STUDIES ON BIOSORPTION OF *RICINUS COMMUNIS* POWDER FOR THE REMOVAL OF CONGO RED DYE

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Abstract: The present investigation is on the removal of Congo red dye from aqueous solutions using Ricinus Communis leaf powder as a biosorbent. The cumulative effects of operating parameters such as biosorbent size, dye concentration, pH of the solution, biosorbent dosage and temperature on the dye biosorption were analyzed using Response Surface Methodology (RSM). For obtaining the mutual interaction between the variables and optimizing these variables a Central Composite Design was utilized. According to ANOVA results, the proposed model for CCD was in suitable accordance with the experimental data. Characterization studies comprising of Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM) analysis was performed to verify the investigation. Experimentally the optimal set of conditions for maximum percentage biosorption of congo red dye is found to be at biosorbent size= 53 µm, pH= 3, biosorption dosage (w) = 30 g/L, initial dye concentration (C_0) = 20 mg/L and temperature=303 K and the biosorption calculated at these values was found to be 89%. The Freundlich isotherm fitted well with a correlation factor followed by Langmuir and Temkin. The entire biosorption process followed pseudo second order kinetics. By applying the Van't Hoff equation the thermodynamic parameters such as enthalpy (ΔH), entropy (ΔS) and free energy (ΔG) were evaluated which described the biosorption process as spontaneous, irreversible and endothermic in nature. The optimized values obtained through central composite design and one factor at a time process is in good agreement.

Index Terms **– Biosorption, Dye, Adsorption, RSM, FTIR, SEM.**

I. INTRODUCTION

Water, which is one of the abundant compounds found in nature, covers approximately three-fourths of the surface of the earth. Over 97% of the total quantity of water is in the oceans and other saline bodies of water and is not readily available for our use. Over 2% is tied up in polar ice caps and glaciers and in atmosphere and as soil moisture. As an essential element for domestic, industrial and agricultural activities, only 0.62% of water found in fresh water lakes, rivers and groundwater supplies, which is irregularly and non-uniformly distributed over the vast area of the globe, is accessible **[1]**. The population explosion and expansion of urban areas have had an increased adverse impact on water resources, particularly in regions in which natural resources are still limited. Currently, water use or reuse is a major concern which needs a solution. Population growth leads to a significant increase in default volumes of wastewater, which makes it an urgent imperative to develop effective and low-cost technologies for wastewater treatment **[2]**. Especially in the textile industry, effluents contain large amounts of dye chemicals which may cause severe water pollution. Also, organic dyes are commonly used in a wide range of industrial applications. Therefore, it is very important to reduce the dye concentration of wastewater before discharging it into the environment. Discharging large amounts of dyes into water resources, organics, bleaches, and salts, can affect the physical and chemical properties of fresh water. Dyes in wastewater that can obstruct light penetration and are highly visible, are stable to light irradiation and heat and also toxic to microorganisms. The removal of dyes is a very complex process due to their structure and synthetic origins **[3]**. Biosorption is a process that uses inexpensive biomaterials to sequester metals from aqueous solutions and the biomaterials used in this process are termed as biosorbents. The by-products from agriculture, food and pharmaceutical industries provide economically viable sources of biosorbents. This makes biosorption an inexpensive alternative treatment method. Recent research on biosorption has shown that biomaterials containing acidic groups such as hydroxyls and carboxyl's were effective in binding metal cations **[4]**. Other biomaterials containing weak basic groups such as amides and amines are efficient for adsorbing metal anions **[5]**. There are three major factors affecting metal Biosorption behavior **[6]**. The first aspect is related to the characteristics of the biosorbent such as surface area, porosity and the number of functional groups. The second factor is related to the characteristics of dyes that are being adsorbed. The third aspect involves the operational conditions such as solution pH, ionic strength and interference of other ions. Temperature is not considered as a major factor because biosorption is usually carried out at room temperature to avoid biomass damage and reduce the process cost. The term biosorption commonly refers to the passive binding of metal ions or radioactive elements by dead biomass. The focus in early studies has been exclusively on the toxicological aspects of biosorption. Recently efforts are being made to harness this phenomenon into a technique for the detoxification of metal bearing industrial effluents by removing or eventually also recovering the metals **[7]**. The Biosorption process involves a solid phase (sorbent or biosorbent; biological material) and a liquid phase (solvent, normally water) containing a dissolved species to be sorbed (sorbate, metal ions). Due to higher affinity of the sorbent for the sorbate species, the latter is attracted and bound there by different mechanisms. The process continues till equilibrium is established between the amount of solid-bound sorbate species and its portion remaining in the solution. The degree of sorbent affinity for the sorbate determines its distribution between the solid and liquid phases **[8]**.

II. EXPERIMENTAL PROCEDURE

II.1. Reagents and Materials:
All the chemicals used in this investigation were of analytical grade and used without further purification. Congo red dye stock solution of 1000 mg/L was prepared by dissolving 1 g of the dye in 1000 ml of distilled water and later adjusted to various concentrations. The pH of dye solution was adjusted to the desired value by addition of 0.1M HCL and 0.1M NaOH.
II.2. Preparation of the biosorbent:
Ricinus Communis leaves are dried till the pigmentation completely disappears and the leaves are crisp. These dried leaves are then finely powdered and sized by passing through a set of sieves ranging from 152 to 53 mesh sizes.
II.3. Preparation of Congo red dye solution:
Congo red dye stock solution of 1000 mg/L is prepared by dissolving 1 g of congo red dye in 1000 ml of distilled water. All the required solutions are prepared with analytical reagents and distilled water. Synthetic samples of different concentrations of the dye are prepared from this stock solution by appropriate dilutions. 20 mg/L stock solution is prepared by diluting 20 mL of 1000 ppm stock solution with distilled water in 1000 mL volumetric flask up to the mark. Similarly solutions with different dye concentrations such as (40, 80, 120 and 160 mg/L) are prepared. The pH of aqueous solution is adjusted to the desired value by addition of 0.1M HCL and 0.1M NaOH.
II.4. Studies on equilibrium biosorption process:
Evaluation of the effects of various parameters like: Agitation time, sorbent size, pH, initial concentration, biosorbent dosage and temperature of the aqueous, which include characterization (FTIR, SEM), Isotherms (Langmuir, Freundlich, Temkin), Kinetics (Lagergren first order, Pseudo second order), Thermodynamics (Entropy, Enthalpy and Gibb's Free Energy) and Optimization through Response surface methodology are investigated to understand the biosorption process and arrive at a conclusion.

III. RESULTS AND DISCUSSION

The effects of various parameters on biosorption of congo red dye are studied. The measured data consists of initial and final concentration of congo red dye, agitation time, biosorbent size, biosorbent dosage, pH of the aqueous solution and temperature of the aqueous solution. The experimental data are obtained by conducting batch experiments. These are followed by Response Surface Methodology studies involving Central Composite Design and Characterization studies comprising of FTIR and SEM.

