Studies on Biosorption of Solo chrome black Dye with Adenanthera pavonina Powder and Optimization through Central Composite Design (CCD)

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Abstract : The major earth resources are being polluted and are seeking a special attention for their originality which has to be reestablished. The present research was investigated using Adenanthera pavonina powder as a potential biosorbent for the removal of Solo chrome black. The operating parameters involved are agitation time, biosorbent size, and pH of the solution, initial concentration of solution, dosage of biosorbent and temperature of the solution. The optimization was also incorporated using Central Composite Design.The optimum size of biosorbent is 53μm,pH was obtained at 6.0 and initial concentration of Solo chrome black is 20 mg/L were compared using one factor at a time with CCD. The kinetics and isotherm studies are also studied along with thermodynamic study.

***IndexTerms*–Adenanthera pavonina; Solo chrome black; biosorbent; CCD**

I. INTRODUCTION

Water – a priceless gift from the nature to the mankind. It is irreplaceable. The role of water in human life is noteworthy without which tasks such as running water for household activities, to rear cattle and farming, or for the industrial usage remain dormant [1].There may be various reasons causing the degradation in quality of water day by day which include weathering, dissolution, precipitation, ion exchange, various biological processes, Sewage leakages ,high population density, oil spillage, Industrial waste dumps, pollution of ground water through drilling activities, flooding during rainy season which carries waste deposits into our waters, radioisotopes, Heavy metal, Combustion, Toxic waste disposal at sea ,Deforestation , Mining Littering ,Pesticides ,herbicides and fertilizers ,Failing septic system ,House hold chemicals ,Animal wastes [2]. In the recent years, population increase has been sharp and both the industrial and domestic needs of people increased tremendously [3].Out of the several uses of water, drinking purpose holds a major role and ground water stands as a major source for drinking needs in most parts of India accounting for about 88% of safe drinking water in rural India For drinking and even 45% irrigation water is supplied from groundwater [4]. There are various techniques in use to treat water that has been polluted such as screening, filtration and centrifugal separation, Sedimentation, gravity separation, coagulation, flotation, Aerobic, Anaerobic, distillation, crystallization, evaporation, solvent extraction, reverse osmosis, ultra filtration, electro dialysis etc. [5]. Industrial discharge has been the major chunk of wastewater contributors this has been one of the main causes of irreversible ecosystem degradation[6].These facts remaining so, water consumption rates are increasing from 313 liters per capita day for the affluent to a mere 16 liters per capita day for the slum dweller [7]. The data obtained on monitoring quality of water exposed the fact that quality of water at most of the monitoring points is poor [8]. On evaluating the water quality for irrigation suggest that the majority of the groundwater samples are not good for irrigation in post monsoon this needs to addressed since agriculture contributes 46% to the gross national product [9].All these demand a sustainable utilization of water and its resources both effectively and efficiently without resulting into scarcity and degradation in the existing quality of water.

II. Experimental procedure

Preparation of the Biosorbent

Adenanthera Pavonina leaves were collected from Andhra university in Visakhapatnam and were washed with water to remove dust and soluble impurities and dried in sun light till the algae became crispy and colorless. By passing it through a set of sieves ranging from 300 to 75 mesh sizes the dried algae were finely powdered and sized. The powder of 53, 75, 105, 125 and 152 micron meters were separated and stored in dry bottles with double cap and used as biosorbent.

Preparation of 1000 Mg/L of Solo chrome black Dye Stock Solution

To prepare 1000 ppm of Solo chrome black dye stock solution 1.0 g of 99 % Solo chrome black dye powder was dissolved in 1.0 L of distilled water. From this stock solution synthetic samples of different concentrations of Solo chrome black dye were prepared by appropriate dilutions. 100 ppm Solo chrome black dye stock solution was prepared by diluting 100 ml of 1000 ppm Solo chrome black stock solution with distilled water in 1000 ml volumetric flask up to the mark. Similarly solutions with different dye concentrations such as 20, 50, 100, 150 and 200 ppm were prepared. Studies on Equilibrium Biosorption Process.The biosorption was carried out in a batch process by adding a pre-weighed amount of the Adenanthera Pavonina algae powder to a known volume of aqueous solution for a predetermined time interval in an orbital shaker. The procedures adopted to evaluate the effects of various parameters via. Agitation time, biosorbent size, pH, initial concentration, biosorbent dosage and temperature of the aqueous, which include characterization (FTIR, XRD, SEM), Isotherms (Langmuir, Freundlich, Temkin), Kinetics (Lagergren First Order, Pseudo Second Order), Thermodynamics (Entropy, Enthalpy and Gibb's Free Energy) and Optimization using Central Composite Design.

III. Results and discussions

In the present investigation, the prospectives of sorbent namely Adenanthera Pavonina powder is evaluated to estimate its performance for the decolorization of Solo chrome black dye present in aqueous solution. The effects of parameters on decolorization of SCB dye were measured, data consisting of contact time, sorbent size, pH of the solution, initial concentration, sorbent dosage and temperature.

Sorption of Solo chrome black dye using Adenanthera Pavonina powder.

