

# Mitigation of Amaranth Dye from Aqueous Solution Using Steam Activated Pigmented Rice Husk Carbon as an Adsorbent

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*Received December 4, 2011; revised and accepted September 14, 2012*

**Abstract:** Dyes represent one of the problematic groups. Though commercial activated carbon is a preferred sorbent for colour removal, its widespread use is restricted due to high cost. In the present work, the steam activated pigmented carbon prepared from rice husk (B.N. *Oryza Sativa*) was investigated as an adsorbent to remove Amaranth dye from aqueous solutions. The adsorbent was investigated under variable system parameters, such as, initial concentration of the aqueous dye solution, agitation time, adsorbent amount and temperature. The results of the present study have indicated that an amount of 0.8 g SAPRHC per litre could remove 43.0% of the dye from an aqueous solution of 10 ppm with agitation time 300 minutes. The interactions were tested with respect to both pseudo first-order and second-order kinetics. The later was found to be more suitable. High value of  $q_m$  indicates high capacity of adsorption and the value of the coefficient  $b$  indicates that the interaction of dye with SAPRHC i.e. (dye + SAPRHC = dye...SAPRHC complex) leads to the formation of a complex, being shifted overwhelmingly towards adsorption. The results obtained indicate a potential use of SAPRHC for removing dyes like Amaranth dye from water.

**Key words:** Steam activated pigmented rice husk carbon, Amaranth dye, adsorption, adsorbent, colour.

## Introduction

Many industries, such as dye stuffs, textile, paper and plastic use dyes in order to colour their products and also consume substantial volume of water. As a result they generate a considerable amount of coloured waste water. It is recognized that public perception of water quality is greatly influenced by the colour. Colour is the first contaminant to be recognized in water (Banat et al., 1996). The traces (presence of very small amounts) of dyes in water (less than 1 ppm for some dyes) are highly visible and undesirable (Robinson et al., 2001).

Many dyes and pigments are toxic in nature with suspected carcinogenic and mutagenic effects (Mckay et al., 1987) which poses great health hazards not only to aquatic biota, but also humans. Over 100,000

commercially available dyes exist and a large quantity of dyes, more than  $7 \times 10^5$  tons per year are produced annually, which is either flushed out as waste or is present in the environment of industries in the form of effluents (Pearce et al., 2003; McMullan et al., 2001), which can adversely effect the health of the workers or the general public in the vicinity of the plants. An indication of the scale of the problem is gauged by the fact that two percent of dyes that are produced are discharged directly in aqueous effluent (Robinson et al., 2001; McMullan et al., 2001). Moreover, waste water containing dyes is very difficult to treat, since the dyes are recalcitrant organic molecules, resistant to aerobic digestion and are stable to light, heat and oxidizing agents (Sun and Yang, 2003; Ravi Kumar et al., 1998).

Effluents having dyes are characterized by fluctuating

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pH with large load of suspended solids and high oxygen demand (Sivraj et al., 2001) and resistance to biological oxidation require tertiary treatment measures (Liakou et al., 1997; Sarasa et al., 1998) such as adsorption on activated carbon etc.

Adsorption onto granulated activated carbon (GAC) or powdered activated carbon (PAC) is widely practiced (Walker et al., 2003; Chen and Wu, 2001) for removal of dyes; however adsorbent-grade activated carbon is cost prohibitive and both regeneration and disposal of the used carbon is often very difficult. This has resulted in a search for developing newer adsorbents based on solid wastes.

Numerous approaches have been studied for the development of cheaper and effective adsorbents. Cost is actually an important parameter for comparing the adsorbent materials. According to Bailey et al., 1999 a sorbent can be considered low-cost if it requires (a) little processing, (b) is abundant in nature, (c) is a by-product or (d) waste material from another industry.

In the light of the above mentioned facts, it is therefore of fundamental importance to develop suitable adsorbent which can adsorb dyes from the aqueous solutions coming out as sewage discharge from industries using dyes.

In the present work, finely powdered Steam Activated Pigmented Rice Husk Carbon (SAPRHC) was used as an adsorbent for dyes with a model system of aqueous Amaranth dye solutions. Amaranth dye (Trisodium (4E) -3-oxo-4 [(4-sulfonato-1-naphthyl) hydrzono] naphthalene - 2, 7-disulfonate) is an anionic azo dye.

## Materials and Methods

### Adsorbate: Amaranth

Amaranth dye obtained from S.D. Fine Chem was used, without further purification, in the experiment. The chemical structure of dye is shown in Figure 1 and its general characteristics are indicated in Table 1.

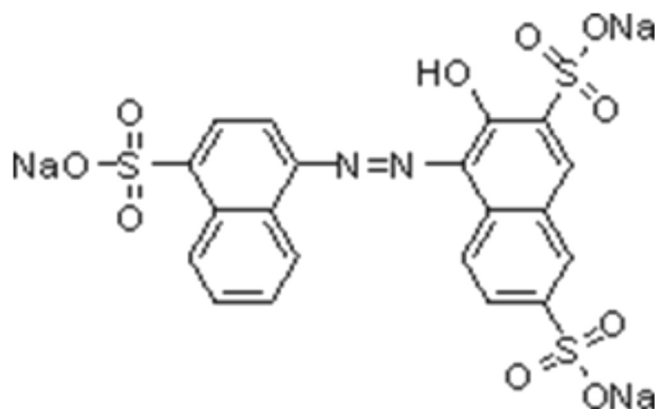
It is an anionic dye made from coal tar. It usually comes as tri sodium salt. It is reddish brown, dark red to purple in colour and is water soluble powder that decomposes at 120°C without melting. It can be applied to natural and synthetic fibres, leather paper and phenol-formaldehyde resins.