III.1. Effect of agitation time:

Duration of equilibrium biosorption is defined as the time required for dye concentration to reach a constant value during biosorption. The equilibrium agitation time is determined by plotting the % biosorption of congo red dye against agitation time as shown fig. 5.1 for the interaction time intervals between 1 to 180 min. For 53 µm size of 10 g/L biosorbent dosage, 30.0 % of dye is biosorbed in the first 5 min. The % biosorption is increased briskly up to 50 min reaching 69%. Beyond 50 min, the % biosorption is constant indicating the attainment of equilibrium conditions. The maximum biosorption of 69 % is attained for 50 min of agitation time with 10 g/L of 53 µm size biosorbent mixed in 50 mL of aqueous solution (C_0 = 20 mg/L). The rate of biosorption is fast in the initial stages because adequate surface area of the biosorbent is available for the biosorption of congo red dye. As time increases, more amount of congo red dye gets biosorbed onto the surface of the biosorbent due to vanderwaal forces of attraction and resulted in decrease of available surface area, when this monomolecular layer covers the surface the biosorbent capacity is exhausted **[9, 10]**. The maximum percentage of biosorption is attained at 50 minutes. The percentage biosorption of congo red dye becomes constant after 50 min. Therefore, all other experiments are conducted at this agitation time.

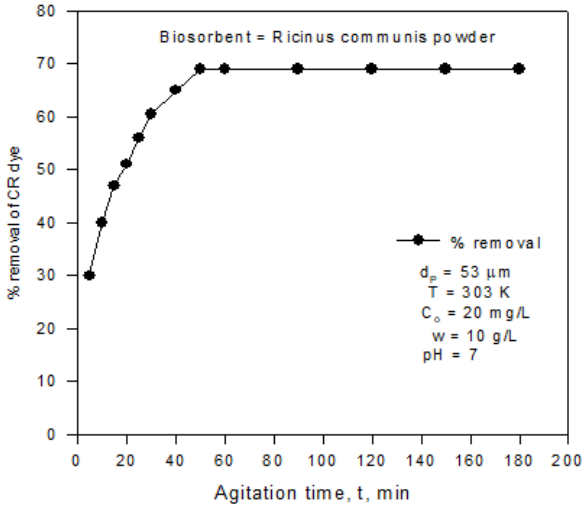


Fig. 1. Effect of Contact time on %removal of congo red dye

III.2. Effect of biosorbent size:

The variations in % biosorption of congo red dye from the aqueous solution with biosorbent size are obtained. The results are drawn in fig.2 with percentage biosorption of congo red dye as a function of biosorbent size. The percentage biosorption is increased from 49.0 % to 69.0 % as the biosorbent size decreases from 152 to 53 µm. This phenomenon is expected, as the size of the particle decreases, surface area of the biosorbent increases; thereby the number of active sites on the biosorbent also increases.

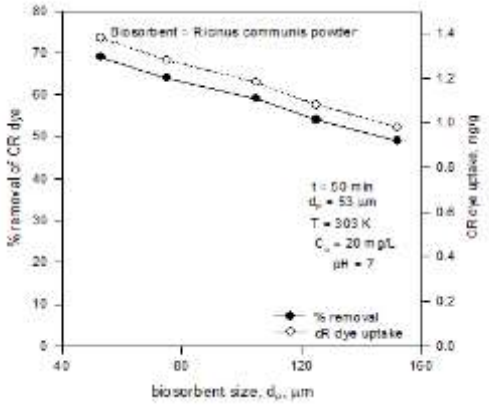


Fig. 2. % Biosorption of congo red dye as a function of biosorbent size

III.3. Effect of pH:

pH controls biosorption by influencing the surface change of the biosorbent, the degree of ionization and the species of biosorbate. In the present investigation, congo red dye biosorption data are obtained in the pH range of 2 to 8 of the aqueous solution (C_0 = 20 mg/L) using 10 g/L of 53 µm size biosorbent. The effect of pH of aqueous solution on % biosorption of congo red dye is shown in Fig.3. The % biosorption of congo red dye is increased from 72.0 % to 80.0 % as pH is increased from 2 to 3 and decreased beyond the pH value of 3. % biosorption is decreased from pH 4 to 8 reaching 65.0 % from 77.0 %. Low pH depresses biosorption due to competition with H+ ions for appropriate sites on the biosorbent surface. However, with increasing pH, this competition weakens and Congo red dye ions replace H+ ions bound to the biosorbent **[11, 12]**.

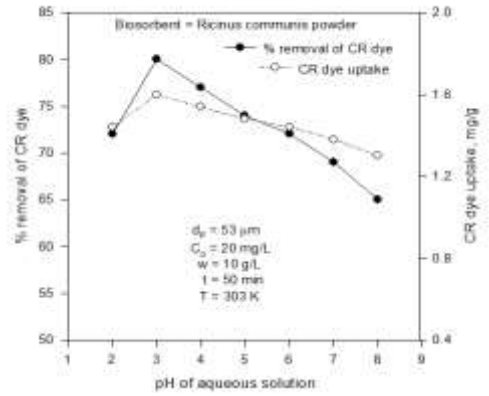


Fig. 3. Observation of pH along with % biosorption of congo red dye

III.4. Effect of initial concentration of congo red dye:

The effect of initial concentration of congo red dye in the aqueous solution on the percentage biosorption of congo red dye is shown in fig.4. The percentage biosorption of congo red dye is decreased from 80.0 % to 60 % with an increase in C_0 from 20 mg/L to 200 mg/L. Such behavior can be attributed to the increase in the amount of biosorbate to the unchanging number of available active sites on the biosorbent **[13]**.

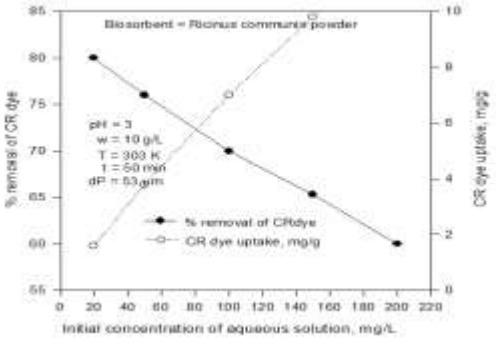


Fig. 4. Variation of initial concentration with % biosorption of congo red dye

III.5. Effect of biosorbent dosage:

The percentage biosorption of congo red dye is drawn against biosorbent dosage for 53 µm size biosorbent in fig.5. The biosorption of congo red dye increased from 80.0% to 92.0% with an increase in biosorbent dosage from 10 g/L to 80 g/L. Such behavior is obvious because with an increase in biosorbent dosage, the number of active sites available for congo red dye biosorption would be more.

