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Capacity of activated carbon in the removal of acid brilliant blue: Determination of equilibrium and kinetic model parameters

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Abstract

The adsorption of acid brilliant blue onto thermally activated coir pith carbon in aqueous solution was studied in a batch system with respect to contact time, pH, and temperature. Acidic pH was favorable for the adsorption of this dye. The surface characterization of thermally activated coir pith carbon was performed using the FT-IR technique. Kinetic studies showed that the adsorption of dye on coir pith carbon was a gradual process. Lagergren-first-order, second-order, intra-particle diffusion model and Bangham were used to fit the experimental data. Equilibrium isotherms were analysed by Langmuir, Freundlich, Dubinin–Radushkevich and Tempkin isotherms. The adsorption capacity was found to be 15.24 mg/g by Langmuir isotherm. The pH effect and desorption studies suggest that chemisorption might be the major mode of the adsorption process. The change is entropy (ΔS°) and heat of adsorption (ΔH°) of coir pith carbon was estimated as185.45 J/(mol K) and 48.02 kJ/mol, respectively. The high negative value of change in Gibbs free energy indicates the feasible and spontaneous nature of adsorption on acid brilliant blue on coir pith carbon.

Keywords: Adsorption; Acid brilliant blue; Coir pith carbon; Kinetics; Isotherms; pH effect; Temperature effect

1. Introduction

Activated carbons are the most widely used adsorbents in industry. Powdered and granular active carbons are used in waste and potable water treatment, in system of air emission cleaning, in chemical processes such as solvent recovery and decolouring, in general domestic applications such as odour and smell removal. The world market for activated carbon in 2000 year was calculated to be 7 lakh tonnes and its growth estimated at 4–6% per year. These adsorbents have a price that ranges over a wide field (US$ 3–12 for kg) relating with origin, quality and quantity. This study is to learn the adsorption behaviour of carbons made from coir pith. Coir pith is a by-product of coir processing industry, is produced more than 7.5 million tonnes annually in southern India [1]. We have analysed the possibility of producing economic and efficient carbons from coir pith and their capability to remove heavy metal [2–4], chlorophenol [5,6] and dyeing [7] substances.

The textile industry (and especially that part focused on the dyeing process) belongs among important sources of contamination responsible for the continuous pollution of the environment. Production of textiles and volume of wastewater containing processed textile dyes steadily increases [8]. Inefficiencies in the dyeing of textiles results in large amounts of the dyestuff being lost directly into wastewater and consequently having a detrimental effect on flora and fauna [9–11]. The American Dye Manufacturers Institute states that dyes and pigments cannot be classified as hazardous chemicals except for benzidine and certain cationic dyes (particularly triphenyl-methane types) which are very toxic to fishes. The real hazard setting aside aesthetic considerations is caused when coloured agents interfere with the transmission of light through water and hinder photosynthesis, so resulting in ecological imbalance [12,13]. There are more than 100,000 dyes available commercially, most of which are difficult to decolourise due to their complex structure and synthetic origin. They are specifically designed to resist fading upon exposure to sweat, light, water and oxidizing agents and as such are very stable and difficult to degrade [14,15]. Acid dyes are organic sulphonic acids; the commercially available forms are usually sodium salts, which exhibit good water solubility.

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In sequence of their importance, acid dyes are mostly used with certain fiber types such as polyamide, wool, silk, modified acrylic, and polypropylene fibers, as well as blends of the aforementioned fibers with other fibers such as cotton, rayon, polyester, regular acrylic, etc. From the aesthetic point of view, the presence of dyes, in particular carcinogenic compounds, in surface and underground waters is not safe, pleasant, or welcomed. Recently, all governments have been under severe pressure by their people to stop this type of effluent to the public watercourses, unless it is treated properly. So the removal of colour from waste effluents has become environmentally important [16,17]. The USEPA (Environmental Protection Agency) has classified textile wastes into four groups, dispersible, hard-to-treat, high-volume, and hazardous and toxic wastes [18].

Hence, the removal of dye from process or waste effluents becomes environmentally important. Because of the high degree of organics present in these molecules and the stability of modern dyes, conventional physicochemical and biological treatment methods are ineffective for their removal. This led to the study of other effective methods [17,19,20]. The adsorption process is one of the effective methods used to remove dyes from aqueous solution. Equilibrium data are known as adsorption isotherms, Langmuir, Freundlich, etc., are the main requirements for the design of adsorption systems. Obtaining equilibrium data for a specific adsorbate/adsorbent system can be carried out experimentally, with a time-consuming procedure that is incompatible with the growing need for adsorption systems design [21].

In this research, the ability of coir pith carbon to remove acid brilliant blue by adsorption has been studied. The adsorption capacity of dye was also examined using the adsorption isotherm technique. The kinetic and thermodynamic parameters were also calculated to determine rate constants and adsorption mechanism. The experimental data were fitted into Langmuir and Tempkin equations to determine which isotherm gives the best correlation to experimental data.