Effect of Contact Time

Duration of equilibrium dye decolorization is defined as the time required for dyes concentration to reach a constant value during dye decolorization. The equilibrium contact time is determined by plotting the % dye decolorization of SCB against contact time as shown fig.1 for the interaction time intervals between 1 to 180 min. The % sorption is found to increase up to 50 min reaching 50%. The rate of sorptionis fast in the initial stages because adequate surface area of the sorbent is available for the sorption of SCB dye. As time increases more amount of SCB dye gets adsorbed onto the surface of the sorbent due to forces of attraction and results in decrease of available surface area. The sorbate, normally, forms a thin one molecule thick layer over the surface. When this monomolecular layer covers the surface, the capacity of the sorbent is exhausted. The maximum percentage of sorption is attained at 50min of contact and becomes constant after 50 min indicating the attainment of the equilibrium with 53 μm size of 10 g/L sorbent dosage mixed in 50ml of aqueous solution(C0=20 mg/L)[10-14].

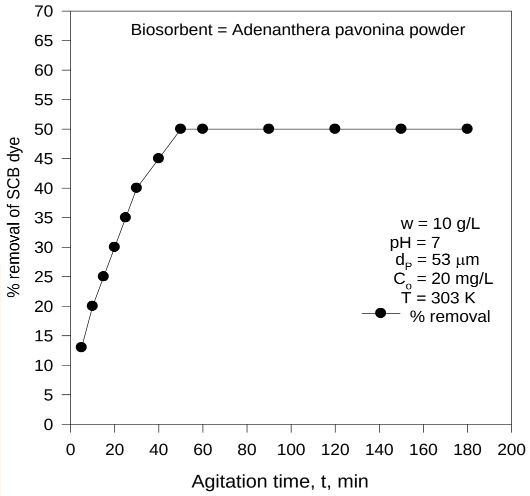

Fig.1: Effect of contact time on % dye decolorization of SCB dye

Effect of Sorbent Size

The variations in % dye decolorization of SCB dye from the aqueous solution with sorbent size are obtained. The results are drawn in fig.2 with percentage dye decolorization of SCB dye as a function of sorbent size. The percentage sorption is decreased from 50 to 36 % as the sorbent size is decreased from 53 to 152 μm. As the size of the particle decreases, surface area of the sorbent enhances and extra number of active sizes on the sorbent are available to the sorbate[15-19]

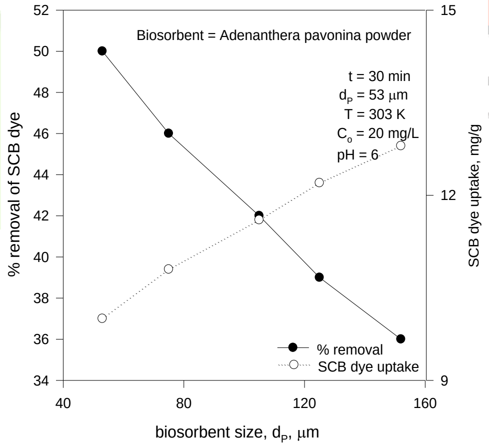

Fig.2: % Dye decolorization of SCB dye as a function of sorbent size

Effect of pH

pH controls dye decolorization by influencing the surface change of the sorbent, the degree of ionization and the species of biosorbate. In the present investigation, SCB dye decolorization data are obtained in the pH range of 2 to 8 of the aqueous solution (C0 = 20 mg/L) using 10 g/L of 53 μm size sorbent. The effect of pH of aqueous solution on % dye decolorization of SCB dye is shown in fig.3. The percentage sorption is increased from 46 % to 62 % as pH is increased from 2 to 6.The percentage sorption is decreased from 62 % to 42% as pH increases from 7 to 8.The principal driving force for dye ion sorption is the electrostatic interaction between sorbent and sorbate. Low pH depresses dye decolorization due to competition with H+ ions for appropriate sites on the sorbent surface. However, with increasing pH, this competition weakens and SCB dye ions replace H+ ions bound to the sorbent. The increase in sorption capacity at higher pH may also be attributed to the reduction of H+ ions which complete with SCB dye lower pH. This is the reason for higher sorption of SCB due in the pH range of 6. At pH higher than 6, precipitation of SCB dye occurred and sorption is reduced [20-29].

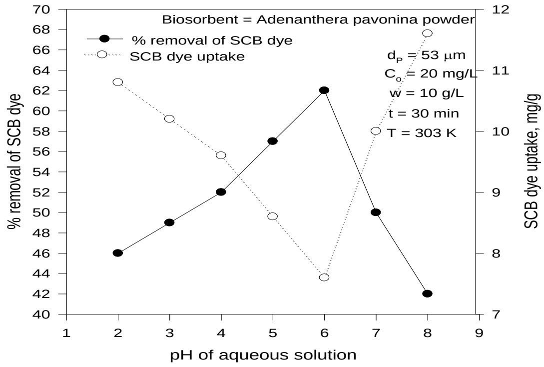

Fig. 3: Observation of pH along with % dye decolorization of SCB dye

Effect of Initial Concentration of SCB Dye

The experiments were carried out using various concentrations of SCB dye in the aqueous solution under the optimum size, pH values and equilibrium contact time. The effect of initial concentration of SCB dye in the aqueous solution on the percentage dye decolorization of SCB dye is shown in fig.4. The percentage sorption is decreased from 62 to 42 % as the initial concentration of SCB dye increased from 20 mg/L to 200 mg/.Such behavior can be attributed to the increase in the amount of sorbate to the uninterrupted number of freely active sites on the sorbent .