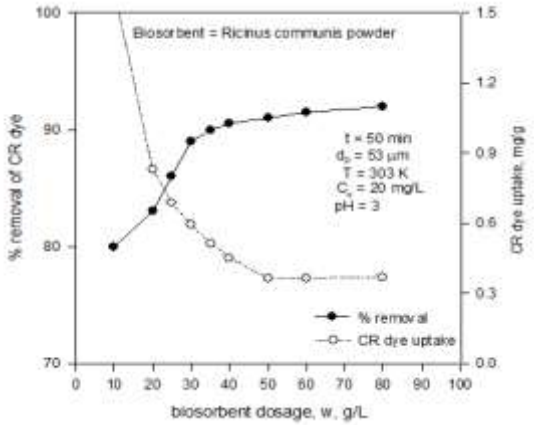


Fig. 5. Dependency of % biosorption of congo red dye on biosorbent dosage

III.6. Effect of Temperature:

The effect of changes in the temperature on the congo red dye uptake is shown in Fig.6. In the current investigation 303K is chosen as the optimum value since there is only a marginal increase in dye uptake with rise in temperature from 303 to 323K.

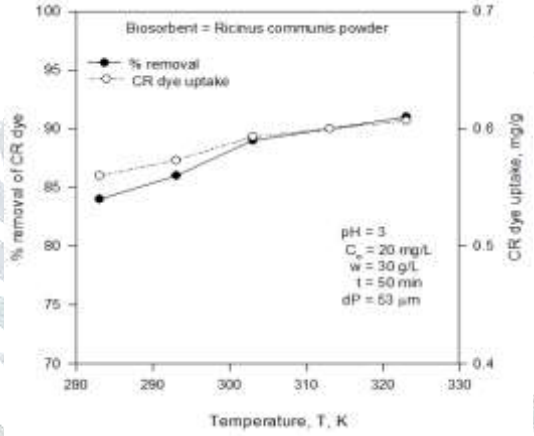


Fig. 6. Effect of temperature on % biosorption of congo red dye

III.7. Equilibrium isotherm models:

Langmuir isotherm is drawn for the present data and shown in Fig.5.7. The equation obtained 'n' $C_e/q_e = 0.05369\ C_e + 2.4170$ with a good linearity (correlation coefficient, R^2~0.99193) indicating strong binding of congo red dye ions to the surface of *Ricinus Communis* powder.

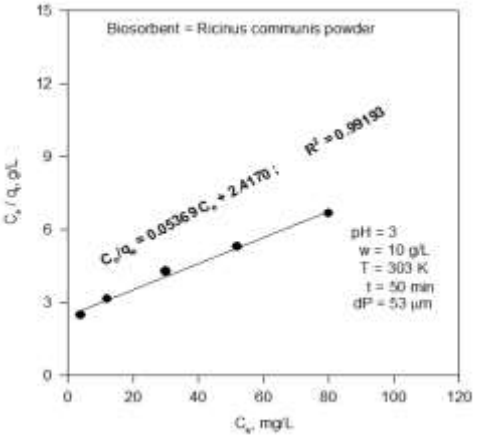


Fig. 7. Langmuir isotherm for % biosorption

Freundlich isotherm is drawn between log q_e = 0.67709ln C_e - 0.4096; ln C_e and ln q_e in Fig.8. The resulting equation has a correlation coefficient of 0.99412.

The 'n' value in the above equations satisfies the condition of 0<n<1 indicating favorable biosorption.

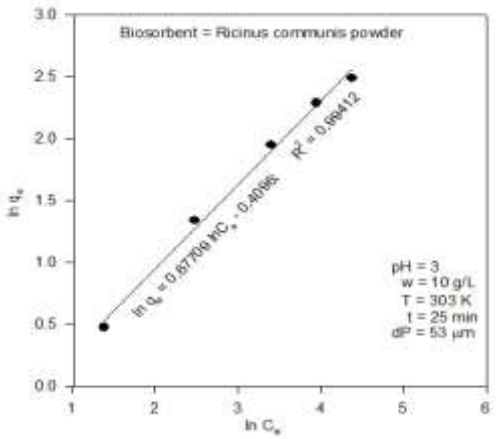


Fig. 8. Freundlich isotherm for % biosorption

The equation obtained for congo red dye biosorption is: q_e = 3.4707 ln C_e – 3.9928 with a correlation coefficient of 0.96419. The best fit model is determined based on the linear regression correlation coefficient (R^2).

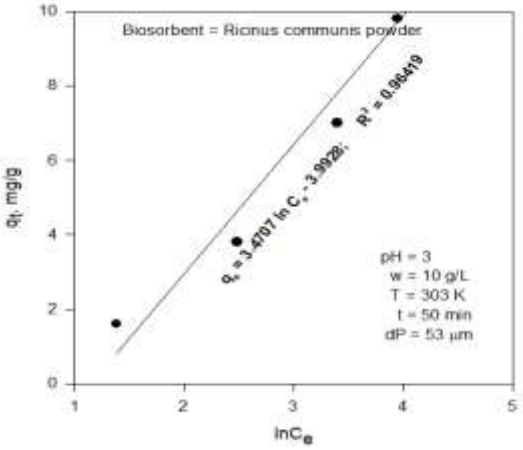


Fig. 9. Temkin isotherm for % biosorption

From the calculation performed, it is found that biosorption data are well represented by Freundlich isotherm.

Langmuir	Freundlich	Temkin
q_m = 18.6254	k_f = 0.66391	A_T = 0.31647
b = 0.02221	n = 0.67709	b_T = 725.8311
R^2 = 0.99193	R^2 = 0.99412	R^2 = 0.96419

Table 1. Isotherm constants

III.8. Kinetics of biosorption:

In the present study, the kinetics are investigated with 50 mL of aqueous solution (C_0= 20 mg/L) at 303 K with the interaction time intervals of 5 min to 180 min. Lagragen plots of log (q_e-q_t) versus agitation time (t) for biosorption of congo red dye the biosorbent size (53 µm) of Ricinis Communis powder in the interaction time intervals of 1 to 180 min are drawn in figs.10 & 11.

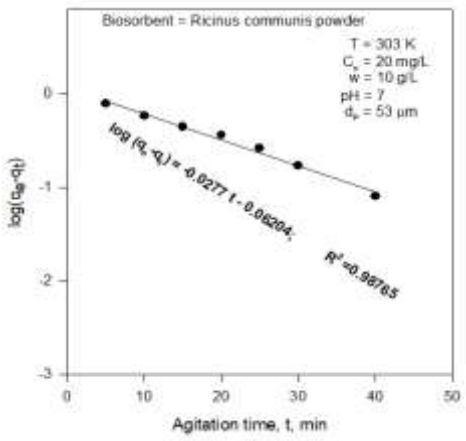


Fig. 10. First order kinetics for % biosorption

The order of interactions has been described using kinetic model. Traditionally, the first order model of Lagergren finds wide application. If the pseudo second order kinetics is applicable, the plot of (t/q_t) vs't' gives a linear relationship that allows computation of q_e and K.