2. Experimental

2.1. Physico-chemical analysis of adsorbent

Coir pith was collected from nearby coconut coir industries, dried in sunlight for 5 h and ground. The dried coir pith powder was sieved to 250–500 μm size. It was subjected to carbonization at 700 °C for 1 h using a muffle furnace under closed conditions. The carbonized material was taken out, sieved to 250–500 μm size again and used for adsorption studies. Morphological features of samples were obtained with a Hitachi 2300 Scanning Electron Microscope. FT-IR spectra were obtained using Shimadzu, model FTIR-8201 PC. The characteristics of the coir pith carbon have been reported in Table 1.

Table 1
Characteristics of coir pith carbon

Physical parameters	
Specific surface area (m^2/g)	167
Bulk density (g/ml)	0.12
Conductivity (1% solution) (mS/cm)	2.3
Mechanical moisture content (%)	5.88
Specific gravity	1.742
Decolourising power (mg/g)	21.0
Iodine number (mg/g)	101.52
pH_{ZPC}	8.0
pH (1% solution)	10.1
Ash content (%)	79.87
Porosity (%)	93.11
Volatile matter (%)	58.38
Fixed carbon (%)	41.62
Ion exchange capacity	Nil
Chemical parameters	
Sodium (%)	0.14
Calcium (%)	0.22
Iron (%)	0.18
Potassium (%)	0.18
Phosphorous (%)	0.01

2.2. Experimental procedure

Adsorption experiments were carried out by agitating 200 mg of carbon with 50 ml of dye solution of desired concentration and pH at 200 rpm, 35 °C in a thermostated rotary shaker (ORBITEK, Chennai, India). Acid brilliant blue concentration was estimated spectrophotometrically by monitoring the absorbance at 550 nm using UV–vis spectrophotometer (Hitachi, model U-3210, Tokyo). pH was measured using pH meter (Elico, model LI-107, Hyderabad, India). The dye solution was separated from the adsorbent by centrifugation at 20,000 rpm for 20 min and its absorbance was measured. Effect of adsorbent dosage was studied with different adsorbent doses (30–400 mg) and 50 ml of dye solutions and agitated for equilibrium time. Langmuir, Freundlich, Dubinin and Radushkevich and Tempkin, equations were employed to study the equilibrium adsorption. Effect of pH was studied by adjusting the pH of dye solutions using dilute HCl and NaOH solutions and the solutions were agitated with 200 mg/50 ml adsorbent dose at 40 and 60 min, respectively, for 10 and 30 mg/l dye concentrations. Desorption studies of the adsorbent that was used for the adsorption of 10 or 30 mg/l of dye solution was separated from the solution by centrifugation. The dye-loaded adsorbent was filtered using Whatman filter paper and washed gently with water to remove any unadsorbed dye. Several such samples were prepared. Then the spent adsorbent was agitated for 25, and 70 min with 50 ml of distilled water, adjusted to different pH values. The desorbed dye was estimated as before. For temperature studies, adsorption of 10 mg/l of acid brilliant blue by 100 mg of adsorbent was carried out at 35, 40, 50 and 60 °C in the thermostated rotary shaker.

3. Results and discussion

3.1. Scanning electron micrograph (SEM) studies

SEM is widely used to study the morphological features and surface characteristics of the adsorbent materials [22,23]. In the present study, scanning electron microscopic photograph (Fig. 1) of coir pit carbon reveals surface texture and porosity. This photomicrograph shows fibrous structure of coir pith carbon.

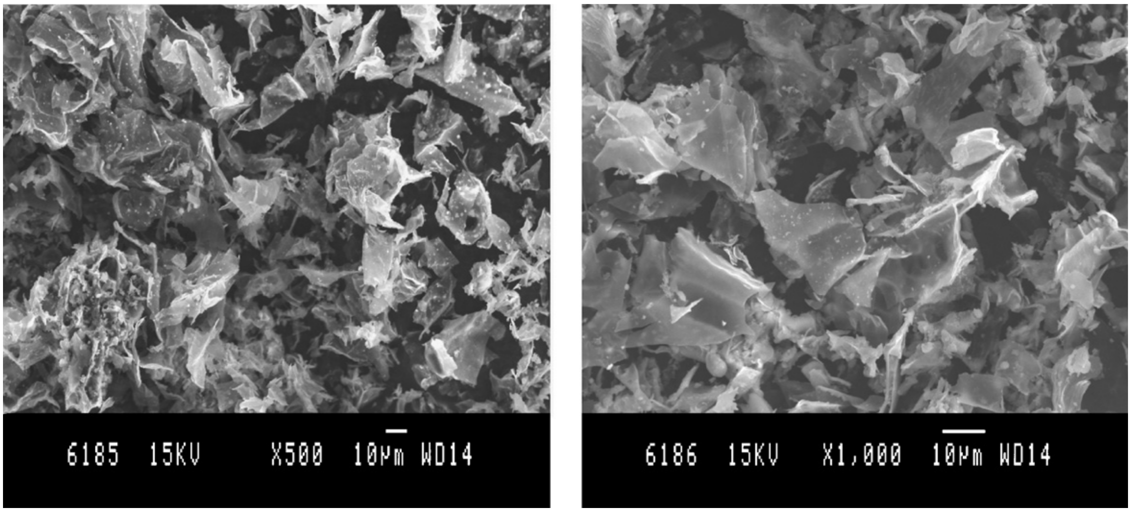

Fig. 1. Scanning electron micrograph coir pith carbon.