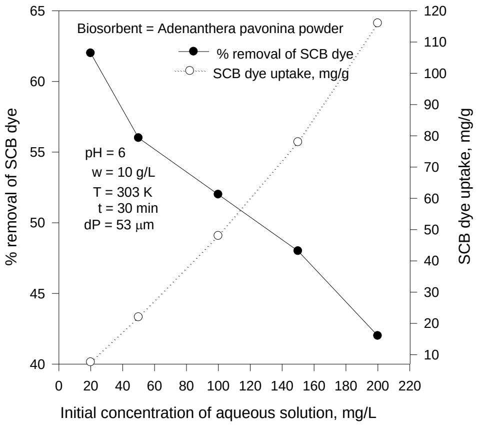

Fig.4: Variation of initial concentration with % dye decolorization of SCB dye

Effect of Sorbent Dosage

The percentage dye decolorization of SCB dye is drawn against sorbent dosage for 53 µm size sorbent in fig.5.The percentage sorption increased with increase in sorbent dosage. For a sorbent size of 53µm, percentage dye decolorization increased from 62 % to 93 %, as dosage is decreased from 7.6 to 1.4 g/L Such behavior is obvious because the number of available sites for dye removal would be more as the amount of the sorbent increases.

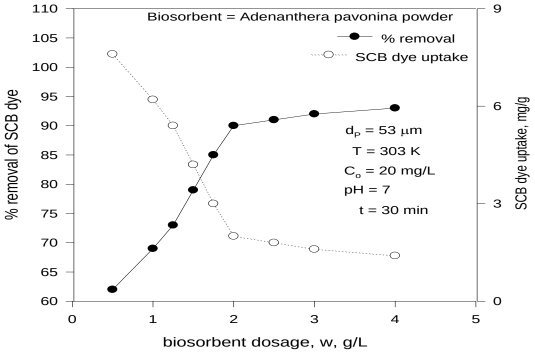

Fig. 5: Dependency of % dye decolorization of SCB dye on sorbent dosage

Effect of Temperature

The effect of temperature on the equilibrium dye uptake was significant. The effect of changes in the temperature on the SCB dye uptake is shown in Fig.6. When temperature was lower than 303 K, SCB dye uptake increased with increasing temperature, but when temperature was over 303 K, the results were on the contrary. This response suggested a different interaction between the ligands on the cell wall and the dye. Below 303 K, chemical dye decolorization mechanisms played a dominant role in the whole dye decolorization process, dye decolorization was expected to increase by increase in the temperature while at higher temperature, the plant powder were in a nonliving state, and physical dye decolorization became the main process. Physical dye decolorization reactions were normally endothermic, thus the extent of dye decolorization generally is constant with further increasing temperature. The sorption capacity of dye is increased at higher temperatures, which indicates that sorption of dyes in this system is an endothermic process. This may be attributed to increased penetration of reactive dyes inside micropores at higher temperatures or the creation of new active sites. The formation of more than one molecular layer on the surface of Adananthera pavonina powder appears to be achieved in the case of SCB dye sorption at higher temperatures.

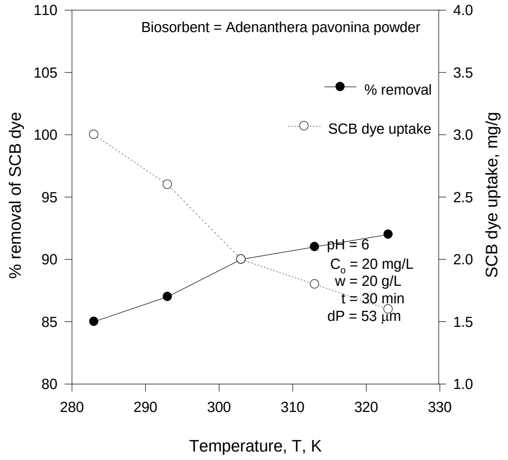

Fig. 6: Effect of temperature on % dye decolorization of SCB dye

Equilibrium Isotherm Models

Irving Langmuir developed an isotherm named Langmuir isotherm. It is the most widely used simple two- parameter equation. This simple isotherm is based on following assumptions: Biosorbates are chemically biosorbed at a fixed number of well- defined sites Each site can hold only one biosorbate specie

All sites are energetically equivalent

There are no interaction between the biosorbate species

The Langmuir relationship is hyperbolic and the equation is:

$qe/qm = bCe/ (1+bCe)$ …….. (1)

Equation (1) can be rearranged as

$(Ce/qe) = 1/(bqm) + Ce/qm$ …….. (2)

From the plots between (Ce/qe) and Ce, the slope {1/ (bqm)} and the intercept (1/b) are calculated.