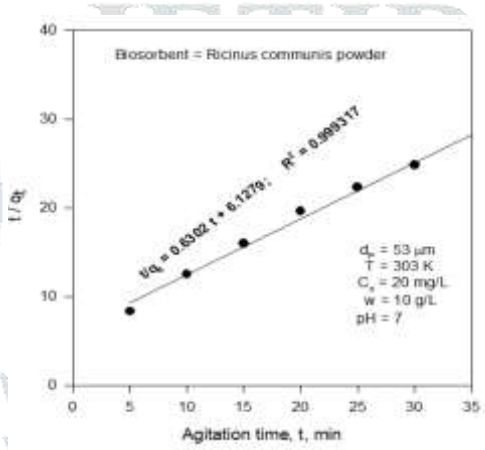


Fig. 11. Second order kinetics for % biosorption

Based on the regression coefficient obtained in the above figures, we notice that the model is best described by the pseudo second order kinetics.

III.9. Thermodynamics of biosorption:

Biosorption is temperature dependent. In general, the temperature dependence is associated with three thermodynamic parameters namely change in enthalpy of biosorption ((ΔH), change in entropy of biosorption (ΔS) and change in Gibbs free energy (ΔG) **[14]**.

Experiments are conducted to understand the biosorption behavior varying the temperature from 283 to 323 K. the plots indicating the effect of temperature on biosorption of congo red dye for different initial dye concentrations are shown in Fig.12. The Vant Hoff's plots for the biosorption data obtained at various initial concentrations of the congo red dye are shown in fig.5.12. The values are ΔG = -9439.5983, ΔH = 12.922406 and ΔS = 31.196438.

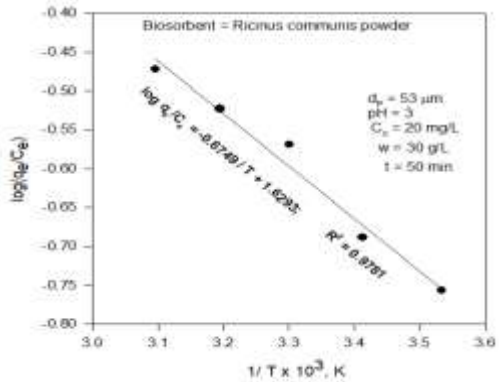


Fig. 12. Vantoff's plot for % biosorption of Congo red dye

III.10. Optimization using CCD

The parameters that have greater influence over the response are to be identified so as to find the optimum condition for the biosorption of Congo Red Dye. The quadratic model is used in the present study, to relate four independent variables and percentage biosorption of Congo Red. The regression equation for is % biosorption of Congo Red (Y) is function of pH (X_1), C_o (X_2), w (X_3) and T (X_4).

Table. 2. Levels of different process variables in coded and un-coded form for % biosorption of Congo Red using *Communis Ricinus* powder

Variable	Name	Range and levels				
		-2	-1	0	1	2
X_1	pH of aqueous solution	2	3	4	5	6
X_2	Initial concentration, C_o, mg/L	10	15	20	25	30
X_3	Biosorbent dosage, w, g/L	20	25	30	35	40
X_4	Temperature, T, K	283	293	303	313	323

The following equation represents multiple regression analysis of the experimental data for the biosorption of *Congo Red Dye*:

$$Y = -4141.54 + 238.23\,X_1 + 7.02\,X_2 + 27.46\,X_3 + 25.96\,X_4 - 76.71\,X_1^2 - 0.17\,X_2^2 - 4.87\,X_3^2 - 0.04\,X_4^2 + 0.02\,X_1X_2 + 1.04\,X_1X_3 - 0.00\,X_1X_4 - 0.20\,X_2X_3 - 0.00\,X_2X_4 - 0.01\,X_3X_4$$

Table.3. Results from CCD for *Congo Red Dye* biosorption by *Ricinus Communis* powder

Run no.	X_1, pH	X_2, C_o	X_3, W	X_4, T	% biosorption of *Congo Red Dye*	
					Experimental	Predicted
1	2	15	1.25	293	74.50000	74.47833
2	2	15	1.25	313	75.68000	75.69667
3	2	15	1.75	293	76.48000	76.51667
4	2	15	1.75	313	77.70000	77.63000
5	2	25	1.25	293	74.28000	74.29333
6	2	25	1.25	313	75.62000	75.59167
7	2	25	1.75	293	75.40000	75.32667
8	2	25	1.75	313	76.48000	76.52000
9	4	15	1.25	293	74.22000	74.20333
10	4	15	1.25	313	75.39000	75.41667
11	4	15	1.75	293	77.30000	77.28167
12	4	15	1.75	313	78.38000	78.39000
13	4	25	1.25	293	74.49000	74.51333
14	4	25	1.25	313	75.82000	75.80667
15	4	25	1.75	293	76.58000	76.58667
16	4	25	1.75	313	77.80000	77.77500
17	1	20	1.5	303	74.28000	74.31167
18	5	20	1.5	303	75.30000	75.29167
19	3	10	1.5	303	77.29000	77.29667
20	3	30	1.5	303	76.48000	76.49667
21	3	20	1	303	73.12000	73.10833
22	3	20	2	303	77.08000	77.11500
23	3	20	1.5	283	75.98000	75.99333
24	3	20	1.5	323	78.39000	78.40000
25	3	20	1.5	303	94.29000	94.29000
26	3	20	1.5	303	94.29000	94.29000
27	3	20	1.5	303	94.29000	94.29000
28	3	20	1.5	303	94.29000	94.29000
29	3	20	1.5	303	94.29000	94.29000
30	3	20	1.5	303	94.29000	94.29000

Experimental conditions [Coded Values] and observed response values of central composite design with 2^4 factorial runs, 6- central points and 8- axial points. Agitation time fixed at 20 min and biosorbent size at 53 µm. Table-5.5 represents the results obtained in CCD. Response obtained from regression in eq.6.1 in the form of ANOVA is presented. From the Fisher's *F*-test (F_{model} = 84278.5714) and a very low probability value ($P_{model} > F$=0.000000), it is known from table–5.6 that the model is highly significant. At 5% level, the computed *F*-value ($F_{0.05\ (14.15)} = MS_{model}/MS_{error}$ = 84278.5714) is greater than that of the tabular *F*-value ($F_{0.05\ (14.15)\ tabulars}$ = 2.42), indicating that the treatment differences are significant.