### Preparation of Aqueous Amaranth Dye Solutions

Solutions of Amaranth were made from a stock solution containing 1000 mg of the dye in one litre, which was made by dissolving the required amount of Amaranth in double distilled water. The aqueous solution of the dye had a pH of 7.1. A number of standard solutions were

made from the stock solution in the concentration range 5 ppm to 50 ppm and a calibration curve was drawn by measuring the absorbance at  $\lambda_{\max} = 560$  nm using the instrument, Vis scan 167, provided by Systronics. The experimental data, reported in Figure 2, were fitted by a straight line with a high determination coefficient ( $R^2 = 1.0$ ).

The high value of the determination coefficient of the calibration line observed in the present study allows us



IUPAC Name –

Trisodium (4E) -3-oxo-4 [(4-sulfonato-1-naphthyl) hydrzono] naphthalene - 2, 7-disulfonate

Figure 1: Chemical structure of Amaranth dye.

Table 1: General characteristics of Amaranth

Dye	Amaranth
Type	Anionic
Form	Powder
Colour	Reddish brown
Molecular wt.(g/mol)	604.47
Maximum wavelength of absorbance $\lambda_{\max}$ (nm)	560

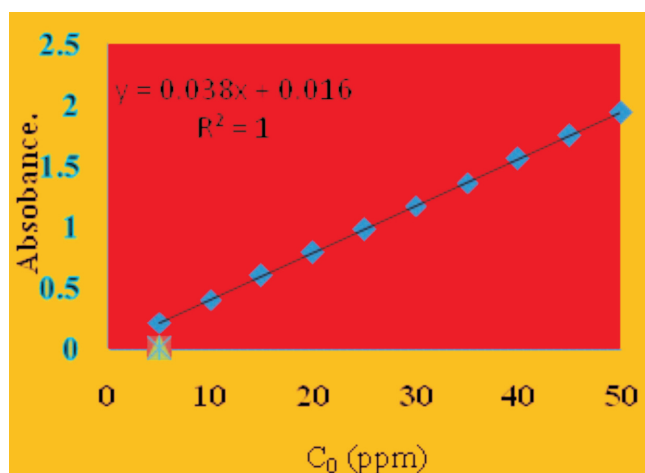


Figure 2: Calibration curve of Amaranth dye.

to consider that the molar extinction coefficient is constant over the concentration range investigated. Thus, the Amaranth concentration will be determined with good precision.

### Adsorbent

This study employed agricultural waste residue that was obtained from Calicut, Kerala, India. Rice husk is a by-product of rice milling industry, accounts for about 20% of the whole rice grain. It possesses a granular structure, which is insoluble in water, and has chemical stability and high mechanical strength.

### Preparation of the Adsorbent

Rice husk carbon was procured from Kerala and after repeated washings with double distilled water it was dried in oven at 473 K and subsequently grinded in a round ball mill (G.S.I. Lab, Faridabad, India) to mesh size 40 to 60  $\mu\text{m}$ . This powdered carbon was activated by steam in a specially designed vessel for 3 to 4 hours. After that, 1%  $\text{AgNO}_3$  solution was added and it was kept in sunlight for pigmentation. Heating of pigmented carbon was done in an oven for 7 to 8 hours at 653 K (in vacuum) and stored in air tight container in desiccators in presence of KOH and  $\text{CaCl}_2$ .

### Adsorption Experiments with Steam Activated Pigmented Rice Husk Carbon

All adsorption experiments were done without adjusting the pH, as the pH of the aqueous solutions of dyes did not change much with dilution. The experimental conditions under which the adsorption experiments were carried out are given in Table 2.

**Table 2: The experimental conditions under which the adsorption experiments were carried out**

Initial Dye Conc. (ppm)	10, 20, 30, 40, 50
Amt. of Adsorbent ( $\text{g L}^{-1}$ )	0.1, 0.2, 0.3, 0.4, 0.5
pH	7.1
Agitation Time (min.)	30, 60, 90, 120, 150, 180, 210,.....300
Adsorption Temp. (K)	283, 293, 303, 313
Particle Size ( $\mu\text{m}$ )	40 - 60

The batch adsorption was carried out in 250 mL Borosil conical flasks by mixing a pre-weighed amount of the SAPRHC with 100 mL of the aqueous dye solution of a particular concentration. The conical flasks were kept on a magnetic shaker maintained at a constant temperature of  $303 \pm 2$  K (except for thermodynamic

studies) and were agitated for a pre-determined time interval at a constant speed.

The system parameters such as adsorbent amount, agitation time and temperature of adsorption were controlled during the experiments. After adsorption was over, 5 mL solution was taken out and centrifuged for 15 to 20 minutes and the un-adsorbed remaining dye was determined spectrophotometrically at 560 nm.

pH of the dye solution was measured with pH meter.