Further analysis of Langmuir equation is made on the basis of separation factor, (RL) defined as

RL = 1/ (1+bCe) 0<RL1 indicates unfavorable adsorption

RL = 1 indicates linear adsorption

RL = 0 indicates irrepressible adsorption Langmuir isotherm, for the present data has yielded the equation

$(Ce/qe) = 0.066777\ Ce + 5.944612$

The correlation coefficient value of 0.9876955 indicates strong binding of SCB dye to the biosorbent

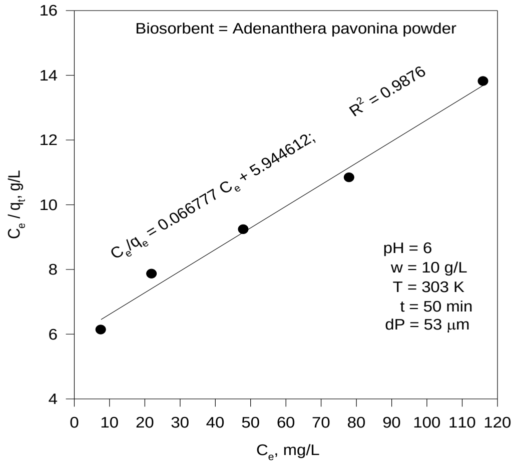

Fig. 7: Langmuir isotherm for % dye decolorization of SCB dye

Freundlich isotherm:

Freundlich presented an empirical dye decolorization isotherm equation that can be applied in case of low and intermediate concentration ranges. It is easier to handle mathematically in more complex calculations.

The Freundlich isotherm is given by

$qe = KfCe^{n}$

Where Kf (mg) represents the dye decolorization capacity when dye equilibrium concentration and n represents the degree of dependence of dye decolorization with equilibrium concentration

Taking logarithms on both sides, we get

$\ln qe = \ln Kf + n \ln Ce$

Freundlich isotherm is drawn between lnCe and lnqe in Fig.8 for the present data. Drawn between lnCe and lnqe, has resulted the equation

$\ln qe = 0.721199 \ln Ce - 1.2117000$ The equation has a correlation coefficient of 0.993569. The ‘n’ value of 0.7211 satisfies the condition of 0<n

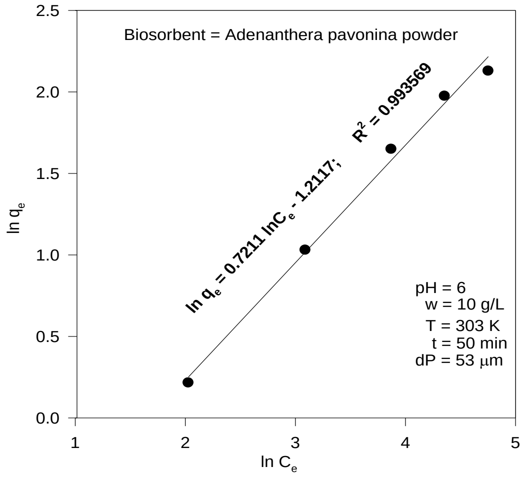

Fig. 8: Freundlich isotherm for % dye decolorization SCB dye

Temkin isotherm:

Temkin and Pyzhev isotherm equation describes the behavior of many dye decolorization systems on the heterogeneous surface and it is based on the following equation

$q_e = RT \ln(A_TC_e)/b_T$

The linear form of Temkin isotherm can be expressed as

$q_e = (RT/b_T)\ln(A_T) + (RT/b_T)\ln(C_e)$

where $A_T = \exp[b(0) \times b(1) / RT]$

b (1) = RT/ bT is the slope b (0) = (RT/ bT) ln (AT) is the intercept and b= RT/b(1)

The present data are analysed according to the linear form of Temkin isotherm and the linear plot is shown in Fig.7. The present data are analysed according to the linear form. The equation obtained for SCB dye sorption is

$q_e = 2.6939 \ln C_e - 4.7846$

The correlation coefficient value is 0.9641. The best fit model is determined based on the linear regression correlation coefficient (R). From the Figs 7, 8 & 9, it is found that dye decolorization data are well explained by Langmuir isotherm (0.9876), Temkin (0.9641) and Freundlich isotherm (0.993569).

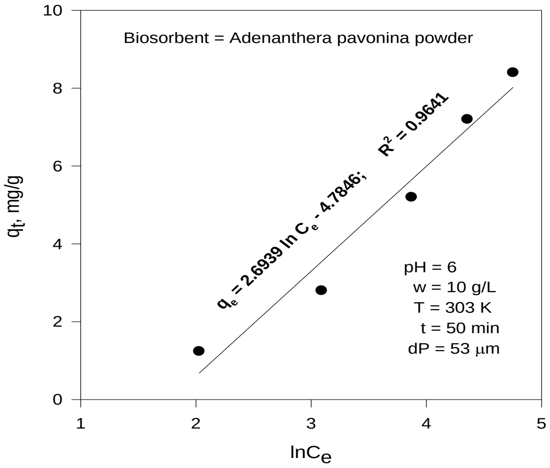

Fig. 9: Temkin isotherm for % dye decolorization of SCB dye

Kinetics

The order of biosorbate – sorbent interactions have been described using kinetic model. Traditionally, the first order model of Lagergren finds wide application. In the case of dye decolorization preceded by diffusion through a boundary, the kinetics in most cases follows the first order rate equation of Lagrangen:

(dqt/dt)= Kad (qe – qt) where qe and qt are the amounts adsorbed at t, min and equilibrium time and Kad is the rate constant of the pseudo first order dye decolorization.