Table.3. ANOVA of *Congo Red Dye* biosorption for entire quadratic model

Source of variation	SS	Df	Mean square(MS)	F-value	*P* > F
Model	1651.868	14	117.990	84278.5714	0.00000
Error	0.021	15	0.0014		
Total	1651.889				

df- degree of freedom; SS- sum of squares; F- factor F; *P*- probability
R^2=0.99999; R^2 (adj):0.99998

Table.4. Estimated regression coefficients for the *Congo Red Dye* biosorption onto *Ricinus Communis* powder

Terms	Regression coefficient	Standard error of the coefficient	t-value	*P*-value
Mean/Intercept	-4141.54	6.95752	-595.262	0.000000
Dosage, w, g/L (L)	238.23	1.193799	119.221	0.000000
Dosage, w, g/L (Q)	-76.71	0.113764	-674.321	0.000000
Conc, Co, mg/L (L)	7.02	0.058910	119.221	0.000000
Conc, Co, mg/L (Q)	-0.17	0.000284	-611.559	0.000000
pH (L)	27.46	0.293176	93.665	0.000000
pH (Q)	-4.87	0.007110	-685.220	0.000000
Temperature, T, K (L)	25.96	0.043704	594.105	0.000000
Temperature, T, K (Q)	-0.04	0.000071	-601.011	0.000000
1L by 2L	0.02	0.001862	13.293	0.000000
1L by 3L	1.04	0.037238	27.928	0.000000
1L by 4L	-0.00	0.000931	-0.134	0.894973
2L by 3L	-0.20	0.007448	-26.989	0.000000
2L by 4L	0.00	0.000186	2.148	0.048427
3L by 4L	-0.01	0.003724	-2.820	0.012935

[a]insignificant ($P \geq 0.05$)

The larger the value of *t* and smaller the value of *P*, the more significant is the corresponding coefficient term. The 't' and '*P*' values are analyzed. It is found that the X_1, X_2, X_3, X_4, X_1^2, X_2^2, X_3^2, X_4^2, X_1X_2, X_1X_3, X_2X_3 and X_2X_4 have high significance to explain the individual and interaction effect of independent variables on *Congo Red Dye* biosorption. The other terms (X_1X_2, X_1X_4 *and* X_2X_4) are insignificant and are not required to explain biosorption. The model is reduced to the following form by removing insignificant terms: $Y = -4141.54 + 283.23\ X_1 + 7.02\ X_2 + 27.46\ X_3 + 25.96\ X_4 - 76.71\ X_1^2 - 0.17\ X_2^2 - 4.87\ X_3^2 - 0.04\ X_4^2 + 1.04\ X_1X_3 - 0.20\ X_2X_3 - 0.01\ X_3X_4$

A synergistic effect is indicated by positive sign of the coefficient which means response increases with an increase in effect, while an antagonistic effect is indicated by a negative sign which means response decreases with an increase in effect. In the observed response values, a measure of the models variability is provided by the correlation coefficient (R^2). In the present study, the value of the regression coefficient (R^2 = 0.9999) for above stated equation indicates that 0.001 % of the total variations are not satisfactorily explained by the model. It is proved from that table that $F_{statistics}$ value for entire model is higher. This large value means that % biosorption can be adequately explained by the model equation. Generally *P* values lower than 0.05 indicates that the model is considered to be statistically significant at 95% confidence level. The % biosorption prediction from the model is shown in Table-3. Among the interaction terms, all the terms ($P < 0.05$) are insignificant on the biosorption capacity. Fig. 13 and

Fig. 14 shows pareto chart and normal probability plot (NPP) of residual values. It could be seen that the experimental points are reasonably aligned suggesting normal distribution

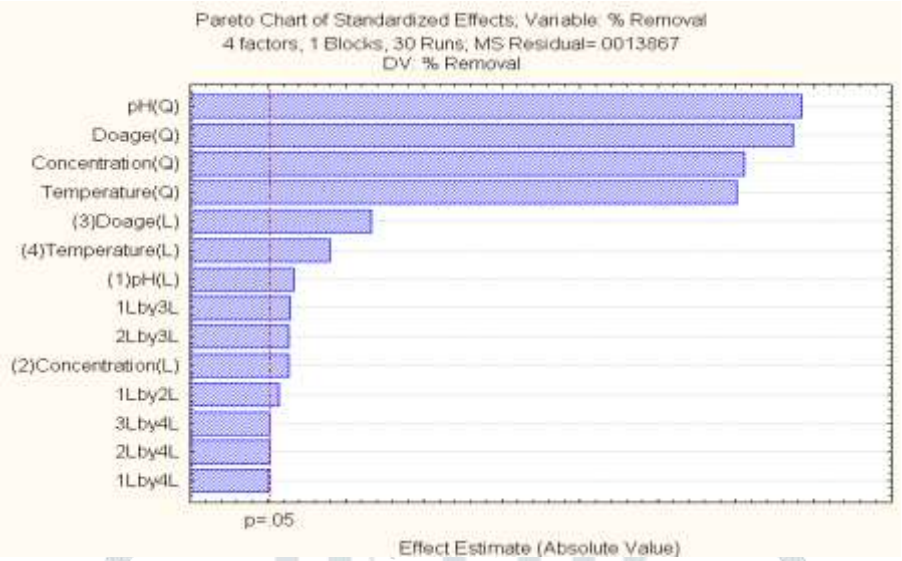


Fig.13. Pareto Chart

Interaction effects of biosorption variables:

The three-dimensional view of response surface contour plots [Fig.18 to 23] show % biosorption as a function of for various combinations of independent variables. The plots are represented as a function of two factors at a time keeping other factors fixed at zero level.

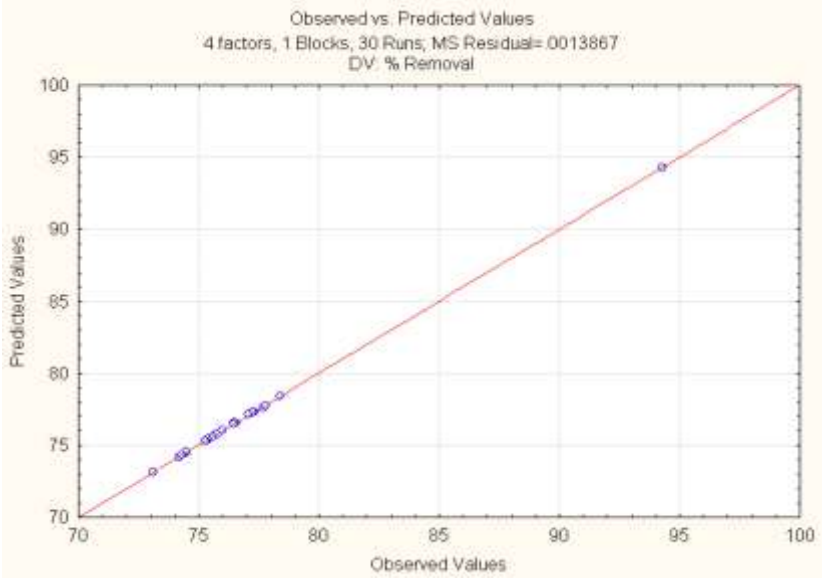


Fig.14. Normal probability plot for % biosorption

It is found from the response surface plots that the % biosorption is maximal at low and high levels of the input variables. However, there exists a region where neither an increasing nor a decreasing trend in % biosorption is observed. The biosorption variables should be optimum to maximize the % biosorption.