### Effects of Contact Time and Adsorbent Doses

The effects of contact time and adsorbent doses were studied at constant initial dye concentration. To investigate the effects of initial dye concentration on the uptake of the dye, experiments were conducted by varying the initial concentrations of the dye from 5 to 50 ppm at constant doses of adsorbent ( $0.8 \text{ g L}^{-1}$ ).

The amount of dye adsorbed per unit mass of the adsorbent, ( $q$ ) in ( $\text{mg g}^{-1}$ ) was computed by using the following expression:

$$q = C_0 - C_t/M$$

where  $C_0$  and  $C_t$  are dye concentrations in ppm before and after adsorption for time  $t$  and  $M$  in gram (g) is the amount of adsorbent taken for 1 L of dye solution. The extent of adsorption in percentage is found by the relation.

$$\text{Adsorption (\%)} = (C_0 - C_t/C_0) \times 100$$

### Kinetics of Adsorption

The order of adsorbate-adsorbent interactions has been described by using various kinetic models. Traditionally, the well known pseudo first-order model of Lagergren has been found of general use, but second-order kinetics has also been successfully applied to describe the interactions.

When adsorption is preceded by diffusion through a boundary, the kinetics in most cases follow the pseudo first-order rate equation of Lagergren.

$$dq_t/dt = k_1 (q_e - q_t) \quad (1)$$

where  $q_t$  and  $q_e$  are the amounts adsorbed at time  $t$  and at equilibrium and  $k_1$  is the rate constant of the pseudo first-order adsorption process. The integrated rate law, after applying the initial condition of  $q_t = 0$  and  $t = 0$ , is

$$\log (q_e - q_t) = \log q_e - (k_1/2.303) t \quad (2)$$

The plot of  $\log (q_e - q_t)$  vs.  $t$  gives a straight line for first order kinetics, which allows computation of the adsorption rate constant,  $k_1$ . If the experimental results do not follow equations (1) and (2), they differ in two important aspects: (i)  $k_1 (q_e - q_t)$  does not represent the number of available sites, and (ii)  $\log (q_e)$  is not equal to

the intercept of the plot of  $\log (q_e - q_t)$  vs.  $t$ . In such cases, pseudo second-order kinetics given by

$$dq_t/dt = k_2 (q_e - q_t)^2 \quad (3)$$

is applicable (Ho and McKay, 2003; Ho et al., 2005), where  $k_2$  is the second-order rate constant. For the boundary conditions  $t = 0$  to  $t = t$  and  $q_t = 0$  to  $q_t = q_t$ , the integrated form of the equation is

$$1/(q_e - q_t) = (1/q_e) + k_2 t \quad (4)$$

This can also be written as

$$q_t = 1/(1/k_2 q_e^2) + t/q_e \quad (5)$$

or in the linear form

$$t/q_t = 1/h + (1/q_e)t \quad (6)$$

where  $h = k_2 q_e^2$  can be regarded as the initial sorption rate as  $t \rightarrow 0$ . If the pseudo second-order kinetics is applicable, the plot of  $q_t$  vs.  $t$  gives a linear relationship, which allows computation of  $q_e$ ,  $k_2$  and  $h$  without knowing any parameter before hand.

### Intra-particle Diffusion

The variation in the amount of adsorption with time at different initial dye concentrations could be further processed for evaluating the role of diffusion in the adsorption process. Adsorption is a multi-step process involving transport of the solute molecules from the aqueous phase to the surface of the solid particulates followed by diffusion of the solute molecules into the pore interiors. The intra-particle diffusion rate is given by the equation (Weber and Morris, 1963).

$$q_t = k_i t^{0.5} \quad (7)$$

where  $k_i$  is the intra-particle diffusion rate constant. The values of  $k_i$  are calculated from the slopes of  $q_t$  vs.  $t^{0.5}$  plots.

### Adsorption Isotherms

The fractional coverage,  $\theta$ , on an adsorbent surface at constant temperature is represented by Langmuir isotherm—the most widely used two-parameter equations for a single component system. This isotherm has the simple form

$$\theta = q_e/q_m = b C_e / 1 + C_e \quad (8)$$

where  $C_e$  is the concentration of the adsorbate at equilibrium,  $q_e$  the amount adsorbed at equilibrium in unit mass of the adsorbent,  $q_m$  the monolayer capacity and  $b$  is the equilibrium constant, given by the ratio  $k_a/k_d$ ,  $k_a$  and  $k_d$  being the rate constant of the adsorption and desorption processes respectively. Equation (8) can be rearranged to

$$C_e/q_e = 1/bq_m + (1/q_m) \times C_e \quad (9)$$

and a plot of  $(C_e/q_e)$  versus  $C_e$  should give a straight line. The slope and the intercept of this line give the values of  $q_m$  and  $b$ .

A further analysis of the Langmuir equation can be made on the basis of dimensionless equilibrium parameter  $R_L$  or the separation factor, defined as

$$R_L = 1/1 + C_{ref} \quad (10)$$

where  $C_{ref}$  is any equilibrium liquid phase concentration of the solute. For favourable adsorption  $0 < R_L < 1$ , while  $R_L > 1$  represents unfavourable adsorption and  $R_L = 1$  represents linear adsorption, while the adsorption process is irreversible if  $R_L = 0$ .

