contour plots for dye removal efficiency and capacity are shown in Figs. 4 and 5 respectively indicate to the effectiveness of the dye removal as a function of various variable. The maximum removal of dye of above 90% and the capacity above 7mg/g is obtained in region of maximum dosage of 40 g/L and speed of 800 rpm.

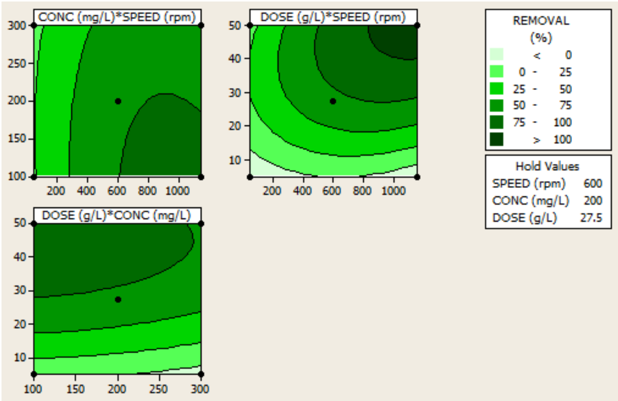

Fig. 4 Contour plots of dye removal efficiency

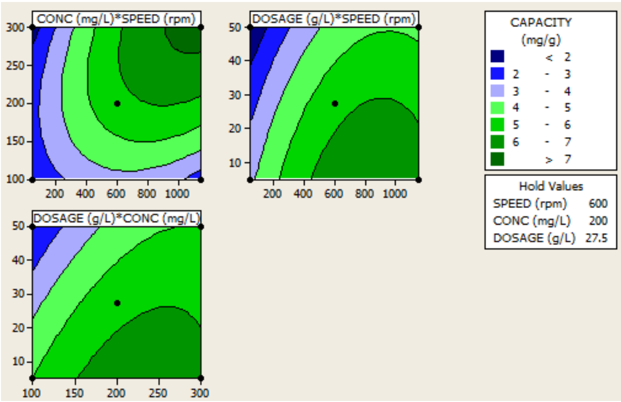

Fig. 5 Contour plots of dye capacity uptake by PSAC

TABLE III
COEFFICIENTS, T, P AND STANDARD DEVIATION FOR REMOVALEFFICIENCY (%)

Term	Coef	Standard Error	T	P
Constant	77.422	7.003	11.055	0.000
Speed (rpm)	21.440	4.289	4.999	0.004
Conc (mg/L)	-10.212	4.289	-2.381	0.063
Dose (g/L)	33.363	4.289	7.779	0.001
Speed X Speed	-18.359	6.313	-2.908	0.033
Conc X Conc	-4.661	6.313	-0.738	0.493
Dose X Dose	-17.556	6.313	-2.781	0.039
Speed X Conc	4.182	6.065	0.689	0.521
Speed X Dose	13.622	6.065	2.246	0.075
Conc X Dose	1.462	6.065	0.241	0.819

R-Sq = 95.7% R-Sq(Adj) = 88.0%

B. Regression Model and Analysis of Variance (ANOVA) Test

The regression coefficient, standard error, 'T' values and 'P' values for all linear, quadratic and interaction effects of the parameters are given Table III.

Based on RSM, the regression models for efficiency of decolorization for Reactive Red 3BS given in following equation:

$$Y = 77.422 + 21.440X_1 + 33.363X_3 - 18.359X_1^2 - 17.556X_3^2 \quad (4)$$

The statistical significance of ratio of mean square due to regression and mean square residual error was tested using ANOVA. ANOVA is a statistical technique that subdivides the total variation in a set of data into component parts associated with specific sources of variation for the purpose of testing hypotheses on the parameter of the model [9][10]. The effects are statistically significance when the 'P' value, defined as the smallest level of significance leading to ejection of null hypothesis, is less than 5%. The ANOVA result for efficiency of dye removal is shown in Table IV.

TABLE IV
ANOVA FOR EFFICIENCY OF COLOR REMOVAL

Source	Degree of Freedom	Sequential Sum of Square	Adjusted Sum of Square	Adjusted Mean of Squares	F	P
Regression	9	16465.9	16465.9	1829.55	12.43	0.006
Linear	3	13416.2	13416.2	4472.08	30.39	0.001
Square	3	2229.0	2229.0	742.99	5.05	0.057
Interaction	3	820.7	820.7	273.57	1.86	0.254
Residual Error	5	735.7	735.7	147.14		
Total	14	17201.6				

Optimization of adsorption was done for target value of 90% efficiency of dye removal using response optimization process. The speed (1150 rpm), initial dye concentration (200 mg/L) and adsorbent dosage (50 g/L) had been found to be optimum conditions for maximum 98.7% dye removal by using palm shell activated carbon.

IV. CONCLUSION

The current study of Reactive Red 3BS removal by palm shell activated carbon adsorption has shown that:

I. At optimal condition the efficiency of dye removal reached more than 90% and the capacity uptake is more than 7 mg/g.
II. As the increasing of adsorbent dosage and the speed, the efficiency of dye removal also increasing.
III. Higher regression coefficient (R-Sq = 93.9%) indicates that near about negligible of total variations were not explained by the model.

IV. Higher adjusted regression coefficient (R-Sq (Adj) = 90.8%) showed that a high significance of the model.

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