The predicted optimal set of conditions for percentage biosorption of *Congo Red Dye* is

pH of aqueous solution	= 3.0276
Initial *Congo Red Dye* concentration	= 19.8725 mg/L
Biosorbent dosage	= 1.5264 g/L
Temperature	= 303.7001 K
% biosorption of *Congo Red Dye*	= 94.36993

The percentage of biosorption of *Congo Red Dye* is strongly influenced by the pH as evident from figs. 15 to 21.

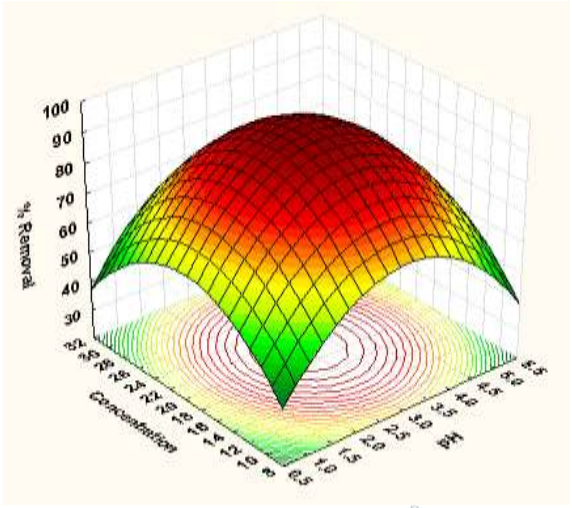


Fig.15. Surface contour plot Effect of pH and Initial Dye concentration on % biosorption

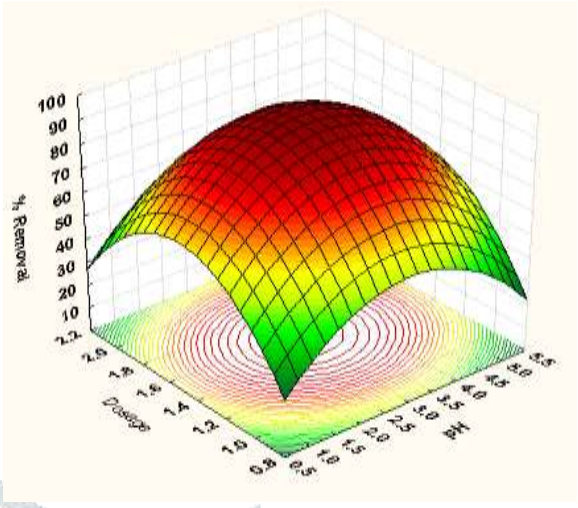


Fig.16. Surface contour plot Effect of pH and dosage on % biosorption

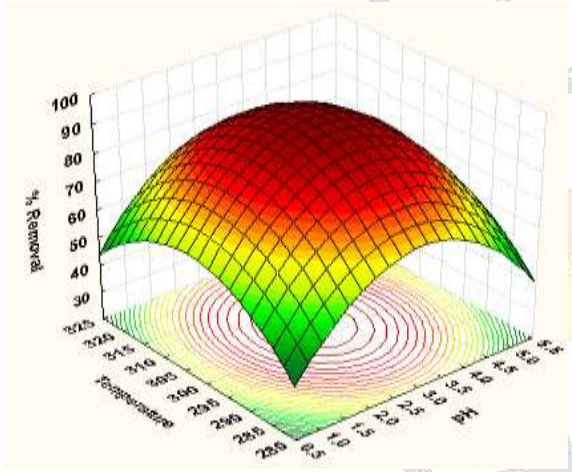


Fig.18. Surface contour plot Effect of pH & Temperature on % biosorption

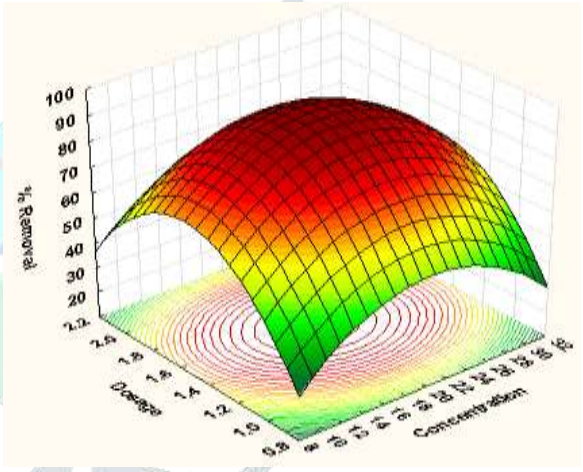
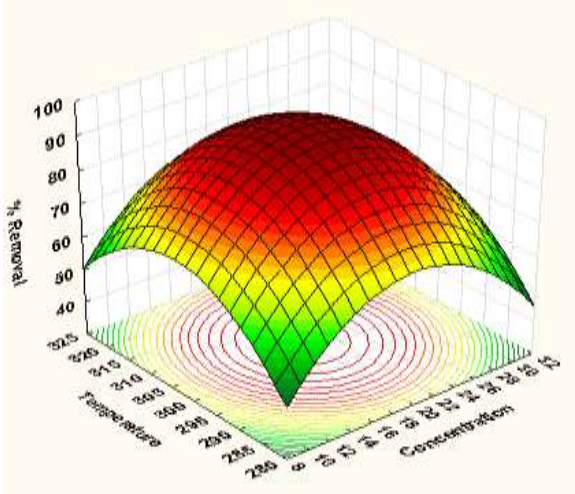


Fig.19. Surface contour plot Effect of initial concentration & dosage on % biosorption



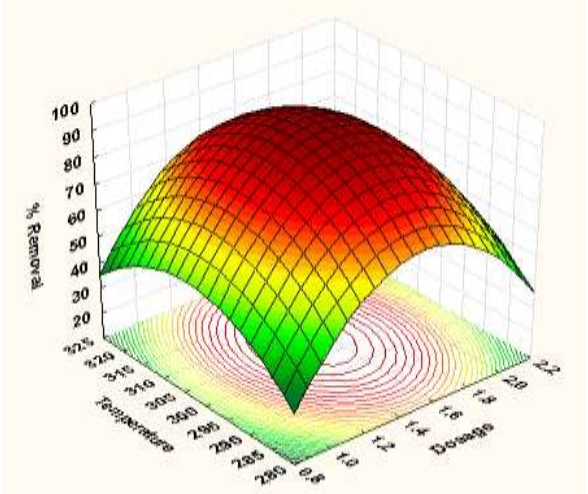


Fig.20. Surface contour plot for the effects of initial concentration and Temperature on % biosorption

Fig.21. Surface contour plot for the effects of Dosage and Temperature on % biosorption