The above equation can be presented as

$\int (dq_t/(q_e - q_t)) = \int K_{ad}\,dt$ $\log(q_e - q_t) = \log q_e - (K_{ad}/2.303)\,t$ $\log(q_e - q_t) = -0.02476\,t + 0.0453$

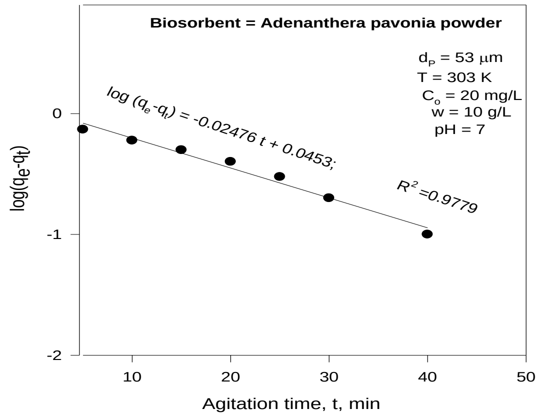

Fig. 10: first order kinetics for % dye decolorization of SCB dye

Lagergren plot of log (qe-qt) vs contact time (t) and pseudo second order kinetics plot between ‘t’vs ‘t/qt’ for sorption of SCB dye. If the experimental results do not follow the above equation, they differ in two important aspects: Kad (qe – qt) does not represent the number of available dye decolorization sites and log qe is not equal to the intercept.

In such cases, pseudo second order kinetic equation:

(dqt/dt) = K (qe – qt)2 is applicable, where ‘K’ is the second order rate constant.

The other form of the above equation is:

(dqt /(qe–qt)2)= Kdt

letqe – qt = x

dqt = dx

1/ x = K x + C

C = 1/ qe at t = 0 and x = qe

Substituting these values in above equation,

we obtain: 1/(qe – qt) = Kt + (1/qe)

Rearranging the terms, we get the linear form as:

(t/qt) = (1/ Kqe2) + (1/qe) t.

t/qt = 0.68063 t + 18.0758

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 1 min to 180 min. Lagragen plots of log (qe-qt) versus contact time (t) for dye decolorization of SCB dye the sorbent size (53 μm) of Adananthera pavonina powderin the interaction time intervals of 1 to 180 min are drawn in figs.10 & 11. The following equations and constants are obtained for lagergren first order and pseudo second order kinetics.

log (qe-qt) = – 0.02476 t + 0.0453 with a correlation coefficient 0.9779. t/qt = 0.68063t + 18.0758 with a correlation coefficient 0.9692 .

Summarize rate constant values for first and second order rate equations. It is noted that both first and second order rate equations explain the sorption interactions. If the pseudo second order kinetics is applicable, the plot of (t/qt) versus‘t’ gives a linear relationship that allows computation of qe and K.

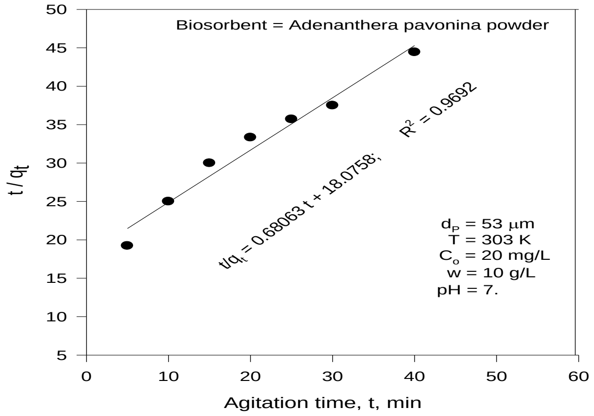

Fig.11: second order kinetics for % dye decolorization of SCB dye

The pseudo second order model based on above equation, considers the rate -limiting step as the formation of chemisorptive bond involving sharing or exchange of electrons between the biosorbate and sorbent.

Thermodynamics of Sorption

Dye decolorization is temperature dependant. In general, the temperature dependence is associated with three thermodynamic parameters namely change in enthalpy of dye decolorization ((ΔH), change in entropy of dye decolorization (ΔS) and change in Gibbs free energy (ΔG). Enthalpy is the most commonly used thermodynamic function due to its practical significance. The negative value of ΔH will indicate the exothermic/endothermic nature of dye decolorization and the physical/chemical in nature of sorption. It can be easily reversed by supplying the heat equal to calculated ΔH.

The ΔH is related to ΔG and ΔS as

$\Delta G = \Delta H - T\ \Delta S\ \Delta S < 1$

indicates that dye decolorization is impossible whereas ΔS > 1 indicates that the dye decolorization is possible. ΔG < 1 indicates the feasibiliSCB of sorption.

The Vant Hoff's equation is

log (qe /Ce) = ΔH/(2.303 RT) + (ΔS/2.303 R)

Where (qe/Ce) is called the dye decolorization affinity

If the value of ΔS is less than zero, it indicates that the process is highly reversible. If ΔS is more than or equal to zero, it indicates the reversibility of process. The negative value for ΔG indicates the spontaneity of dye decolorization. Whereas the positive value indicates is non spontaneity of sorption. Experiments are conducted to understand the dye decolorization behavior varying the temperature from 283 to 323 K. the plots indicating the effect of temperature on dye decolorization of SCB dye for different initial dye concentrations are shown in fig.12 A series of thermodynamic parameters - change in Gibbs free energy (ΔG) change in enthalpy (ΔH) and change in entropy (ΔS) are determined. ΔG value of –10729.4 J/mole indicates that sorption of SCB dye by Adananthera pavonina powdercould take place spontaneously. Higher temperatures have benefitted sorption and increased the equilibrium sorption capacity. Positive ΔH of 13.94678 J/mole indicates indicates endothermic nature of sorption while positive ΔS = 35.45668 J/mole-K demonostrates the affinity of Adananthera pavonina powder to SCB dye.