3.2. IR Spectroscopy studies of coir pith carbon

IR analysis permits spectrophotometric observation of the adsorbent surface in the range 400–4000 cm^{-1}, and serves as a direct means for the identification of the organic functional groups on the surface. An examination of the adsorbent surface before and after adsorption reaction possibly provides information regarding the surface groups that might have participated in the adsorption reaction and also indicates the surface site(s) on which adsorption has taken place. IR studies indicate the participation of the specific functional groups in adsorption interaction.

IR spectrum of the carbon showed (Fig. 2) peaks at 3417.6 and 3244 cm^{-1} which can be assigned to the O–H stretching vibration mode of hydroxyl functional groups including hydrogen bonding and peaks in the range of 2923.9 and 2856.4 cm^{-1} indicate the presence of aliphatic C–H stretching. The presence of the band around 2400 cm^{-1} denotes the presence of C=O stretching. The overlapping bands in the region 1600–1500 cm^{-1} may be related to C=C vibration and around 1660–1550 cm^{-1} is attributed to the presence of highly conjugated C–O in a quinone/carbonyl structure. Quinone type oxygen accounts for about 25% of the total oxygen present on the surface of the carbon. The band for 1480–1300 cm^{-1} may be due to the presence of the OH bending vibration and indicates the presence of phenolic group. The band around 900–800 cm^{-1} region may be attributed to symmetric CO_3 stretch and is associated with the deformation of the carbonate group. The overlapping bands in the region of 800–600 cm^{-1} may be due to out of plane ring deformation (621 cm^{-1} CH_2 Rocking).

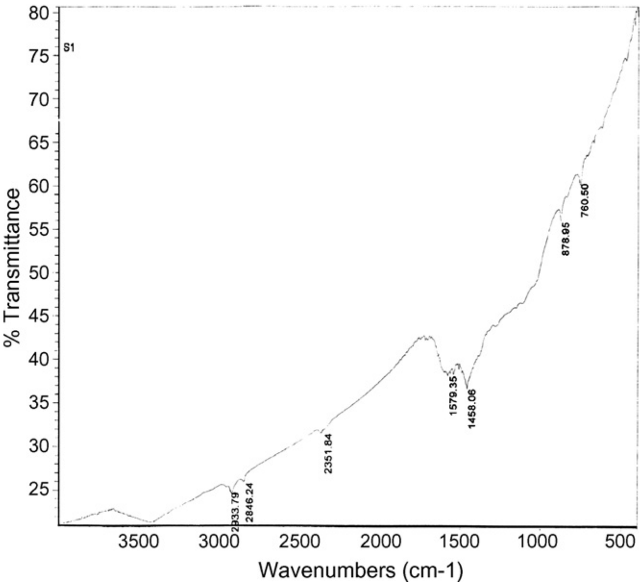

Fig. 2. FT-IR Spectra of Coir pith carbon.

3.3. Effects of agitation time and concentration of dye on adsorption

The amount of dye adsorbed (mg/g) increased with increase in agitation time and reached equilibrium. The equilibrium time was 25 min for 10 mg/l, 70 min for 30 and 50 mg/l, and 150 min for 70 mg/l of dye concentration, respectively. The amount of dye removal at equilibrium increased from 2.5 to 13.68 mg/g with the increase in dye concentration from 10 to 70 mg/l. It is clear that the removal of dyes depends on the concentration of the dye.

3.4. Adsorption dynamics

The rate constant of adsorption is determined from the first order rate expression given by Lagergren [24].

$$\log(q_e - q) = \log q_e - \frac{k_1 t}{2.303} \tag{1}$$

where q_e and q are the amounts of dye adsorbed (mg/g) at equilibrium and at time t (min), respectively and k_1 is the rate constant of adsorption (l/min). Values of k_1 were calculated from the plots of $\log(q_e - q)$ versus t (figure not shown) suggested the first order kinetics of the removal of acid brilliant blue. The values of k_1

Table 2
Kinetic parameters for the removal of acid brilliant blue by coir pith carbon

Concentration	k_1 (min^{-1})	q_e (mg/g)	R^2	Temperature (°C)	k_1 (min^{-1})	q_e (mg/g)	R^2
Pseudo-first-order constants							
10	0.11	0.271	0.856	35	0.117	2.314	0.967
20	0.06	2.413	0.967	40	0.124	1.992	0.989
30	0.04	1.638	0.898	50	0.103	1.314	0.971
40	0.02	2.180	0.927	60	0.081	0.586	0.927