The empirical isotherm due to Freundlich is also used to describe adsorption. This has the form

$$q_e = k_f C_e^n \quad (11)$$

where  $k_f$  and  $n$  are known as Freundlich coefficients obtainable from the plots of  $\log q_e$  vs.  $\log C_e$  on the basis of the linear form of the equation

$$\log q_e = \log k_f + n \log C_e \quad (12)$$

### Effect of pH

The effects of pH on the adsorption of dyes were examined by varying the initial pH of the dye from 2 to 10. The adjustment of initial pH of the dye solutions was made by NaOH and HCl solutions. Mixture of dye and adsorbent was allowed to equilibrate for 90 and 120 minutes in a shaker prior to measurement of the final pH.

## Results and Discussion

### Adsorption of Amaranth Dye on SAPRHC

#### Effect of Agitation Time and Kinetics

The kinetics was investigated with a constant dye concentration of 25 ppm at 300 K with five different adsorbent concentrations 0.1, 0.2, 0.4, 0.6 and 0.8 g/L in the interaction time intervals of 30 to 300 minutes. A gradual increase in the extent of adsorption with time was observed as shown in Figure 3.

Amaranth dye adsorption increased from 5.3 to 43.0% and 1.3 to 10.9% in the given time interval for adsorbent amounts 0.1 to 0.8 g/L respectively. Such behaviour is expected in a batch reactor with constant adsorbent amount and varying initial adsorbate concentration. An increase in the adsorbent amount results in increase in percentage removal of Amaranth dye from solution. The nature of the adsorbent and its concentration affected the time needed to reach equilibrium. In the present case,



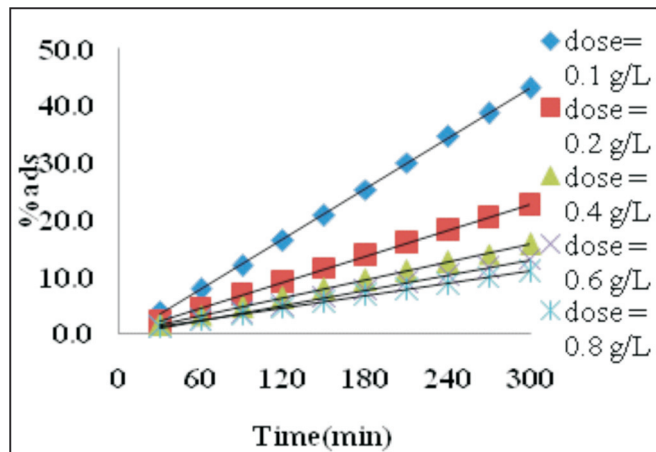


Figure 3: Influence of agitation time with adsorbent dose at constant initial concentration.

the adsorbate-adsorbent interactions approached at pseudo equilibrium at around 300 minutes.

Lagergren plots of  $\log(q_e - q_t)$  vs.  $t$  (agitation time) for adsorption of Amaranth dye on SAPRHC at 300 K were linear in nature as shown in Figure 4. The rate constant calculated from the slopes of the best-fit lines in all the cases was  $4.6 \times 10^{-3} \text{ min}^{-1}$  (correlation coefficient were in the range of 0.896 to 0.978 with a mean value of  $R = 0.908$ ).

The pseudo first-order equation of Lagergren is adequate to describe the adsorption process in a large number of cases despite of its failure to provide a concrete mechanism of the adsorption process (Ho et al., 2001). In the present work, it was observed that  $\log q_e$  values computed from the experimentally obtained  $q_e$  values, did not agree with  $\log q_e$  values obtained from Lagergren plots. This indicates that pseudo first-order kinetics might not be sufficient to describe the mechanism of Amaranth dye-SAPRHC interactions. The pseudo second-order model based on equation of second-order kinetics equation, which considers the rate limiting step as the formation of the chemisorptive bond involving sharing or exchange of electrons between the adsorbate and the adsorbent was therefore applied. The plot of  $t/q_t$  vs.  $t$  yields straight lines as shown in Figure 5. Success with the second-order kinetics suggests chemisorptions as the rate controlling step.

Kinetics of adsorption of Amaranth dye on Steam Activated Pigmented Rice Husk Carbon also followed the Elovich equation with the plot of  $q_t$  versus  $\ln t$  yielding straight lines as shown in Figure 6, with high correlation coefficient of 0.897 to 0.916 in all the cases. The Elovich equation does not predict any definite mechanism but it is useful in describing adsorption on highly

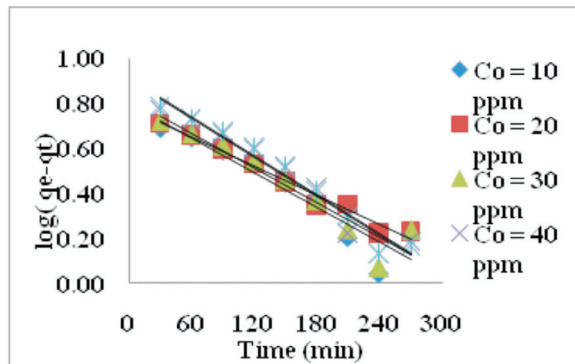


Figure 4: Lagergren plots.