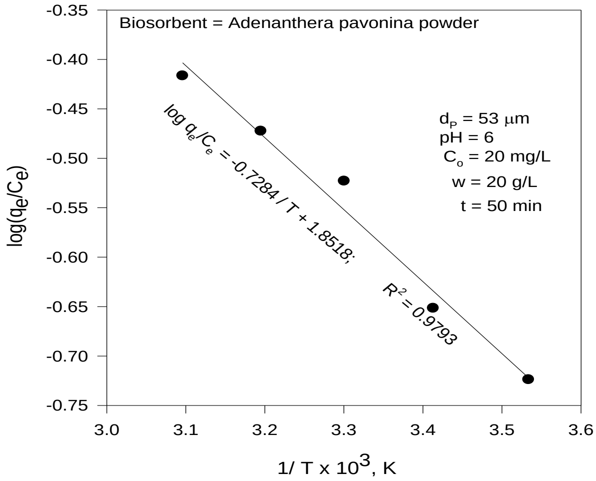

Fig. 12: Vantoff's plot for % dye decolorization of SCB dye

Optimization of the Selected Parameters using CCD

In the present study,thelevels of four process input variables for % dye decolorization Based on the results of the preliminary experimental studies, pH, initial SCB dye concentration, sorbent dosage and temperature were chosen as the independent input variables and percentage dye decolorization was used as the dependent output variable. A CCD was employed to analyze the interactive effects of these parameters and to arrive for an optimum values. The experiments with different pH values of 3–7, different SCB dye concentrations of 10–30 mg/L, different sorbent dosages of 20–40 g/L and different temperatures of 283–323 K were coupled to each other and varied simultaneously to cover the combination of parameters in the CCD.

	pH	Concentration	Dosage	Temperature	% Removal	% Removal	Predicted
1	5	15	1.5	293	72.4	75.69	75.74167
2	5	15	1.5	313	76.4	79.28	79.33750
3	5	15	2.5	293	74.6	79.12	79.07083
4	5	15	2.5	313	76.4	81.49	81.54167
5	5	25	1.5	293	71.4	75.2	75.15417
6	5	25	1.5	313	75.4	78.7	78.67500
7	5	25	2.5	293	73.4	76.78	76.80833
8	5	25	2.5	313	75.6	79.18	79.20417
9	7	15	1.5	293	73.2	76.68	76.72083
10	7	15	1.5	313	75.8	80.02	79.94167
11	7	15	2.5	293	74.6	78.92	78.87500
12	7	15	2.5	313	77.6	81.02	80.97083
13	7	25	1.5	293	74.5	76.88	76.90833
14	7	25	1.5	313	77.4	80.1	80.05417
15	7	25	2.5	293	73.2	77.4	77.38750
16	7	25	2.5	313	75.2	79.38	79.40833
17	4	20	2	303	71.2	63.6	63.57083
18	8	20	2	303	71.8	64.8	64.75417

19	6	10	2	303	92	83.69	83.73750
20	6	30	2	303	88	81.6	81.58750
21	6	20	1	303	86	80.28	80.32083
22	6	20	3	303	92	82.98	83.00417
23	6	20	2	283	90	82.7	82.65417
24	6	20	2	323	95.6	88.3	88.27083
25	6	20	2	303	95.4	95.38	95.40000
26	6	20	2	303	95.4	95.38	95.40000
27	6	20	2	303	95.4	95.38	95.40000
28	6	20	2	303	95.4	95.38	95.40000
29	6	20	2	303	95.4	95.38	95.40000
30	6	20	2	303	95.4	95.38	95.40000

The parameters that have greater influence over the response are to be identified so as to find the optimum condition for the biosorption of SCB dye. For optimization of medium constituents, the regression equation is: % biosorption of SCB dye is a function of pH (X1), Co (X2), w (X3), and T (X4). The variations in the corresponding coded values of four parameters and response are presented in table-3.13 depending on experimental runs and predicted values proposed by CCD design.

	SS	**df**	**MS**	**F**	**p**
(1)pH (L)	2.257	1	2.257	3873	0.000000
pH (Q)	1666.883	1	1666.883	2860237	0.000000
(2)Concentration(L)	6.805	1	6.805	11677	0.000000
Concentration(Q)	278.132	1	278.132	477253	0.000000
(3)Dosage (L)	10.854	1	10.854	18625	0.000000
Dosage (Q)	324.225	1	324.225	556344	0.000000
(4)Temperature(L)	47.320	1	47.320	81198	0.000000
Temperature(Q)	167.424	1	167.424	287286	0.000000
1L by 2L	0.504	1	0.504	865	0.000000
1L by 3L	1.357	1	1.357	2329	0.000000
1L by 4L	0.093	1	0.093	160	0.000000
2L by 3L	3.080	1	3.080	5285	0.000000
2L by 4L	0.006	1	0.006	10	0.007217
3L by 4L	1.440	1	1.440	2471	0.000000
Error	0.009	15	0.001		
Total SS	2003.765	29			

