

## Adsorption of Congo Red Dye from Aqueous Solution using Kapok Hull Carbon

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### Abstract

A sorbent prepared from Kapok Hull by acid treatment was tested for its efficiency in removing Congo red dye. Batch mode experiments were conducted for initial dye concentration, agitation time, carbon dose and particle size at different temperatures. The adsorption process followed Lagergren first order rate equation. Both Langmuir and Freundlich isotherm models could describe the adsorption data. Intraparticle diffusion was found to be the rate-limiting step. It is confirmed by Box-Behnken model. The contour plot affirms that particle size is the main factor in the sorption phenomenon. The properties and morphology of activated carbon were determined by standard methods, XRD and SEM studies respectively. This study reveals that the activated carbon prepared from Kapok hull is suitable for the removal of Congo red dye from aqueous solution.

**Keywords:** Activated carbon, Adsorption, Particle Size, X-ray diffraction, Scanning Electron Microscope.

### Introduction

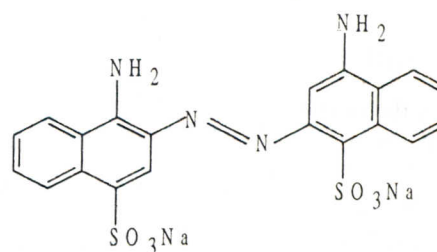
In water resource management, the concept of reuse, recycle and reduce (3R concept) has been very well conceived by process industries. The efforts in this direction need to be accelerated. Color waters are often objectionable on aesthetic grounds for potable needs, agricultural purposes and industrial needs. Color affects the nature of water by inhibiting sunlight penetration, thus reducing photosynthetic action. The conventional method for the removal of dyes using alum, ferric chloride, lime, etc. is not economical. Therefore, there is a considerable need to treat such dyes prior to discharge. Adsorption has been shown to be a good method of color contaminant removal. A further benefit is that adsorption can be very simple and offers sludge free operation. The low cost conventional adsorbent for the treatment of industrial wastewater had been reviewed<sup>1</sup>. Adsorbents used include agricultural solid wastes such as banana pith<sup>2</sup>, coir pith<sup>3</sup> and jackfruit peel<sup>4</sup>. Accumulation of Kapok hull waste in and around silk cotton processing

industries is a big problem and utilization of this material for carbon synthesis may give solution to solid waste management in silk cotton industry and in the removal of pollutants. The present study is envisaged by activated carbon prepared from Kapok hull for the removal of Congo red from aqueous solution which is most widely used in various textile-processing industries by varying parameters like contact time, dye concentration, carbon dose, pH and temperature.

### Material and Methods

The kapok hull was cut into small pieces, dried in sunlight, then at 60°C for 24 hours in hot air oven. The dried material is subjected for acid treatment (ratio 1:1) and kept at room temperature overnight. Then it was washed with doubled distilled water to remove the excess acid and kept in hot air oven at 110°C for 12 hours. Then it was taken in an iron vessel in muffle furnace and the temperature was gradually raised to 550°C for an hour, ground well by using ball mill and then sieved into particle size of 250, 150 and 100 BSS mesh numbers. The characterization of KHAC was carried out and the results are tabulated in table 1.

The structure of Congo red is as follows and the  $\lambda_{\max}$  is 497nm. It belongs to direct dye and water-soluble substantive dye. These dye solutions were taken for adsorption studies with KHAC.



Structure of Congo red

The adsorbent KHAC sieved particle size of 250BSS mesh number was magnified by Scanning Electron Microscope (SEM) studies by using JOEL JSM 8404 Scanning microscope as shown in the Fig.1. The X-ray Diffraction studies of KHAC were carried out using Rotoflux X-ray Diffractometer 20KW/20A, Model 10.61 with a



Microprocessor recorder. The XRD pattern of the KHAC is shown in the Fig.2. The morphological and XRD studies clearly revealed that the adsorbent is amorphous and highly porous in nature. From the SEM analysis it was found that there were holes and cave type openings on the surface of the adsorbent, which would have more surface area available for adsorption.

The Freundlich and Langmuir isotherm studies and Lagergran kinetic studies at ambient temperature, dye solution of various concentrations was agitated with 1g of the adsorbent of 250, 150 and 100BSS mesh number particle size over a period of time with constant stirring at constant pH (2.5). The carbon dosage of 100mg to 1500mg was agitated with a known concentration of dye solution.

## Results and Discussion

**Langmuir Adsorption Isotherm:** Langmuir represented the following equation:

$$q_e = (Q_0 \times b \times C_e) / (1 + (b \times C_e))$$

where,  $q_e$  is equal to the quantity of dye adsorbed in mg/g of the adsorbent,  $Q_0$  is the maximum quantity of dye adsorbed in mg/gram of the adsorbent,  $b$  and  $C_e$  are the constants of Langmuir adsorption and the dye concentration at equilibrium in mg/l respectively. Langmuir adsorption parameters are determined by transforming the equation, which is in linear form. The Linear plot of  $C_e/q_e$  Vs  $C_e$  showed that the adsorption followed Langmuir isotherm model. The values of monolayer capacity ' $Q_0$ ' and Langmuir constant ' $b$ ' have been evaluated from the intercept and slope of these plots by using graphical techniques.