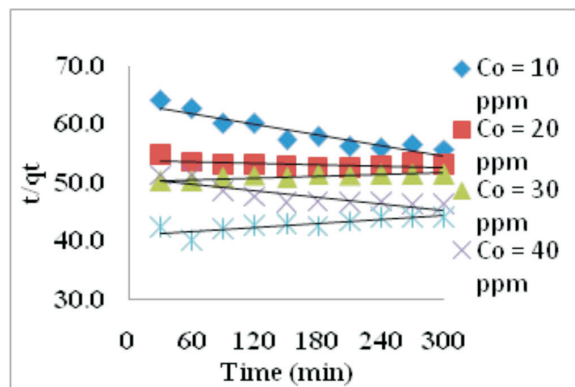


Figure 5: Pseudo second-order kinetics plots.

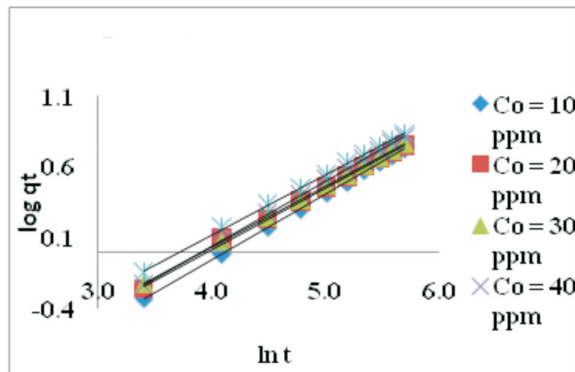


Figure 6: Plots for Elovich equation.

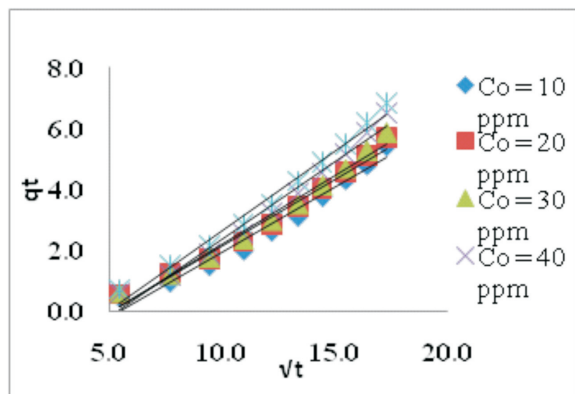


Figure 7: The plots  $q_t$  vs  $t^{1/2}$ .

heterogeneous adsorbents similar to rice husk carbon (Ho et al., 2001). Applicability of the Elovich equation shows that the adsorption of Amaranth dye on SAPRHC is predominantly chemical in nature (Ho et al., 2001).

An adsorption process is normally controlled by three diffusion steps: (1) transport of the solute from bulk solution to the film surrounding the adsorbent, (2) transfer from the film to the adsorbent surface, leading to surface adsorption and (3) diffusion from the surface to the internal sites followed by binding of the adsorbate on the active sites. The slowest of these steps determines the overall rate of adsorption process. The initial rate of the intra-particle diffusion is obtained with the help of equation (9) by plotting  $q_t$  versus  $t^{0.5}$ . The plots show multi linearity with two or more steps as shown in Figure 7.

The first sharper portion represents adsorption on the external surface, which is almost instantaneous. The second portion indicates a comparatively slower adsorption when the adsorbate diffuses gradually into the interior surface of the particles and the adsorption becomes intra-particle diffusion controlled (Wu et al., 2000). In few curves, a third portion can also be distinguished as the final equilibrium stage when the intra-particle diffusion starts to slow down due to saturation of most of the adsorption sites. The multi linear curves might be due to adsorption on the irregular non-uniform sites in the steps and edges of the particles.

#### *Intra-particle Diffusion*

The plots of  $q_t$  vs.  $t^{0.5}$  were found to yield straight lines (Figure 7) with regression coefficients 0.973 to 0.983. The intra-particle diffusion rate constant  $k_i$  was in the range of 0.425 to 0.521 ppm/g min<sup>0.5</sup> (mean  $k_i$  = 0.468 ppm/g min<sup>0.5</sup>). The linearity of the plots showed that intra-particle diffusion might have a significant role in the adsorption of the dye (Amaranth) on the adsorbent.

The adsorption of the dye on adsorbent (SAPRHC) cannot be described by simple mechanism of surface interactions only (Wu et al., 2000). It is likely that the adsorption on surface was followed by diffusion into the pores by large number of steps. If the two steps are independent of each other, the plot of  $q_t$  vs.  $t^{0.5}$  appears as a combination of two or more intersecting lines (Wu et al., 2000). The first line of two lines represents surface adsorption and the second, intra-particle diffusion. The presence of such distinctive features in the plots of the present work could be interpreted due to very little distinction between the two steps. Surface adsorption and intra-particle diffusion were likely to take place

simultaneously and both the processes control the kinetics of the dye-solid interactions. The pores and the steps on the SAPRHC particles were such that they could accommodate the Amaranth dye molecules.

Still, it is not easy to draw a conclusion about the rate limiting step. Waber and Morris (1963) had proposed that if the uptake of the adsorbate varies with the square root of time, intra-particle diffusion can be taken as the rate limiting step. Equation (7) requires that  $q_t$  vs.  $t^{0.5}$  plots should have zero intercept if the intra-particle diffusion is the sole rate limiting step (Ho and McKay, 2003). Since this was not the case in the present work, so it is concluded that intra-particle diffusion is not the dominating mechanism for the adsorption of the dyes on SAPRHC.