	Regressn	**Std.Err.**	**t(15)**	**p**	**-95.%**	**+95.%**
Mean/Interc.	-2666.67	4.542717	-587.02	0.000000	-2676.35	-2656.99
(1)pH (L)	96.62	0.194138	497.68	0.000000	96.21	97.03
pH (Q)	-7.80	0.004609	-1691.22	0.000000	-7.81	-7.79
(2)Concentration(L)	5.24	0.038324	136.73	0.000000	5.16	5.32
Concentration(Q)	-0.13	0.000184	-690.83	0.000000	-0.13	-0.13
(3)Dosage (L)	81.54	0.383240	212.76	0.000000	80.72	82.36
Dosage (Q)	-13.75	0.018438	-745.88	0.000000	-13.79	-13.71
(4)Temperature(L)	15.29	0.028377	538.65	0.000000	15.23	15.35
Temperature(Q)	-0.02	0.000046	-535.99	0.000000	-0.02	-0.02
1L by 2L	0.04	0.001207	29.41	0.000000	0.03	0.04
1L by 3L	-0.58	0.012070	-48.26	0.000000	-0.61	-0.56
1L by 4L	-0.01	0.000604	-12.63	0.000000	-0.01	-0.01
2L by 3L	-0.18	0.002414	-72.70	0.000000	-0.18	-0.17

2L by 4L	-0.00	0.000121	-3.11	0.007217	-0.00	-0.00
3L by 4L	-0.06	0.001207	-49.71	0.000000	-0.06	-0.06

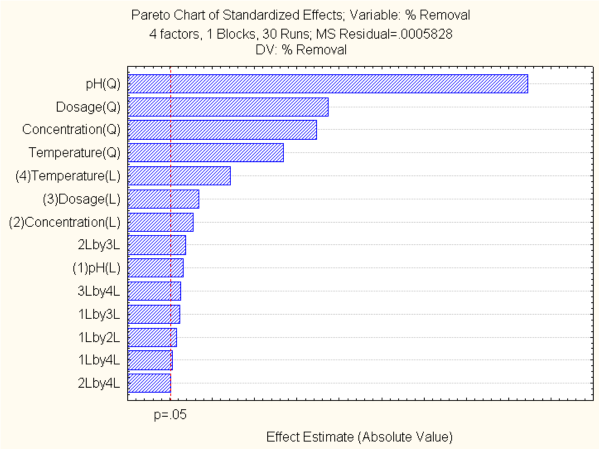

Fig. 13 Pareto Chart

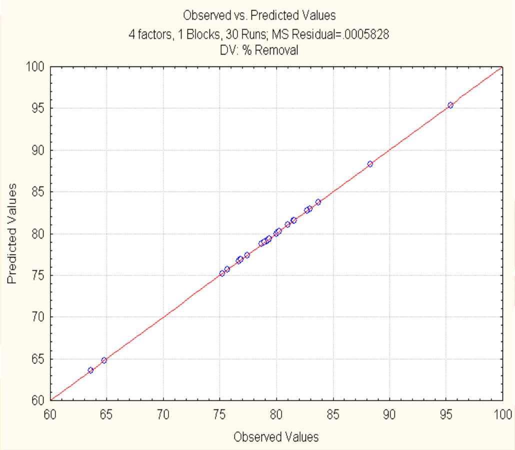

Fig. 14 Normal probability plot for % biosorption of SCB dye

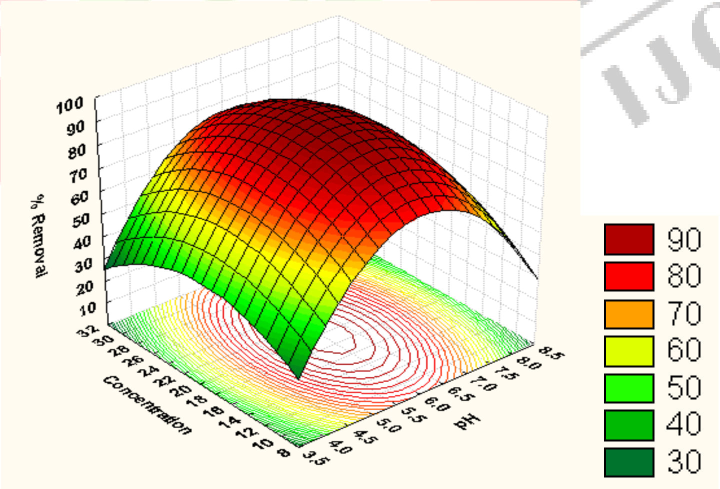

Fig. 15 (a) Surface contour plot for the effects of pH and initial concentration of SCB dye on % biosorption

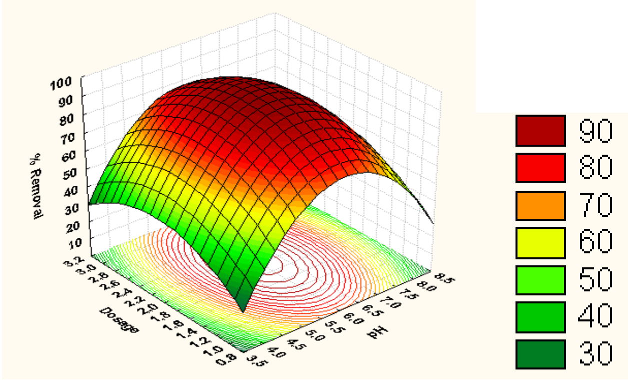

Fig. 15 (b) Surface contour plot for the effects of pH and dosage on % biosorption of SCB dye