Table.5. Comparison between optimum values from CCD and experimentation

Variable	CCD	Experimental value
pH of aqueous solution	3.0276	3
Initial concentration, mg/L	19.8725	20
Biosorption dosage, w, g/L	30.5264	30
Temperature, K	303.7001	303
% biosorption	94.36993	89

Table.6. Congo red dye uptake capacities for different biosorbents

Authors	Biosorbent	q_t, mg/g
Youzhou Zhou [15]	Shrimp shell powder	288.2
K. Rasool [16]	Activated sulfidogenic sludge	238.9
Mohammad Foroughi-Dahr [17]	Tea Waste	32.26
Zaib Hussain [18]	*Saccharum bengalense*	125
Xue Song Wang [19]	Wheat Bran	22.73
Jing Ping Chen [19]	Rice Bran	14.63
Present investigation	*Ricinis Communis* powder	18.6254

III.11. **Characterization Studies**

III.11.1. Fourier Transform Infra-Red Spectroscopy (FTIR)

Infrared spectroscopy belongs to the group of molecular vibrational spectroscopies which are molecule-specific and give direct information about the functional groups, their kind, interactions and orientations. The shift of the bands and the changes in signal intensity allow the identification of the functional groups involved in dye sorption. **[20-23]**. The functional groups present in the *Ricinus Communis* powder were investigated by FTIR spectra within the range of 400-4000cm-1 wave number. The below mentioned figures indicate the band positions in the FTIR spectra of the *Ricinus Communis* powder before and after Congo Red dye biosorption.

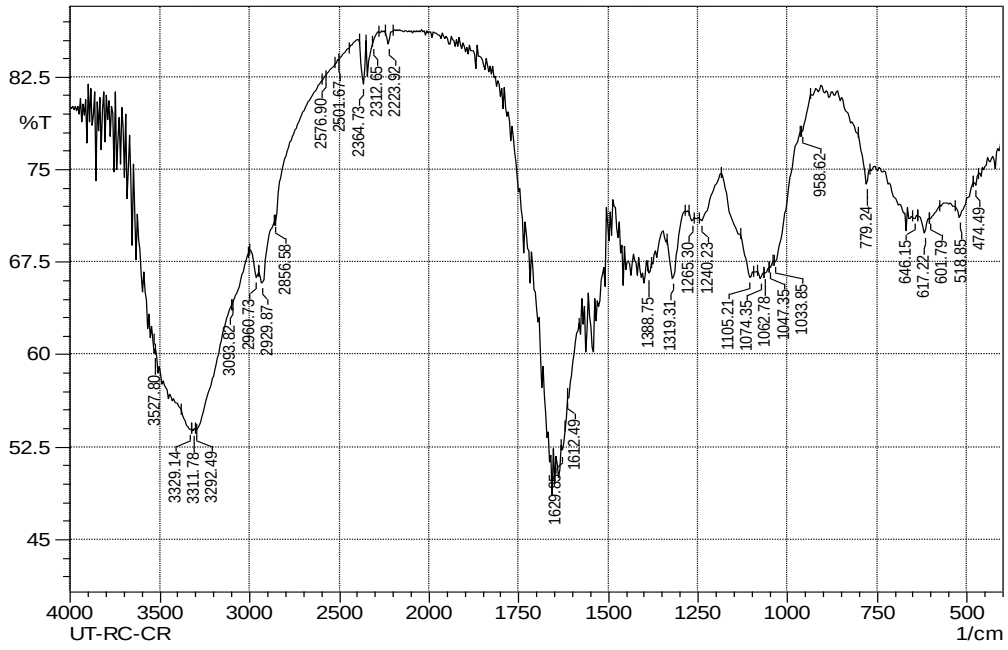


Fig.22. FTIR spectrum of *Ricinus Communis* before biosorption

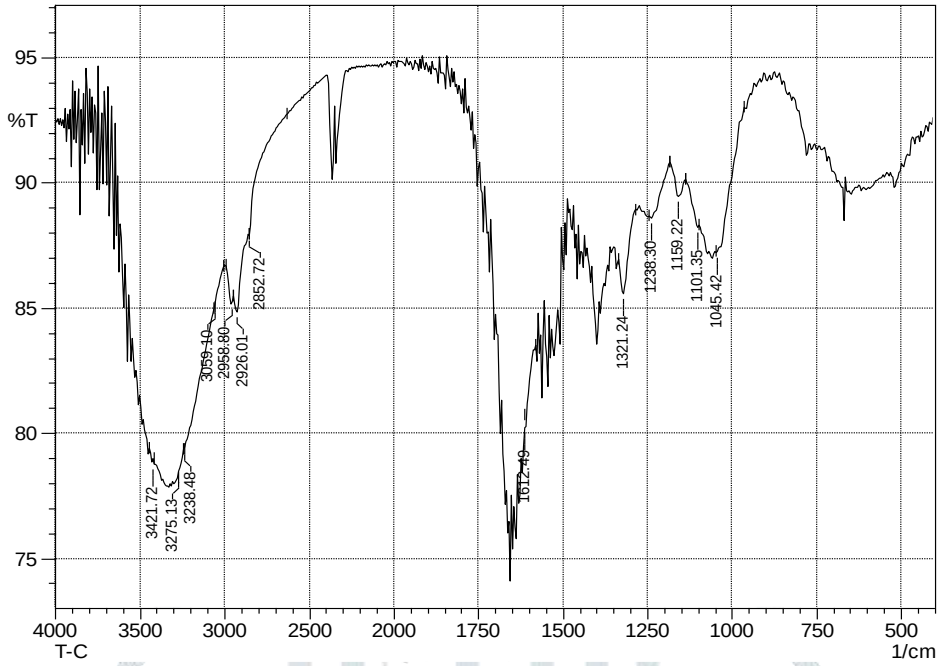


Fig.23. FTIR spectrum of *Ricinus Communis* after Biosorption

The below table explains the FTIR peaks for the untreated and treated powder,

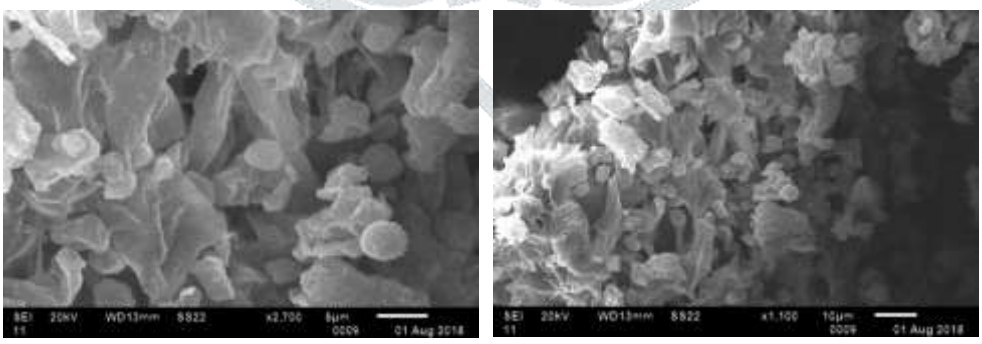
Table-7. Shift of FTIR peaks for *Ricinus Communis* powder