#### *Effect of Adsorbent Amount and Initial Concentration of the Adsorbate*

The variation in the extent of adsorption with the amount of adsorbent for a constant Amaranth dye concentration is given in Table 3. The adsorption increased rapidly as more and more of the adsorbent was added. The adsorption increased from 5.3 to 43.0% for solution of 10 ppm concentration, when the adsorbent amount was increased from 0.1 to 0.8 g/L for an agitation time of 300 minutes (Figure 8).

**Table 3: Variation of adsorbed amount of Amaranth dye with adsorbent dose**

Dose(g/L)	0.1	0.2	0.4	0.6	0.8
%ads (Co= 10 ppm)	5.3	10.8	21.3	31.8	43.0
%ads (Co= 20 ppm)	2.8	5.8	11.4	17.1	22.6
%ads (Co= 30 ppm)	2.0	4.0	7.9	11.8	15.6
%ads (Co= 40 ppm)	1.6	3.3	6.5	9.8	13.0
%ads (Co= 50 ppm)	1.3	2.6	5.3	8.1	10.9

This is due to the fact that increase in the amount of the adsorbent makes a large number of sites available leading to an increase in adsorption (Figure 9). With an increase in the concentration of Amaranth at constant amount of adsorbent the adsorption came down for the same agitation time (Table 4).

#### *Adsorption Isotherms*

The adsorption equilibrium was supported both by Langmuir and Freundlich isotherms (Equations 9 and 12) which yield very good results. Both isotherms are given in Figures 10 and 11, for adsorption of the dye from aqueous solutions on different doses of SAPRHC at 300 K with a contact time of 300 minutes. The

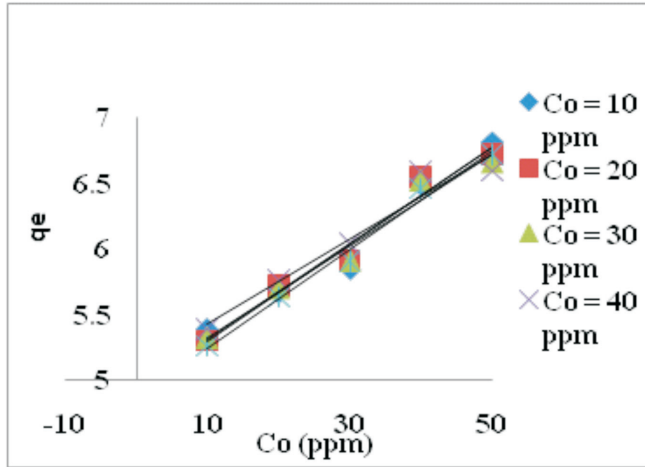


Figure 8: Influence of initial concentration of dye adsorbed on per unit mass of adsorbent.

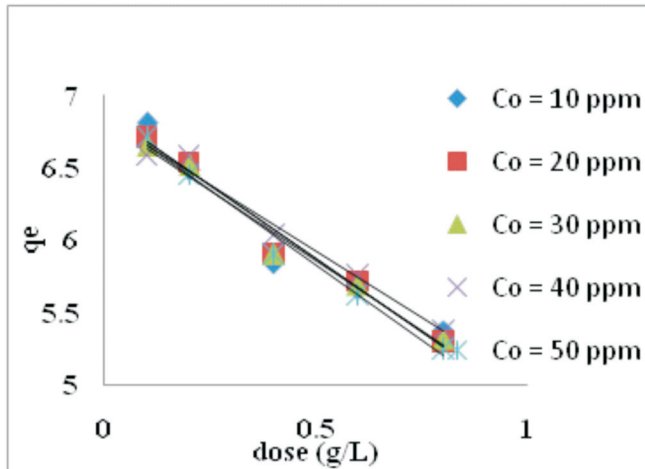


Figure 9: Influence of adsorbent dose on amount of dye adsorbed on per unit mass of adsorbent.

Table 4: Variation of amount of Amaranth dye adsorbed with agitation time (Constant adsorbent dose)

Time	%ads	%ads	%ads	%ads	%ads
0	0.00	0.00	0.00	0.00	0.00
30	3.75	2.20	1.60	1.17	1.14
60	7.75	4.50	3.20	2.30	2.40
90	12.00	6.80	4.70	3.70	3.44
120	16.25	9.10	6.26	5.00	4.52
150	20.75	11.40	7.90	6.40	5.60
180	25.25	13.75	9.40	7.70	6.80
210	30.00	16.05	10.96	9.00	7.78
240	34.50	18.20	12.50	10.30	8.76
270	38.75	20.35	14.00	11.65	9.84
300	43.00	22.70	15.60	13.00	10.92
	$C_0 = 10$	$C_0 = 20$	$C_0 = 30$	$C_0 = 40$	$C_0 = 50$

Freundlich plots (regression coefficients,  $R$  from 0.949 to 0.988) are nearly parallel to one another with similar slopes while the Langmuir plots (regression coefficients,  $R$  from 0.997 to 0.999) appeared to be converging towards the origin with wide difference in slopes. This might be due to lack of uniformity in size, shape and surface energy of the SAPRHC particles.