Concentration	h (mg/(g min))	k_2 (g/(mg min))	R^2	Temperature (°C)	h (mg/(g min))	k_2 (g/(mg min))	R^2
Pseudo-second-order constants							
10	5.5858	0.9149	0.9999	35	1.8957	0.086	0.999
20	2.8061	0.0569	0.9986	40	2.4779	0.109	0.999
30	9.4788	0.0811	0.9997	50	3.7037	0.164	0.999
40	6.9055	0.0371	0.9998	60	7.8872	0.343	1.000

Concentration	k_0 (ml/(g l))	α	R^2	Temperature (°C)	k_0 (ml/(g l))	α	R^2
Bangham constants							
10	58.27	0.0601	0.8723	35	146.11	0.2027	0.9959
20	39.17	0.1257	0.9916	40	164.23	0.1794	0.9807
30	44.75	0.0792	0.9264	50	203.22	0.1228	0.9801
40	38.83	0.0697	0.9284	60	248.52	0.0759	0.8894

Concentration	k_{id} (mg/(g min))	R^2	Temperature (°C)	k_{id} (mg/(g min))	R^2
Intra-particle diffusion constants					
10	0.0733	0.8056	35	0.3286	0.9743
20	0.0313	0.9595	40	0.295	0.9396
30	0.3109	0.8194	50	0.2098	0.9443
40	0.2443	0.8124	60	0.1301	0.8068

and q_e at different concentrations were calculated from the slops and intercepts of these curves are represented in Table 2.

3.5. The second-order kinetic model [25] is expressed as

$$\frac{t}{q} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{2}$$

the initial adsorption rate, h (mg/(g min)), as $t \rightarrow 0$ can be defined as

$$h = k_2 q_e^2 \tag{3}$$

The initial adsorption rate (h), the equilibrium adsorption capacity (q_e), and the second-order constants k_2 (g/(mg min)) can be determined experimentally from the slope and intercept of plot of t/q versus t (Fig. 3). Calculated correlations are closer to unity for second-order kinetics model; therefore the adsorption kinetics could well be approximated more favorably by second-order kinetic model for acid brilliant blue. The k_2 (g/(mg min)) and h (mg/(g min)) values as calculated from Fig. 4 are listed in Table 2. Similar phenomena have been observed in the adsorption of congo red and 2-chlorophenol on coir pith carbon [5,7].

3.6. Intra-particle diffusion study

An empirically found functional relationship, common to the most adsorption processes, is that the uptake varies almost proportionally with $t^{1/2}$, the Weber–Morris plot, rather than with the contact time, t [26].

$$q_t = k_{id} t^{1/2} + C \tag{4}$$

where k_{id} is the intra-particle diffusion rate constant. According to Eq. (4), a plot of q_t versus $t^{1/2}$ should be a straight line with a slope k_{id} and intercept C when adsorption mechanism follows the intra-particle diffusion process. Values of intercept give an idea about the thickness of boundary layer, i.e., the larger the intercept the greater is the boundary layer effect [27]. In Fig. 4, plot of mass of dye adsorbed per unit mass of adsorbent, q_t versus $t^{1/2}$ is presented for acid brilliant blue. The linear plots are attributed to the macropore diffusion which is the accessible sites of adsorption. This is attributed to the instantaneous utilization of the most readily available adsorbing sites on the adsorbent surface. The values if k_{id} as obtained from the slope of straight lines are listed in Table 2.

3.7. Bangham's equation

Kinetic data were further used to know about the slow the step occurring in the present adsorption system using Bangham's equation [28].

$$\log \log \left(\frac{C_0}{C_0 - q_t m}\right) = \log \left(\frac{k_0 m}{2.303\mathrm{V}}\right) + \log(t) \tag{5}$$

where C_0 is the initial concentration of adsorbate in solution (mg/l), V the volume of solution (ml), m the weight of adsor-