The effect of isotherm shape has been taken into consideration with a view to predict whether the studied adsorption system is favorable or unfavorable. The essential features of the Langmuir isotherm may be expressed in terms of equilibrium parameter  $R_L$ , which is a dimensionless constant referred to as separation factor or equilibrium parameter<sup>5</sup>:

$$R_L = 1/(1 + bC_0)$$

where  $C_0$  is the initial concentration and ' $b$ ' is the constant related to the energy of adsorption (Langmuir constant). The values of  $R_L$  indicate the nature of the isotherm, if the conditions  $R_L > 1$ ,  $R_L = 1$ ,  $0 < R_L < 1$  and  $R_L = 0$  are unfavorable, linear, favorable and irreversible respectively. The value of  $R_L$  was less than one which showed that the adsorption process was favorable.

**Effect of Temperature:** The adsorption study was carried out for Congo red at various temperatures like 300, 318 and 330K. From this study it can be possible to evolve the fact about adsorption and pores volume. When the temperature increases, the pore volume increases up to 318K, it is revealed

that further increase in temperature does not alter the pore volume. It is supported from the adsorption data of the dye.

Further, the results were analyzed and found that the adsorption process was endothermic and best fitted to Langmuir adsorption isotherm model. By employing graphical and mathematical methodologies, the  $Q_0$ ,  $b$  and  $R_L$  values for different particle size for the dye were evolved and it was revealed that  $R_L$  values lie between 0 and 1. It was inferred that the adsorption process followed Langmuir model and is favorable for adsorption.

To decide the nature of adsorption phenomenon, the free energy change ( $\Delta G^\circ$ ), enthalpy change or total energy change ( $\Delta H^\circ$ ) and entropy change ( $\Delta S^\circ$ ) values were evolved from the following thermodynamic formulae:

$$\text{Free energy change, } \Delta G^\circ = -RT \ln b$$

Enthalpy change or total energy change ( $\Delta H^\circ$ ) can be calculated by using the thermodynamics formula:

$$\ln [b_1/b_2] = \Delta H^\circ / RT$$

The Gibbs free energy change is-

$$\Delta G^\circ = [\Delta H^\circ - \Delta S^\circ] / T$$

The results of  $\Delta G^\circ$ ,  $\Delta H^\circ$  and  $\Delta S^\circ$  are summarized in the table 5. The positive values of  $\Delta H^\circ$  indicate that the adsorption is involved with weak forces of attraction. It was observed that the  $\Delta H^\circ$  values increased with decrease of particle size. The adsorption was found to be endothermic in nature. The positive and increased  $\Delta S^\circ$  values for smaller particle size indicated that the KHAC showed greater affinity towards the dye. Further, the negative  $\Delta G^\circ$  value indicated the spontaneous nature of the adsorption model.

For unimolecular reactions, the energy of activation was evolved by using the following equation:

$$E_a = \Delta H^\circ + RT$$

If the energy of activation of adsorption system was less than 42KJ/mol, then the process was confirmed to be diffusion controlled or if fell above 42KJ/mol, the sorption process was due to chemisorptions, and if fell in between 5 to 20KJ/mol, the sorption process was due to activated sorption. The calculated value of the present investigation is between 5 to 20KJ/mol and it confirms that the sorption process was due to activated sorption. From above thermodynamic studies, the adsorption is found to be endothermic in nature ( $\Delta H^\circ$  increased with decrease of particle size), KHAC shows greater affinity towards the Congo red ( $\Delta S^\circ$  value is positive and increases for smaller particles), it is spontaneous in nature (negative  $\Delta S^\circ$  value), there is activated adsorption and it follows Langmuir adsorption isotherm. Similar pattern of results was inferred<sup>6</sup>.



**Freundlich Adsorption Isotherm:** The linear plot of  $\log X/m$  Vs  $\log C_e$  showed that the adsorption followed Freundlich adsorption isotherm model. The values of  $X/m$  and  $C_e$  observed from the adsorption experiments carried over by using KHAC of different particle sizes namely 100, 150 and 250BSS mesh numbers of constant mass by agitation with Congo red of known concentration at various temperatures to the respective equilibrium periods are presented in table 3. Based upon these experiments Freundlich adsorption isotherm plot was formed by plotting  $\log X/m$  Vs  $\log C_e$  and the slope and intercept of this linear portion of isotherm plots were determined by adopting graphical methodology. These slope values had indicated adsorption intensity 'n' and the intercept values indicated an idea about adsorption capacity  $K_F$ . These values are tabulated in table 4. It was observed that the adsorption capacity of the KHAC had increased with decrease of particle size at 300, 318K of the dye selected for the present study and there is no change for adsorption at the elevated temperatures namely 330K.