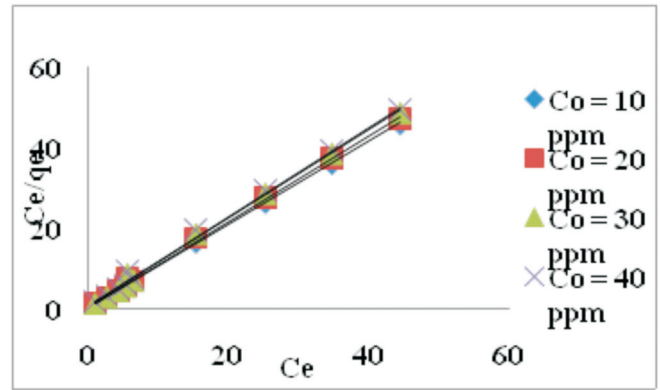


Figure 10: Langmuir adsorption isotherms.

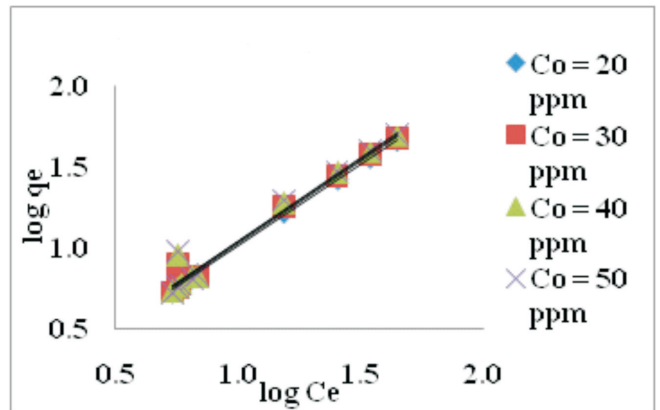


Figure 11: Freundlich adsorption isotherms.

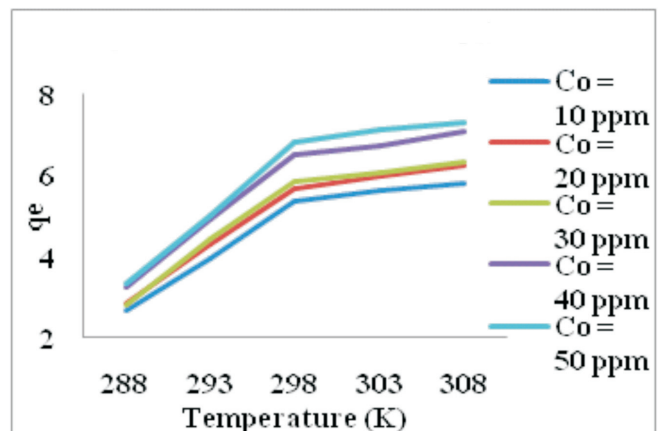


Figure 12: Influence of temperature on amount of adsorption per unit mass of adsorbent.

The large difference in intercepts of the Freundlich curves for the SAPRHC amounts of  $0.1 \text{ g L}^{-1}$  and those of higher amounts were also significant. The adsorption coefficients computed from the curves are given in Table 5.

**Table 5: Freundlich coefficients and Langmuir coefficients for adsorption of Amaranth dye on SAPRHC at 300 K**

Temperature (K)	Langmuir coefficients			Freundlich coefficients	
	$q_m$ (mg/g)	$b$ (L/mmol)	$R_L$	$N$	$k_f$ (L/g)
288	0.971	1.81	0.0522	0.037	83,753
293	0.945	1.86	0.0261	0.036	85,113
298	0.919	1.33	0.0244	0.035	92,044
303	0.908	1.09	0.0222	0.037	123,310
308	-	-	-	0.037	72,777
	0.935	1.52	0.0312	0.035	91,399

The Freundlich coefficient,  $n$ , varied from 0.035 to 0.037 with a mean value of 0.0354. The values being  $< 1$  indicate a favourable adsorption. The other coefficient  $k_f$  was in the range of 72,777 to 123,310  $\text{L g}^{-1}$  (mean value 91,399  $\text{L g}^{-1}$ ) with values showing a decreasing trend with increasing SAPRHC amount.

The Langmuir coefficient  $q_m$ , which is the amount required for complex monolayer coverage of unit mass of the adsorbent, had values starting from 0.908 to 0.971  $\text{m mol g}^{-1}$  (equivalent to 548.8 to 586.9  $\text{mg g}^{-1}$ ) with the mean value 0.935  $\text{m mol g}^{-1}$  (565.2  $\text{mg g}^{-1}$ ). The values decrease with an increasing amount of SAPRHC (Figure 12).

The large Amaranth dye molecules would be occupying an appreciable area on the surface of the SAPRHC particles and the number of the dye molecules covering the adsorbent surface may not be very large, but the high molecular mass ensured a substantial value of monolayer capacity. The  $b$  values are also significantly large, ranging from 1.333 to 1.098  $\text{mmol}^{-1}$  with a mean value of 1.527  $\text{m}^{-1}$ , indicating that the equilibrium, SAPRHC + dye (Amaranth) = [SAPRHC-Amaranth complex] was shifted predominantly to the right. This signifies the potential of SAPRHC as a potential adsorbent for the removal of dyes like Amaranth from aqueous solutions. The dimensionless Langmuir parameter  $R_L$  was found to have small values in the low range, which indicates favourable adsorption (Hall et al., 1966).