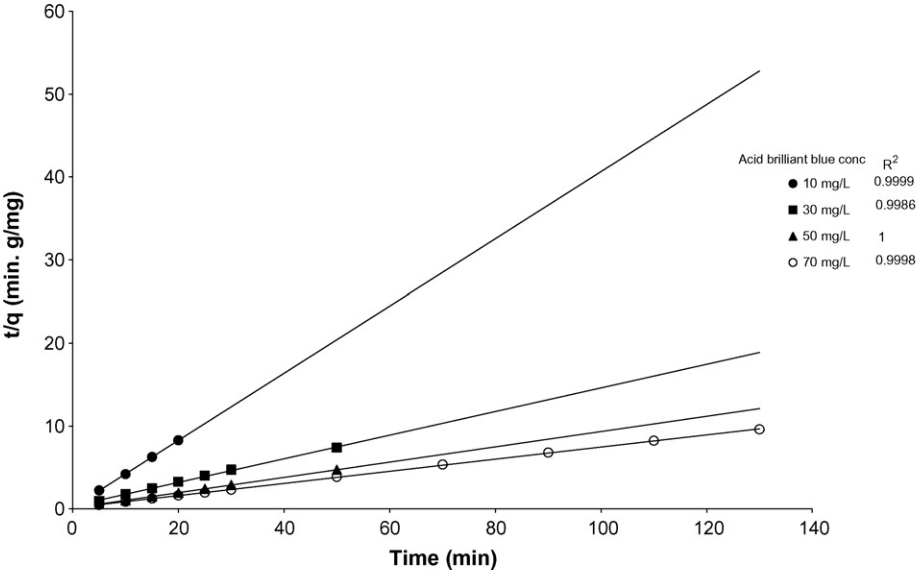

Fig. 3. Second-order kinetics plots for the removal of acid brilliant blue: at different initial dye concentrations: adsorbent dose, 300 mg/50 ml; initial pH, 6.9, temperature, 35 °C.

bent per liter of solution (g/l), q_t (mg/g) the amount of adsorbate retained at time t, and α (<1) and k_0 are constants. The double logarithmic plot (Fig. 5) according to above equation yielded perfect linear curves for acid brilliant blue removal by carbon showing that the diffusion of adsorbate into pores of the adsorbent is not the only rate controlling step [29].

3.8. Adsorption equilibrium study

To optimize the design of an adsorption system for the adsorption of acid brilliant blue, it is important to establish the most appropriate correlation for the equilibrium curves. Various isotherm equations have been used to describe the equilibrium nature of adsorption. Some of these equations are Langmuir, Freundlich, Dubinin and Radushkevich and Tempkin equations.

3.8.1. Adsorption isotherms

Langmuir isotherm [30] is represented by the following equation:

$$\frac{C_e}{q_e} = \frac{1}{Q_0 b} + \frac{C_e}{Q_0} \qquad (6)$$

where C_e is the concentration of dye solution (mg/l) at equilibrium. The constant Q_0 signifies the adsorption capacity (mg/g) and b is related to the energy of adsorption (l/mg). Linear plot of C_e/q_e versus C_e shows that adsorption follows Langmuir isotherm (figure not shown). Values of Q_0 and b were calcu-

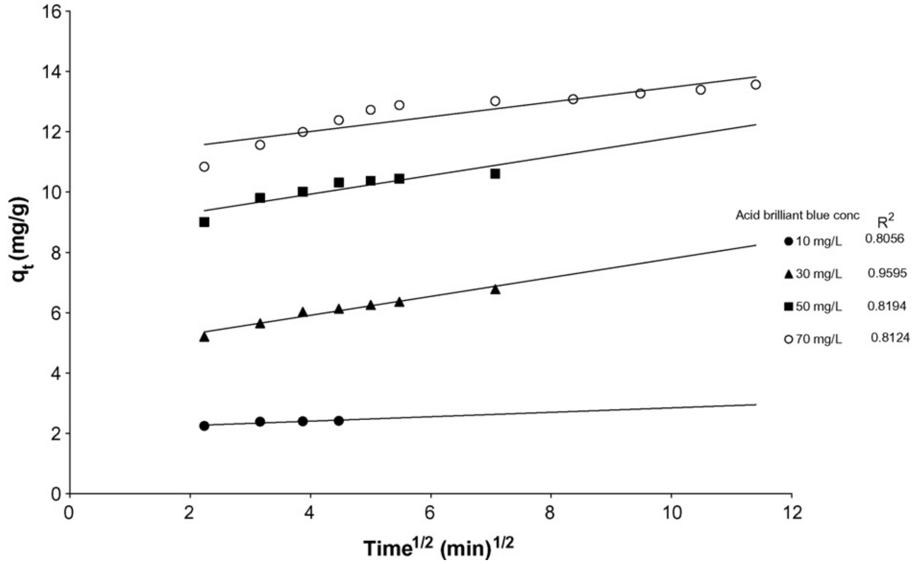

Fig. 4. Weber and Morris intra-particle diffusion plots for removal of acid brilliant blue: at different initial dye concentrations: adsorbent dose, 300 mg/50 ml; initial pH, 6.9, temperature, 35 °C.