The surface energy  $q_e$  is a function of heat for adsorption. The term  $K_F$  and  $n$  are adsorption constants and are used to explain adsorption process<sup>7</sup>. The Freundlich adsorption isotherm is as follows:

$$q_e = X/m = K_F C_e^{1/n}; \ln X/m = \ln q_e = \ln K_F + 1/n \ln C_e;$$

where  $q_e$ ,  $C_e$ ,  $X$  and  $M$  are adsorbed amount on the adsorbent at equilibrium, equilibrium concentration of dye in solution (mg/l), amount of dye adsorbed (mg) and weight of the adsorbent used (g). The constant  $K_F$  represents the quantity of dye adsorbed in mg/g adsorbent for a unit equilibrium concentration, which is an approximate indicator of adsorption capacity. These constants can be evolved by linearising the above equation by adopting mathematical techniques.

The  $1/n$  is a measure of adsorption intensity. If  $n=1$ , then that the partition between the two phases was independent of the concentration. If the  $1/n$  value is below one, it indicates a normal adsorption. On the other hand  $1/n$  being above one, indicates cooperative adsorption<sup>8</sup>. It is generally stated that the value of 'n' in the range of 2 to 10 represents good adsorption isotherm. It was also observed that the 'n' values of the adsorbent for the dye at various temperature and particle sizes were found out and this value is from 2 to 10 which confirmed that the activated carbon underwent a favorable for Freundlich isotherm. The experimental data fitted well into Freundlich adsorption isotherms. Thus the system followed Freundlich adsorption isotherm model and the adsorbent's surface under study were heterogeneous. The correlation coefficient was evolved with graphical techniques and it was tabulated in table 4.

These values exhibited some deviation from linearity and tried to form curves. It was clearly indicated in

the graphs under observations. The reason for this behavior was that the initial curve portion represented the formation of monolayer followed by intraparticle diffusion at later stages and final plateau portion indicate the saturation of adsorption process. It was summarized that the KHAC followed Freundlich adsorption isotherm model, the derived 'n' value for almost all dyes being in the value from 1 to 10. The graphical studies showed that the mechanism of adsorption followed the formation of monolayer, intraparticle diffusion and saturation in a favorable pattern.

**Kinetics of Adsorption:** The adsorption kinetic study is quite significant in wastewater treatment as it describes the solute uptake rate which in turn controls the residence time of adsorbate uptake at the solid-solution interface. Dosage study is an important parameter because it determines the capacity of adsorbent for a given initial concentration of the dye solution. In this present investigation, the kinetics of the adsorption systems were studied by plotting the amount of dye adsorbed on the adsorbent with time for different adsorbent dosages at a constant initial concentration (100 mg/l) at different temperatures and particle size 250, 150, 100 BSS mesh numbers. In all the experiments, it was observed that with increase in adsorbent loading, the fraction of dye removal increases and it was graphically plotted. From the nature of the curves, the amount of dye adsorbed on the adsorbent more or less remained constant. Moreover, the smoothness of the curves for dye adsorption showed that the process of adsorption was continuous and involved either monolayer formation on the adsorbent surface or monolayer coupled with other mechanism predominantly with intra particle diffusion. Since the increase in active adsorption sites increased with adsorbent dosage, the amount of dye adsorbed increased with sorbent dosage. The large availability of adsorption sites with higher adsorption dosage has a positive effect on the initial rate of dye uptake. Similar type of trends in adsorption of dyes on different types of low cost adsorbents was reported<sup>9</sup>.

**Adsorption rate constant:** Determination of efficiency of adsorption process requires a thorough understanding of kinetics of uptake of adsorbate by adsorbent or the time dependence of the concentration distribution of the solute in both bulk solution and solid adsorbent and identification of rate determining step.

In order to investigate the mechanism of sorption and potential rate controlling steps such as mass transport and chemical reaction processes, the Lagergren kinetic model (Fig.4) known as pseudo-first order equation, has been used to test the experimental data.

**Pseudo – First order Equation:** The pseudo-first order equation of Lagergren is generally expressed as follows:

$$dq / dt = K_{ad} (q_e - q_t)$$



where  $q_e$  and  $q_t$  are the sorption capacity at equilibrium and sorption capacity at time  $t$  and  $K_{ad}$  is the rate constant of pseudo – first order sorption (1/min). After integration and applying boundary condition  $t = 0$  to  $t = t$  and  $q = 0$  to  $q = q_t$ , the integrated form becomes:

$$\log (q_e - q_t) = \log q_e - [K_{ad} / 2.303] t.$$

Data for Lagergren plots of dyes were presented in Fig. 4. The linear plots of  $\log (q_e - q_t)$  Vs  $t$  showed that adsorption followed the pseudo first order rate expression given by Lagergren. The  $K_{ad}$  value for Congo red was calculated from the slope of linear plots. The rate constants for adsorption (1/min) of dye at ambient temperature of different particle size are presented in the Figures. From these observations, the KHAC follows Lagergren pseudo first order kinetics.