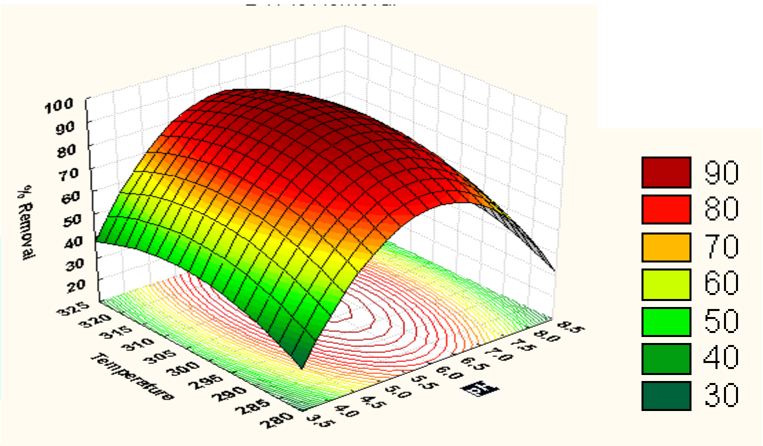

Fig. 15 (c) Surface contour plot for the effects of pH and Temperature on % biosorption of SCB dye

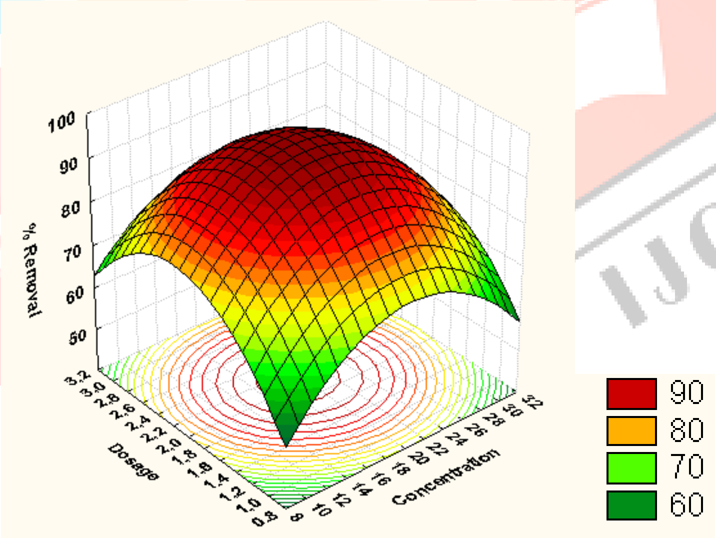

Fig. 15 (d) Surface contour plot for the effects of initial concentration and Dosage on % biosorption of SCB dye

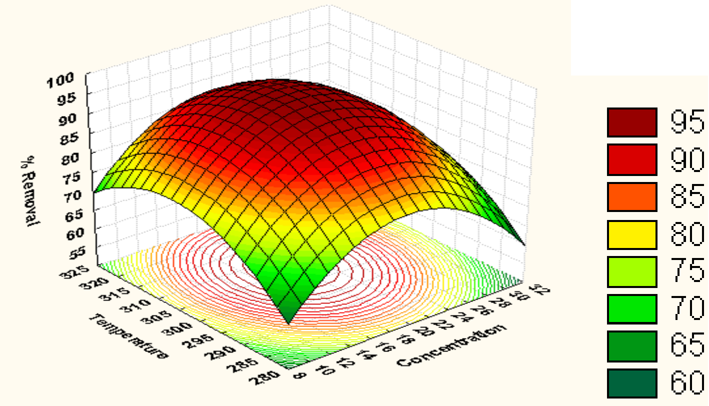

Fig. 15 (e) Surface contour plot for the effects of initial concentration and Temperature on % biosorption of SCB dye

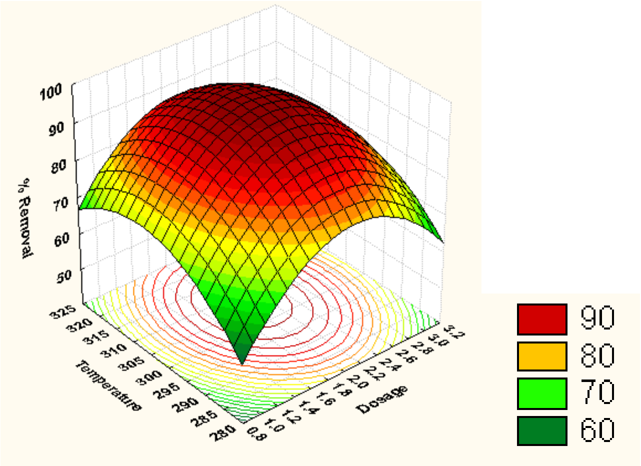

Fig.15 (f) Surface contour plot for the effects of Dosage and Temperature on % biosorption of SCB dye

IV CONCLUSIONS

The equilibrium agitation time for SCB dye biosorption is 50 minutes. The optimum dosage for biosorption is 35 g/L. Maximum extent of biosorption is noted at pH = 6. From the predicted values of RSM results, maximum biosorption of SCB dye (85.03392 %) is observed when the processing parameters are set as pH = 5.9549, w = 30.3234 g/L, Co = 19.7484 mg/L and T = 303.3380 K.

The investigation also reveals the:

1. Endothermic nature of biosorption as ΔH is positive (13.94678 J/mole)
2. Spontaneity of the biosorption as ΔG is negative (–10729.4J/mole)
3. Irreversible nature of biosorption as ΔS is positive (35.45668)

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