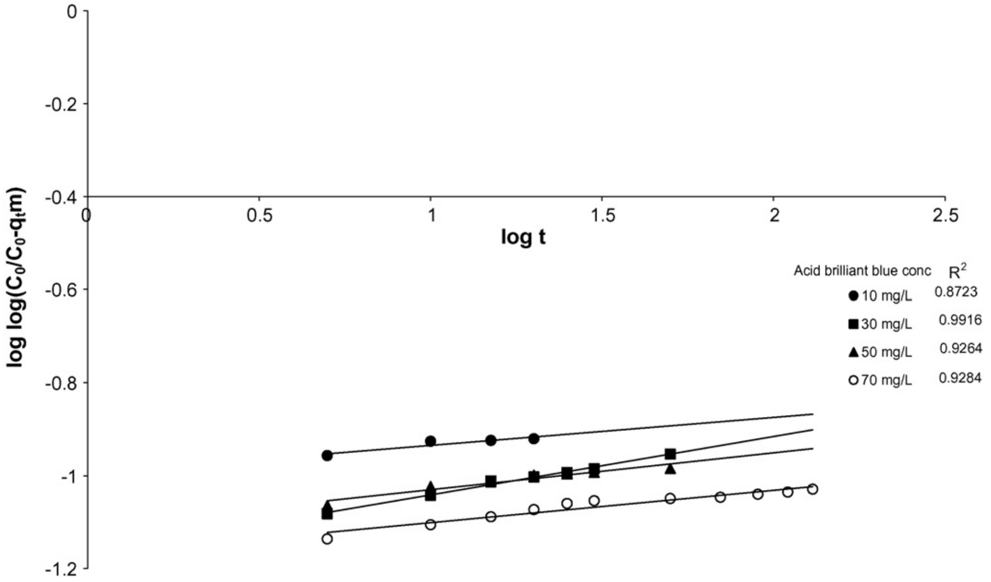

Fig. 5. Bangham's plot for removal of acid brilliant blue, at different initial dye concentrations: adsorbent dose, 300 mg/50 ml; initial pH, 6.9, temperature, 35 °C.

lated from the slope and intercept of the linear plots and are presented in Table 3. Values of Q_0 and b were observed using biogas residual slurry [31] and banana pith [32] as adsorbent for the removal of acid brilliant blue are 13.51, 0.13 and 4.35, 0.13, respectively.

The essential characteristics of Langmuir isotherm can be expressed by a dimensionless constant called equilibrium parameter R_L, defined by Weber and Chakkravorti [33]:

$$R_L = \frac{1}{1/bC_0} \tag{7}$$

where b is the Langmuir constant and C_0 is the initial dye concentration (mg/l), R_L values indicate the type of isotherm. Table 3 shows R_L values between zero and one, which indicate favorable adsorption.

Table 3
Isotherm parameters for removal of acid brilliant blue by coir pith

Concentration	Q_0 (mg/g)	b (l/mg)	R_L
Langmuir constants			
10	15.24	0.471	0.18
30			0.07
50			0.04
70			0.03

Concentration	k_f ($\mathrm{mg}^{1-(1/n)}\,\mathrm{L}^{1/n}\,\mathrm{g}^{-1}$)	n	R^2
Freundlich constants			
10	4.37	3.00	0.9998
30	4.30	2.17	0.9998
50	2.81	1.81	0.9999
70	2.31	1.68	0.9992

Concentration	q_s (mg/g)	E (kJ/mol)	R^2
Dubnin–Radushkevich constants			
10	10.32	2.673	0.8791
20			
30			
40			

Concentration	K_t (1/mg)	B_1	R^2
Tempkin constants			
10	10.50	2.5411	0.9587
20			
30			
40			

3.8.2. *Freundlich isotherm [34] was also applied to plot the equilibrium data of the adsorption:*

$$\log_{10}\left(\frac{x}{m}\right) = \log_{10}k_f + \left(\frac{1}{n}\right)\log_{10}C_e \tag{8}$$

where x is the amount of dye adsorbed (mg), m the weight of the adsorbent used (g), C_e is the equilibrium concentration of dye in solution (mg/l), k_f ($\mathrm{mg}^{1-(1/n)}\,\mathrm{L}^{1/n}\,\mathrm{g}^{-1}$) and $1/n$ are Freundlich constants. n is related to the adsorption energy distribution, and k_f indicates the adsorption capacity. The correlation coefficients were found to be less than 0.9 (Fig. 6) and values of k_f and n were calculated from the intercept and slope of the plots and are presented in Table 3. Values of k_f and n were observed using biogas residual slurry and banana pith as adsorbent for the removal of acid brilliant blue are 0.50, 1.238 and 1.0, 2.63, respectively.