## Conclusion

A batch system was applied to study the adsorption of Amaranth dye from water by SAPRHC adsorbent prepared from rice husk waste residue obtained from agriculture industry. From the experimental findings in the present work, the following conclusions can be drawn:

1. SAPRHC has shown sufficient potential as an adsorbent for the removal of Amaranth dye from water. A small amount ( $0.8 \text{ g L}^{-1}$ ) of the adsorbent can decolourize as much as 43% of Amaranth dye from aqueous solutions (10 ppm) if agitated for 300 minutes.
2. It was seen that there is a constant trend for the adsorption capacity at pH values between 3 and 9. So during the adsorption experiments no pH adjustment was done. All experiments were carried out at natural pH for all dye solutions.
3. It was concluded that variation in agitation rate has no effect on the rate of adsorption and adsorption capacity of SAPRHC, so during the adsorption experiments no adjustment was done in agitation rate. All experiments were carried out at constant agitation rate.
4. Experimental data properly fit with both Langmuir and Freundlich isotherms and the adsorption coefficients agreed well with the conditions of favourable adsorption. Value of adsorption coefficients shows great potential of the adsorbent SAPRHC for the practical purposes in colour removal processes.
5. Linearity of the Langmuir isotherm plots indicated the chemical nature of the interactions while the linear Freundlich isotherms pointed to non-specific and energetically non-uniform nature of the adsorption sites.
6. The values of Langmuir monolayer capacity ( $q_m$ ) show the suitability of SAPRHC for high adsorption capacity of Amaranth dye on SAPRHC. In case of Amaranth dye the values of  $q_m$  are above  $0.9 \text{ mg/g}$ .
7. Both pseudo first-order and second-order kinetics were applied to the adsorption of the dye on SAPRHC. It was seen that second-order kinetics is followed by interactions between dye and SAPRHC. On the basis of kinetic studies, the calculated rate constants showed that pseudo second-order model fit better to the experimental



results. The rate constants calculated from the slopes of the best-fit lines (correlation coefficients were in the range of 0.896 to 0.978 with a mean value of  $R = 0.908$ ) in all the cases was  $4.6 \times 10^{-3} \text{ min}^{-1}$  for Amaranth dye.

8. The results of the experiments showed that most of the dye adsorption took place in the first 15 to 30 minutes of contact times and equilibrium reached within 300 minutes for SAPRHC, at optimum dose of 0.8 g/L of the adsorbent dose.
9. Furthermore, intra-particle diffusion was not the only step to control adsorption of the dye. Diffusion of dye particles into the pores follows a large number of steps.

### Recommendations

Recently, there are increasingly stringent restrictions imposed on the organic contents of the industrial effluents. However, many textile industries fail to meet the effluent discharge standards set by the regulatory bodies. It is found that adsorption is the best, very rapid and highly efficient method for the removal of dye from textile effluents.

The Steam Activated Pigmented Rice Husk Carbon (SAPRHC) prepared from rice husk waste residue obtained from agriculture industry can be considered as low cost adsorbent as its preparation method is very easy and economic. Furthermore, this adsorbent is abundant in nature and there is no economic aspect involved. It prevents the disposal problems and hence we need not to worry about its regeneration. Thus there is a promising scope for the large scale application of the adsorbent to remove the most problematic, water soluble dyes from textile effluents. However, much work is yet required in this area to study the mechanism of adsorption process for dye removal from real textile effluents under a wide range of operating conditions. Moreover, better understanding of adsorption mechanism is also essential to estimate economic feasibility of SAPRHC for large scale applications.

Thus, SAPRHC can truly be termed as a low-cost adsorbent.

### Significance

Utilization of agriculture waste is of great significance in India where more than 2000 million ton of agricultural

residue is generated annually (Reddy, 2006). Disposal of this agricultural waste is also a big problem as it involves lot of time, money and burning of it causes increase of alkalinity of soil. Also, many textile industries release their waste water directly into drains, water bodies or on land. These effluents contain an appreciable amount of the dye which is hazardous to the environment. If we can prepare suitable low cost adsorbent from agricultural waste which is available in plenty and can adsorb dyes from textile effluents at normal/moderate conditions (following the rules of Green Chemistry), this will help us:

1. In pretreatment of waste water before discharging them in water bodies and on land as waste water decreases the soil fertility and significantly contributes in water pollution.
2. In saving drinking water. As the effluents seeps through the soil, it get mixed with the ground water, thus making it unfit for consumption.
3. In saving organic productivity as textile effluents show adverse effects on productivity.
4. It will provide additional employments and income to marginal farmers and landless agricultural labourers especially in developing countries (Reddy, 2006).
5. Dyes adsorbed on the adsorbent can be recycled, preventing a great amount of the dye from being wasted.
6. SAPRHC not only showed promising results into adsorbing organic pollutants but also the heavy metals can be adsorbed on it.
7. It also improves the colour quality of water coming out of dye industries, thus helps in maintaining the flora and fauna of rivers and/or lakes.
8. Use of small tablets made from SAPRHC can remove fluoride ion and other toxic contents of drinking water.
9. More research is required to establish SAPRHC as an effective adsorbent for gases coming out from mines and chimneys of industries. It will help in reducing acid rain and release of green house gases into the atmosphere.

### Acknowledgement

Author B. Janveja gratefully acknowledges University Grants Commission, Government of India for research fellowship through its FIP programme.

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