### Diffusion Studies

**Pore Diffusion Coefficient ( $D_p$ ):** The pore diffusion coefficient values fall between  $10^{-11}$  to  $10^{-13}$  and the process is said to be controlled due to intraparticle diffusion coefficient<sup>3</sup>. Similarly, if the external diffusion coefficient value falls between  $10^{-5}$  to  $10^{-8}$ , then the process is said to follow external mass transfer. The geometry of the adsorbent particles is spherical in nature based upon the Helfferich assumption. The studies of Webber prove that the adsorption kinetics with pore diffusion coefficient are inter related and the rate determining step is based upon pore diffusion coefficient<sup>6</sup>.

$$\text{Pore Diffusion Coefficient } D_p = 0.03 (r_0^2) / t_{1/2}$$

where,  $t_{1/2}$  - Time for half-change (mins);  $r_0$  - Radius of adsorbent (cm).

The values of pore diffusion coefficients were calculated on the particles size for the dye and these inferences were compared with the results and it was inferred that pore diffusion was not the rate-limiting step. Based upon different ideas available in literature, it is possible to determine the nature of adsorption process with reference to the pore diffusion coefficient. If the values fall between  $10^{-11}$  to  $10^{-13}$  (cm<sup>2</sup>/sec) then the process is said to be controlled due to intraparticle diffusion coefficient<sup>3</sup>, but the dye system under the study showed the value within the limit ( $10^{-11}$  cm<sup>2</sup>/sec). It confirms that the process is controlled due to intraparticle diffusion. These values are presented in the table 3.

**Intra-particle Diffusion ( $q$ ):** The intraparticle diffusion rate constant can be given as follows:

$$q = K_p T^{1/2}$$

$K_p$  values for the adsorption of the dye are presented in the table 3. The rate constant for intraparticle diffusion  $K_p$  was calculated from the slope of the linear equation by  $q$  (mg/g)

Vs  $T^{1/2}$  (sec).

From the plots it was found that the initial sharp portion with subsequent linearity indicated that more than one mode of sorption mechanism was in operation. The first sharp portion may be due to external surface adsorption stage for instantaneous adsorption. The second gradual linear portion may be due to gradual intraparticle diffusion stage. The third linear may be due to final equilibrium stage<sup>9</sup>. The values of  $K_p$  generally increased with the increase in dye concentration and it can be related to concentration diffusion.

**Initial adsorption coefficient ( $\gamma$ ):** The initial adsorption coefficient equation can be given as:

$$\gamma = (dC / dt) t_0 \times V / M C_0$$

where  $dC$ ,  $dt$ ,  $V$ ,  $M$ , and  $C_0$  are concentration at equilibrium time, equilibrium time, volume of solution, mass of carbon and initial dye concentration (mg/l) respectively.

The values for the adsorption coefficient of the dyes are presented in the table 3. The initial adsorption coefficients increased with increase in initial dye concentration and therefore it is concentration dependent. From the results, an overall examination of effect of dye concentration on rate constant  $K_{ad}$  describes the mechanism of adsorption taking place. In the cases of strict surface adsorption, a variation of rate should be proportional to the concentration. The relationship between initial solute concentration and the rate of adsorption was not linear. This was due to the limitation caused by pore diffusion of the adsorption. It is clearly indicated in the Table 3. It was concluded that pore diffusion also limited the overall rate of adsorption.

**Box-Behnken Model:** Response surface methodology is an empirical modelization technique devoted to the evaluation of the relationship of a set of controlled experimental factors and observed results (table 6). In the present investigation the adsorption of Congo red by KHAC from aqueous solution is optimized by Box-Behnken method. The influence of the three factors such as temperature, pH and adsorbent particle size on adsorption was investigated and the results found for the linear coefficients and quadratic cross product coefficients  $A_0$ ,  $A_1$ ,  $A_2$ ,  $A_3$ ,  $A_{11}$ ,  $A_{22}$ ,  $A_{33}$ ,  $A_{12}$ ,  $A_{13}$  and  $A_{23}$  were 359.17, 5.167, -31.833, -64.333, -19.833, 14.167, 27.167, -5.000, 30.00 and -8.00 respectively. The summary of the analysis of variance (ANOVA) is listed in table 7.

From the table 7, it was found that quadratic regression and quadratic square regression are significant at the confidence level of >98%. This indicates that the selected variance (Temperature, pH and particle size) have a combined effect on the adsorption of Congo red by KHAC. The theoretical values of dye adsorption on adsorbents by the Box-Behnken model at each experimental point and experimentally observed values were compared and found