3.8.3. *Dubinin and Radushkevich isotherm*

Another equation used in the analysis of isotherms was proposed by Dubinin and Radushkevich [35]

$$q_e = q_s \exp(-B\varepsilon^2) \tag{9}$$

where q_s is D–R constant and ε can be correlated:

$$\varepsilon = RT\,\ln\left(1 + \frac{1}{C_e}\right) \tag{10}$$

The constant B gives the mean free energy E of adsorption per molecule of adsorbate when it is transferred to the surface

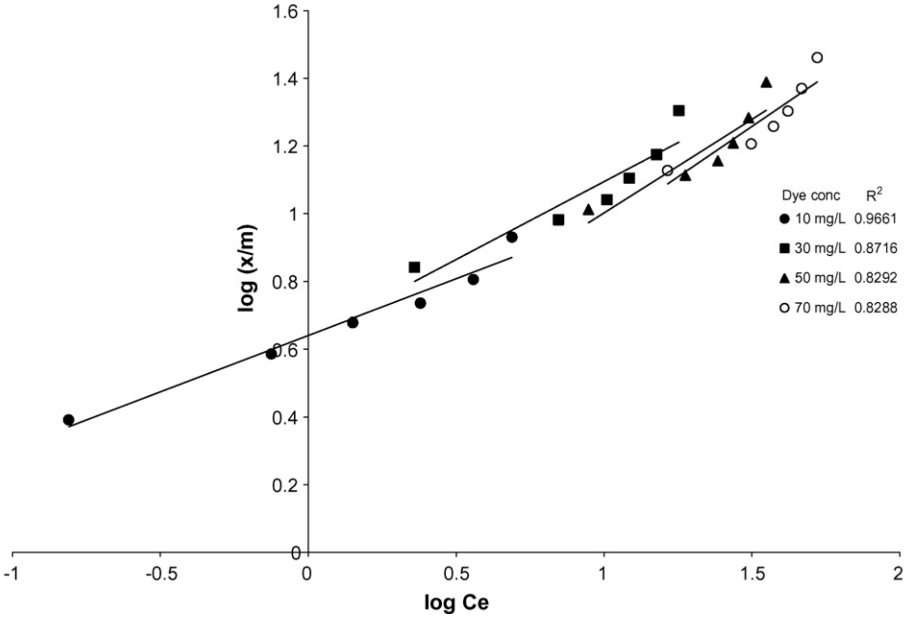

Fig. 6. Freundlich plots for the adsorption of acid brilliant blue by coir pith carbon.

of the solid from infinity in the solution and can be computed using the following relationship [36]:

$$E = \frac{1}{(2B)^{1/2}} \tag{11}$$

Calculated Dubinin–Radushkevich constants for the adsorption of acid brilliant blue on coir pith carbon are shown in Table 3; the values of correlation coefficients are much lower than the other three isotherms values. In this case, the D–R equation represents the poorer fit of experimental data than the other isotherm equation.

3.8.4. Tempkin isotherm

Tempkin isotherm contains a factor that explicitly takes into account adsorbing species–adsorbate interactions. This isotherm assumes that: (i) the heat of adsorption of all the molecules in the layer decreases linearly with coverage due to adsorbate–adsorbate interactions, and (ii) adsorption is characterized by a uniform distribution of binding energies, up to some maximum binding energy [37]. Tempkin isotherm is represented by the following equation:

$$q_e = \frac{RT}{b} \ln (K_t C_e) \tag{12}$$

Eq. (12) can be expressed in its linear form as:

$$q_e = B_1 \ln K_t + B_1 \ln C_e \tag{13}$$

where

$$B_1 = \frac{RT}{b} \tag{14}$$

The adsorption data can be analysed according to Eq. (13). A plot of q_e versus $\ln C_e$ enables the determination of the isotherm constants K_t and B_1. K_t is the equilibrium binding constant (l/mol) corresponding to the maximum binding energy and constant B_1 is related to the heat of adsorption. The values of the parameters are given in Table 3.

3.9. Pore diffusion coefficient

Assuming spherical geometry for the adsorbent, the time for half adsorption can be correlated to the pore diffusion coefficient [38].

$$t_{1/2} = \frac{0.03 r_0^2}{D_p} \tag{15}$$

where $t_{1/2}$ is the time for half adsorption (s), r_0 is the radius of the adsorbent particle (cm) and D_p is the diffusion coefficient (cm^2/s). Values of D_p have been calculated for different temperatures and different concentrations of dye. The removal of dye follows pore diffusion process since the coefficient values are in the range of 10^{-11} to 10^{-13} cm^2/s. values of D_p for acid brilliant blue are 1.414 cm^2/s for 10 mg/l, 0.505 cm^2/s for 30 and 50 mg/l and 0.236 cm^2/s for 70 mg/l and for temperature studies 0.884 cm^2/s for 10 mg/l at 35, 40, 50 and 60 °C have also been observed.