S. No	Peaks in untreated powder, cm^{-1}	Peaks in Treated Ricinus Communis	Bond and Functional group Description
1	474.49	------	-C-C-group
2	518.85	------	-C-C-group
3	601.79	------	-C-C-group
4	617.22	------	$-CH_2-O-CH_2-$linkage
5	646.15	------	C–O stretching
6	779.24	------	C–O stretching
7	958.62	------	$-SO_3$ stretching
8	1033.85	------	-C-C-group
9	------	1045.42	C-Br stretch bands from Alkyl halides
10	1047.35	-----	C-Br stretch bands from Alkyl halides
11	1062.78	------	C-H Bending Vibrations
12	1074.35	------	C-H Bending Vibrations
13	------	1101.35	C-C Stretching mode
14	1105.21	-----	C-C Stretching mode
15	-----	1159.22	C-C Stretching mode
16	------	1238.30	C-O Stretching mode
17	1240.23	-----	C-O Stretching mode
18	1265.30	-----	SO_3 stretching
19	1319.31	------	$–CH_2$ bending vibrations

20	-----	1321.24	$-CH_2$ bending vibrations
21	1388.75	-----	$-CH_2$ bending vibrations
22	1612.49	1612.49	Oleifinic C = C and Carbonyl C = O stretching
23	1629.85	------	Oleifinic C = C and Carbonyl C = O stretching
24	2223.92	------	C=S stretching mode
25	2312.65	------	C=S stretching mode
26	2364.73	------	
27	2501.67	-----	
28	2576.9	-----	
29	-----	2852.72	
30	2856.58	------	
31	-----	2926.01	=C-H bend alkenes mode
32	2929.87	-----	
33	2903.92	-----	
34	------	2958.80	
35	2960.73	------	
36	------	3059.10	
37	3093.82	------	
38	------	3238.48	Bounded –OH and –NH groups
39	------	3275.13	
40	3292.49	------	
41	3311.78	------	
42	3329.14	------	Alkyl C-H stretch mode
43	------	3421.72	Amine N-H stretch mode
44	3527.80	------	Assymetric $-CH_2-$, symmetric $-CH_3$ and $-CH_2-$ stretching vibrations

5.14 Scanning Electron Microscope (SEM):

The SEM pictures of *Ricinus Communis* powder shown in fig. 24, demonstrates the surface morphology of powder as porous and uneven. SEM analysis after biosorption as shown in fig.25, depicts that the surface has irregular texture with globular, elongated grains and shiny particles over the surface of biosorbent which are absent in the fresh biosorbent. These elongated grains show that the Congo Red dye particles are adhered onto the surface of the biosorbent. From the SEM images, it is evident that the investigated sorbent is porous material due to the presence of pores and cavities.



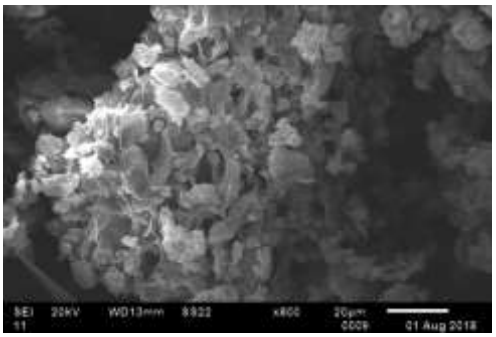


Fig.24. SEM pattern of *Ricinus Communis* powder before Biosorption

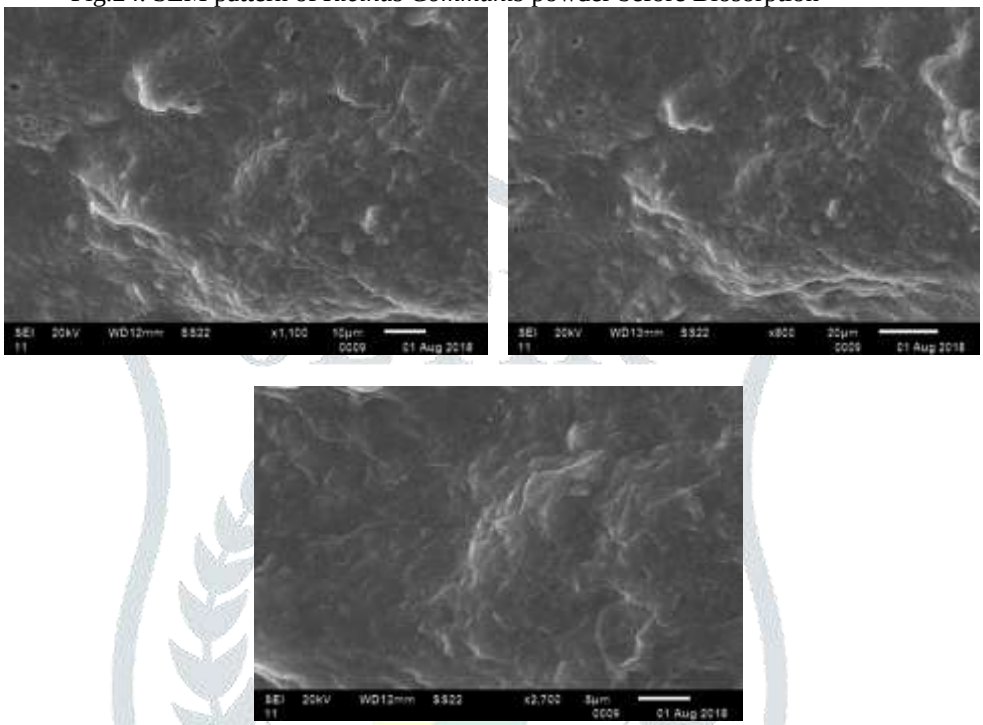


Fig.25. SEM pattern of *Ricinus Communis* after Biosorption

IV. CONCLUSION:

The equilibrium agitation time for dye biosorption is 50 minutes. The percentage biosorption of dye decreased with the increase in biosorbent size from 53 µm (69 %) to 152 µm (49 %). Percentage biosorption of dye from the aqueous solution increases significantly with increase in pH from 2 (72 %) to 3 (80 %) and then decreases. With an increase in temperature there is an increase in the percentage of biosorption. From the predicted values of RSM results, maximum sorption of 94.36993% congo red dye is observed when the processing parameters are set as pH = 3.0276, w = 1.5264 g/L, Co = 19.8725 mg/L and T = 303.7001 K. The investigation also reveals that the biosorption is endothermic in nature as ΔH (12.922406) is positive, irreversible in nature as ΔS (31.196438) is positive and spontaneous as indicated by negative ΔG = –9439.5983 J/mole.

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