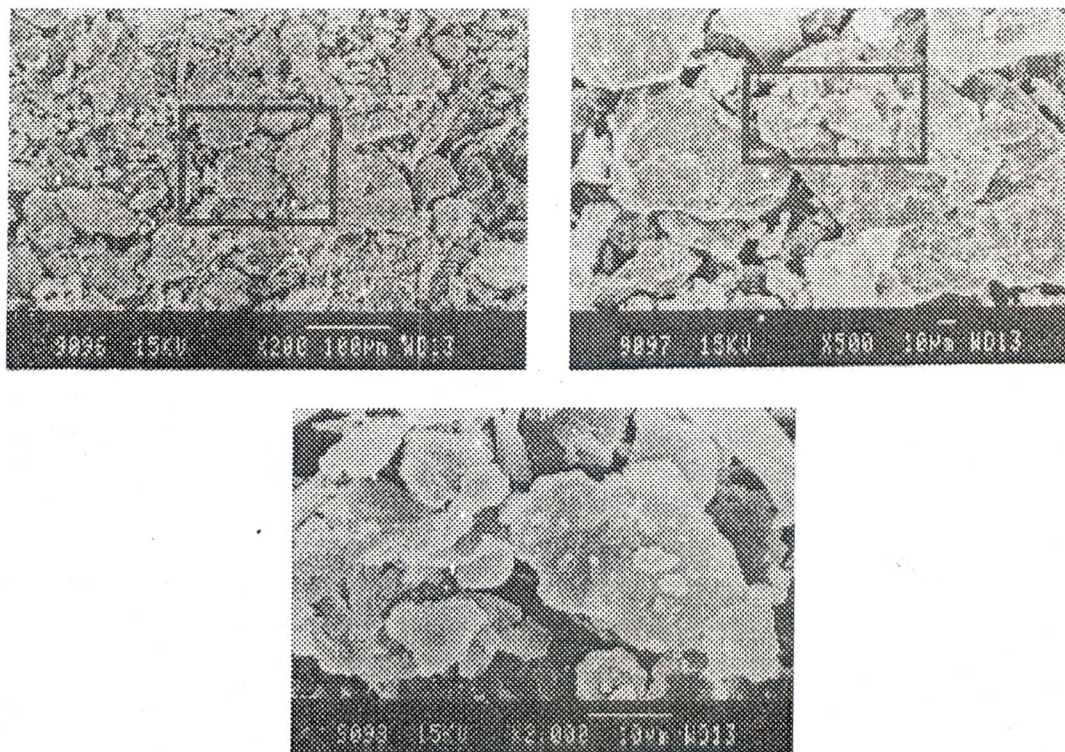


Fig. 1: SEM photograph of Kapok Hull Activated Carbon (KHAC) at various magnifications (x200, x500 and x2000)

Table I  
Characteristic of KHAC

S.No	Parameters	Obtained Result
1.	pH solution	6.7
2.	Moisture content (%)	2.4
3.	Ash content (%)	1.856
4.	Decolorizing power (mg/g)	22.5
5.	Ion-exchange capacity (milliequi/g)	0.0415
6.	Surface area (m <sup>2</sup> /g)	158-228
7.	Apparent Density (g/l)	0.42
8.	Particle size (μm)	125
9.	Volatile matter (%)	12.0
10.	Fixed carbon (%)	86.0
11.	Calcium (%)	16.0
12.	Sodium (mg/g)	7.0
13.	Potassium (mg/g)	13.0
14.	Water soluble matter (%)	2.0
15.	HCl soluble matter (0.25N) (%)	7.0
16.	Phenol number, mg	11.2

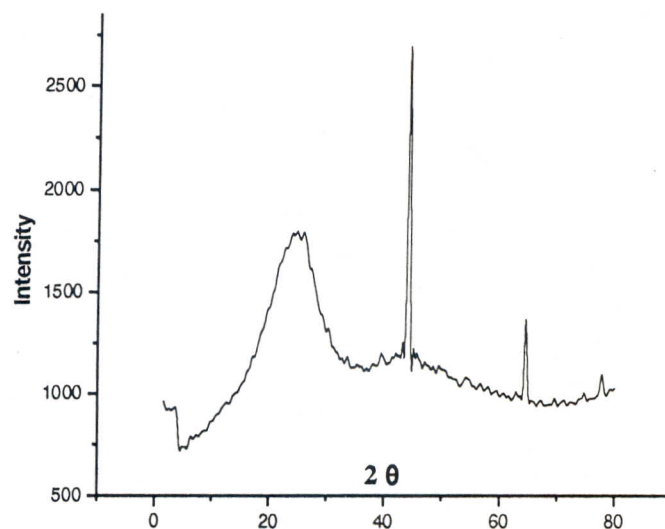


Fig. 2 X-ray Diffraction pattern for KHAC

that a close agreement exists between the experimental values and the theoretical values for 15 trials. The experimental values are 371.4, 391.5, 318.2, 318.6, 451.1, 401.9, 264.3, 333.9, 483.7, 436.6, 372.2, 293.3, 355.6 355.6 and 355.6. The predicted values are 375.2, 395.5, 321.5, 321.8, 455.7, 406, 267, 337.3, 488.6, 441, 376, 296.3, 359.2, 359.2 and 359.2.

**Effect of Contour Plot:** The effect of variables was analyzed



and plots were obtained to assess the effect of each factor graphically. The effect of certain factors is function that describes how the response moves as the level of those factor changes, when the other factors are fixed at their optimum levels. From the Fig.5, it can be observed that each of the three variables used in the present study has its individual effect on adsorption. From the contour plots, it has been found that there is a gradual increase in adsorption of dyes with increase in temperature from the lower level 300K (Coded value -1) to the middle level 318K (Coded value -0) and there is no further increase to adsorption even if the temperature is increased to 330K (Coded value +1). Similarly, the adsorption increases with respect to the particle size of KHAC from 100, 150 and 250BSS mesh numbers (Coded value -1, 0 and +1). It is also revealed that the Congo red dye would have no marked change to adsorption with respect to pH change. The pH level selected for this study

was 4, 6.7 and 9 (coded value -1, 0, +1).