3.10. Studies on pH effect

Effect of pH on the removal of acid brilliant blue is shown in Fig. 7. The adsorption of this anionic dye group onto the adsorbent surface is primarily influenced by the surface charge on the adsorbent, which in turn is influenced by the solution pH [39]. The maximum removal for acid brilliant blue with carbon was hence observed at pH 2, when the surface is positively charged with excess protons in solution. The percent removal was nearly the same for 10 mg/l dye concentration and slightly decreased

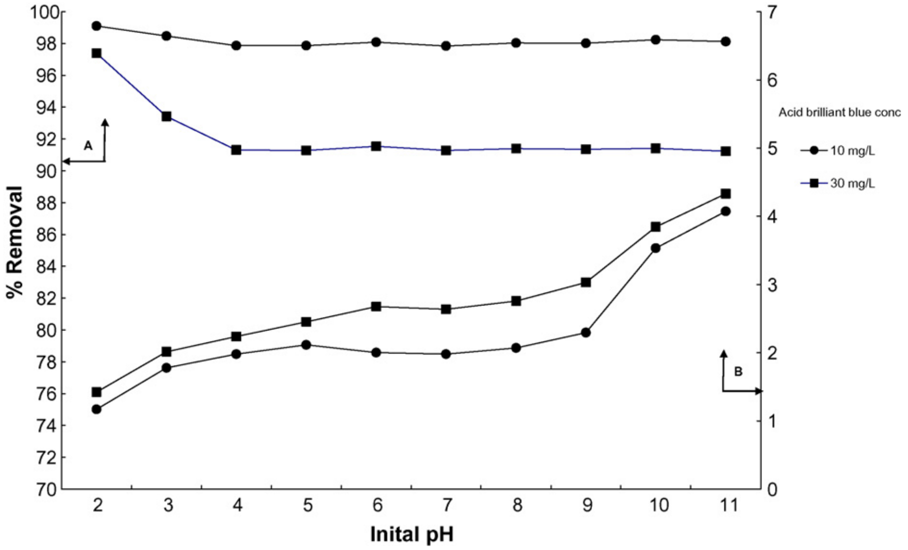

Fig. 7. Effect of pH on removal of acid brilliant blue: adsorbent dose, 300 mg/50 ml;10 mg/l, agitation time 40 min; 20 mg/l, agitation time 60 min (B) Effect of pH on desorption of dye from dye-loaded adsorbent. Adsorbent dose, 300 mg/50 ml;10 mg/l, agitation time 40 min; 20 mg/l, agitation time 60 min.

from 97 to 91 for 30 mg/l dye concentration when the pH was increased from 2 to 11.

3.11. Desorption studies

To make the adsorption process more economical, it is necessary to regenerate the spent carbon and dye solution, which can be further recycled. As the desorbing pH was increased, the percent removal increased slightly from 1.0 at pH 2 to 4.0 at pH 11 for the dye concentration of 10 and 30 mg/l. Very low desorption of dye suggests that chemisorption like surface complex formation might be the major mode of dye removal by the adsorbent. This is also substantiated by the significant adsorption of the dye in the alkaline pH though electrostatic attraction does not favor the adsorption (Fig. 7).

3.12. Effect of temperature

Increase of temperature increased the percent removal. The change in standard free energy, enthalpy and entropy of adsorption were calculated using the following equations:

$$\Delta G^\circ = -RT \ln K_c \tag{16}$$

where R is gas constant and K_c is the equilibrium constant and T is the temperature in K.

According to van't Hoff equation,

$$\log_{10} K_c = \frac{\Delta S^\circ}{2.303} - \frac{\Delta H^\circ}{2.303RT} \tag{17}$$

Positive values of ΔH° (48.02 kJ/mol) show the endothermic nature of adsorption. The negative values of (−9.24, −9.66, −12.29 and −13.57 kJ/mol) ΔG° indicate the spontaneous nature of adsorption for acid brilliant blue at 35, 40, 50 and 60 °C. Entropy of activation can be regarded as a measure of the "saddle point of energy" over which reactant molecules must pass as activated complexes. Thus, ΔS° conveys whether a particular reaction proceeds faster or slower than another individual reaction [40]. The positive values of ΔS° (185.45 J/mol/K) suggest the increased randomness at the solid/solution interface during the adsorption of dye on coir pith carbon. Kinetic models also applied for temperature studies and it shows perfect linear curves for acid brilliant blue at different temperature studies and the equilibrium data obtained for all the kinetics are presented in Table 2.

4. Conclusions

Having an excess of positive charge on their surfaces, activated carbon has a greater capacity to adsorb acid brilliant blue. With respect to the suitability of the first-order and second-order kinetic models for acid brilliant blue adsorption onto carbon, it has been represented that the adsorption kinetics of acid brilliant blue corresponding obey preferably the second-order kinetics which provide the best correlation of the data. However, the evidence is provided that the adsorption of dye onto coir pith carbon is a complex process, so it cannot be adequately described by a single kinetic model throughout the whole process. In this manner, for instance, intraparticle diffusion played a significant role, but it was not the main rate-determining step during the adsorption. By comparing the correlation coefficients determined for each linear transformation of isotherm analysis, the Langmuir and Tempkin isotherm model, which fit the experimental data reasonably well, were found to provide the best prediction for the adsorption of acid brilliant blue. The activation energy of adsorption can be evaluated with the second-order rate constants. Since the raw material coir pith is freely available in large quantities in coir industries the treatment method seems to be economical. Based on the above good results this relatively cheap, low-cost material is recommended as effective and cheap adsorbent for removal of dye from textile effluents.

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