The results obtained by adapting Box-Behnken model in the study of absorption of various dyes on KHAC prove that absorption of dye depends only upon the particle size of absorbent and it was not influenced by pH or temperature. The experimental values and the predicted values of Box-Behnken design model are in close agreement with quadratic regression >98%.

From the contour plots Fig.5, it is revealed that the carbon particle of 250BSS mesh number has highest level of absorption<sup>10</sup>.

### Conclusion

Carbon prepared from waste Kapok hull was found to be cost effective in removing Congo red dye from aqueous solution. The adsorption is faster and the rate is mainly

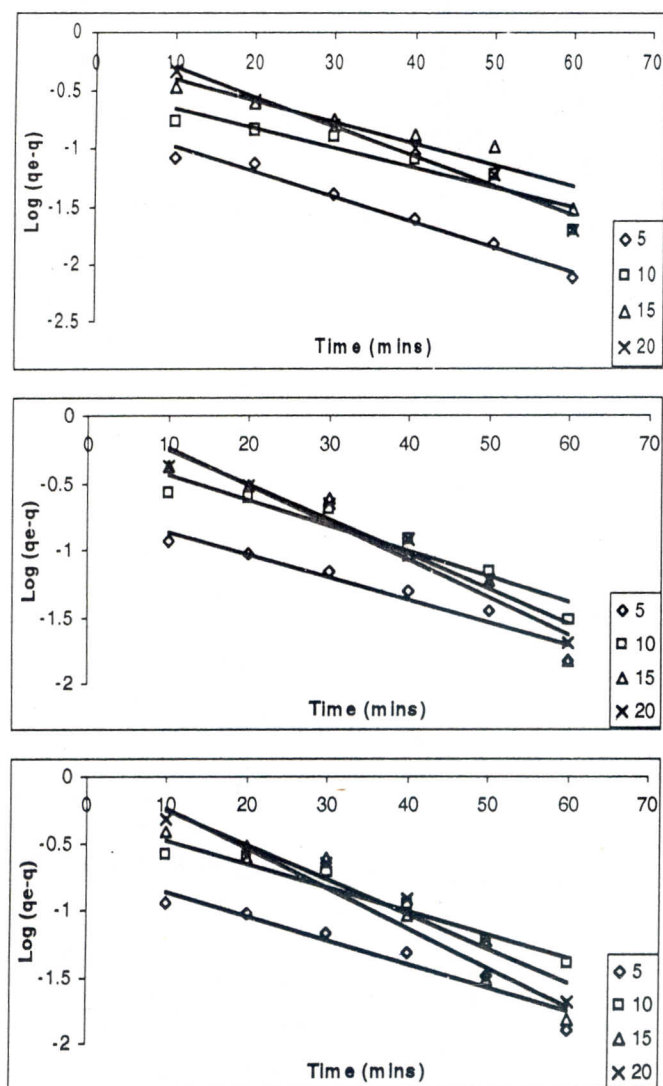


Fig. 3: Lagergren plot for Congo red removal of (a) 100 (b) 150 (c) 250BSS particle size at 300K

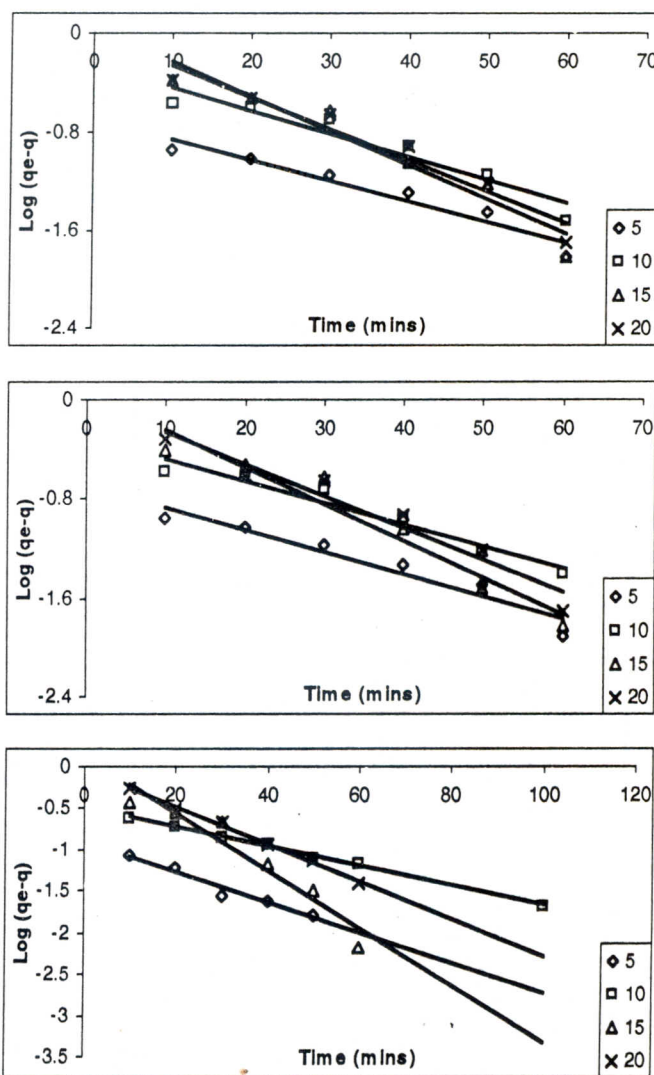


Fig. 4: Lagergren plot for Congo red removal of (a) 100 (b) 150 (c) 250BSS particle size at 318K

controlled by intraparticle diffusion. The surface morphology studies using SEM proves that, it contains more pores that leads to develop more adsorption sites. The XRD pattern confirms the amorphous nature of the adsorbent.

The % removal for the dye decreased with increase of pH. The adsorption of Congo red dye on KHAC does not involve ion exchange mechanism. It is supported by the fact that  $\Delta H^\circ$  values obtained is in between 5–20KJ therefore it is an activated adsorption, which indicates irreversible

adsorption probably due to non-polar interactions. It is evident from the studies that the use of chemically modified Kapok hull activated carbon for the removal of Congo red dye is technically feasible.

KHAC is eco-friendly and it can be proposed to use for the treatment of dye house wastewater before subjecting it for reverse osmosis process, thereby it increases the life expectancy of valuable resins.

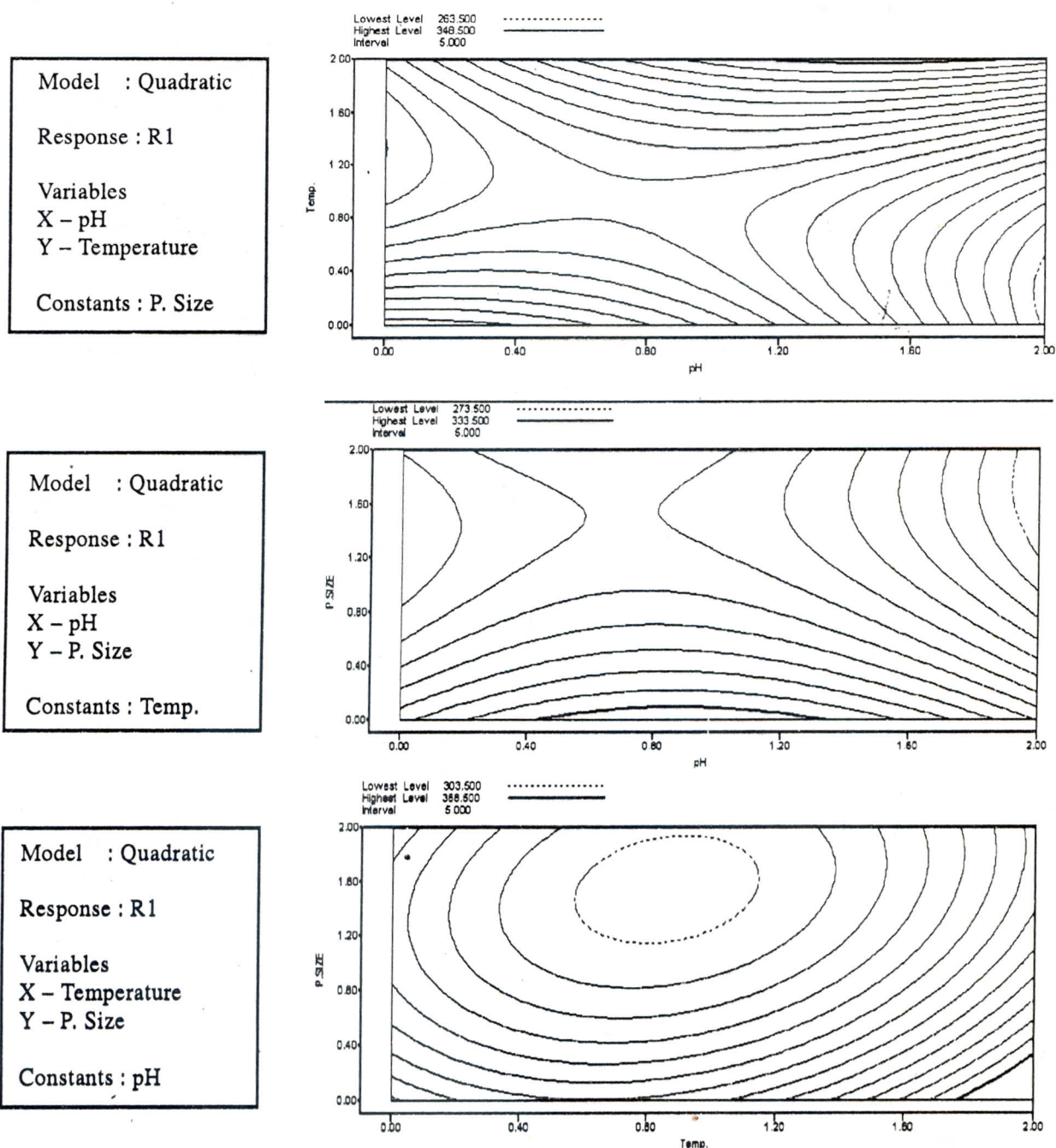


Fig.5: Response surface plot for the adsorption of Congo red



**Table II**  
Effect of adsorbent dosage and particle size on the removal of Congo red (100mg/l) at 300K

Carbon dose	% Removal			Log (X/M)			Log Ce		
	250	150	100	250	150	100	250	150	100
100	17	18	18	-2.77	-2.745	-2.745	-0.081	-0.086	-0.086
200	19	21	20	-3.022	-2.979	-3	-0.092	-0.102	-0.097
300	25	22	22	-3.079	-3.135	-3.135	-0.125	-0.108	-0.108
400	30	30	25	-3.125	-3.125	-3.204	-0.155	-0.155	-0.125
500	33	33	30	-3.18	-3.18	-3.222	-0.174	-0.174	-0.155
600	38	37	34	-3.198	-3.21	-3.247	-0.208	-0.201	-0.18
700	43	46	40	-3.212	-3.182	-3.243	-0.244	-0.268	-0.222
800	49	50	44	-3.213	-3.204	-3.26	-0.292	-0.301	-0.252
900	53	52	50	-3.23	-3.238	-3.255	-0.328	-0.319	-0.301
1000	56	56	52	-3.252	-3.252	-3.284	-0.357	-0.357	-0.319
1100	66	66	62	-3.26	-3.222	-3.249	-0.4685	-0.4685	-0.4202
1200	76	77	71	-3.233	-3.193	-3.228	-0.6198	-0.6383	-0.5376
1300	86	87	81	-3.212	-3.174	-3.205	-0.8538	-0.8861	-0.7212
1400	94	97	90	-3.203	-3.159	-3.192	-1.2219	-1.5229	-1
1500	100	100	100	-3.176	-3.176	-3.176	-	-	-

**Table III**  
Adsorption kinetic data for dye removal with various particle sizes, equilibrium time for 120mins at 300K

Particle Size (BSS mesh No.)	Dye conc. (mg/100ml)	$q_e$	$\gamma \times 10^{-5}$	$K_{ad}$	$K_p$	$D_p \times 10^{-10}$
100	5	0.45	9.00	0.0216	0.033	0.164
	10	0.83	8.30	0.0173	0.074	
	15	1.29	8.60	0.0188	0.097	
	20	1.66	8.30	0.0255	0.102	
150	5	0.48	9.60	0.017	0.035	0.109
	10	0.92	9.20	0.019	0.066	
	15	1.35	9.00	0.028	0.098	
	20	1.70	8.50	0.026	0.135	
200	5	0.48	9.6	0.018	0.036	2.58
	10	0.93	9.3	0.018	0.067	
	15	1.38	9.2	0.030	0.105	
	20	1.74	8.7	0.026	0.138	

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**Table IV**  
Freundlich constants for the adsorption of Congo red  
at various particle sizes at 300K

Particle Size (BSS Mesh)	$n \times 10$	$K_F \times 10$	$R^2$
250	1.1105	2.8464	0.6646
150	1.2122	2.8263	0.6487
100	1.2596	2.8652	0.7544

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**Table V**  
Langmuir constants and thermodynamic parameters for Congo red adsorption  
with different temperatures and particle size

Particle Size	Temp K	Slope	Intercept	B (l/mg)	$Q_s \times 10^2$ (mg/g)	$R_L$	$\Delta H^\circ$	$\Delta G^\circ$	$\Delta S^\circ$
100	300	2.1234	0.0823	25.800	0.4700	0.0860	676	-41.79	39.87
	318	2.4255	0.1002	24.206	0.4122	0.0761			
150	300	2.1234	0.0823	25.800	0.4090	0.0860	8104	-601	483.61
	318	4.3259	0.0786	55.420	0.2312	0.0441			
250	300	2.4255	0.1002	24.206	0.4122	0.0761	15120.8	-896.8	896.77
	318	1.8446	0.0183	100.79	0.5421	0.0978			

**Table VI**  
Box-Behnken design for three independent variables

Trial No.	pH	Particle Size (BSS Mesh No.)	Temperature (K)
1.	-1	-1	0
2.	+1	-1	0
3.	-1	+1	0
4.	+1	+1	0
5.	-1	0	-1
6.	+1	0	-1
7.	-1	0	+1
8.	+1	0	+1
9.	0	-1	-1
10.	0	+1	-1
11.	0	-1	+1
12.	0	+1	+1
13.	0	0	0
14.	0	0	0
15.	0	0	0

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**Table VII**  
ANOVA for Box-Behnken Model  
for the adsorption of Congo red

Source	Sum of Squares	Degrees of Freedom	Mean Square	F value
Model	4052	6	675.33	5.089
Error	1062.2	8	132.7	
Cor. Total	4214.2	14	R-Squared	0.952
Root MSE	11.55		Adj R-Squared	0.927
C.V	0.118			

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(Received 1st June 2006, accepted 25th July, 2006).