

Anionic Dye Adsorption Characteristics of Surfactant-Modified Coir Pith, a 'Waste' Lignocellulosic Polymer

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ABSTRACT: The surface of coir pith, an agricultural solid waste, was modified using a cationic surfactant hexadecyltrimethylammonium bromide. Adsorption of anionic dyes on surfactant-modified coir pith was investigated in a series of batch adsorption experiments. Two anionic dyes, acid brilliant blue (acid dye) and procion orange (reactive dye), were used in the adsorption studies. The effect of process variables such as contact time, concentration of the dyes, adsorbent dose, temperature, and pH were studied in order to understand the kinetic and thermodynamic parameters of the process. The kinetics of adsorption obeyed the second-order rate equation.

The equilibrium adsorption data were fitted into the Langmuir and Freundlich isotherms. It was found that modified coir pith yielded adsorption capacities of 159 and 89 mg/g for acid brilliant blue and procion orange, respectively. Mechanisms involving ion exchange and chemisorption might be responsible for the uptake of dyes. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 100: 1538–1546, 2006

Key words: adsorption; dyes/pigments; surfactant; macroporous polymers; waste

INTRODUCTION

There is a growing interest in the use of renewable biomaterials as sorbents for the treatment of wastewater containing dyes. In the past, the focus was on using traditional sorbents, such as activated carbon and polymeric resins, for the treatment of dye-containing wastewater from textile discharges. In addition to requiring high initial capital investment and operating costs in large-scale applications, resin sorbents are derived from nonrenewable resources, and activated carbon often poses disposal problems after use. Many investigators have studied the feasibility of using inexpensive alternative materials like wood,¹ Fuller's earth and fireclay,² flyash,³ biogas residual slurry,^{4,5} waste Fe(III)/Cr(III) hydroxide,⁶ waste orange peel,⁷ red mud,⁸ banana pith,⁹ peat,¹⁰ chitin,¹¹ and chitosan¹² to remove dyes from wastewater. However, several factors, including variability in composition, source, and low sorption capacities, have limited their use despite their low cost. Anionic dyes are extensively used in the dyeing process, but about 20%–40% of these remain in the effluents.¹³ Because anionic dyes are highly soluble in water, removing them from wastewater is very difficult.¹⁴ So the goal of our research was to develop an effective sorbent for anionic dyes from low-cost renewable biomaterials.

Coir pith is a light fluffy waste material that is generated in the separation process of the fiber from the coconut husk. It is estimated that the production of coir pith in India is about 7.5 million tons per year.¹⁵ Raw coir pith and carbonized coir pith also have been used as adsorbents for the removal of dyes.^{16–18} Coir pith consists mainly of biopolymers such as cellulose and lignin. In solution, these groups in the pith lose hydrogen ions and form a particle surface with a negative potential.¹⁹ Recently, the application of a surfactant in environmental remediation has drawn greater attention.²⁰ Cationic surfactants have strong affinity for coir pith, making them suitable for surfactant modification. The cationic surfactant used in this study, hexadecyltrimethylammonium (HDTMA) bromide, is a tetra-substituted ammonium cation with permanently charged pentavalent nitrogen and a long straight alkyl (C16) chain that imparts a high degree of hydrophobicity. After modification, coir pith exhibits high sorption capacity for anionic contaminants. So the objective of this study was to examine the adsorption of a commonly used anionic acidic dye such as acid brilliant blue (ABB) and an anionic reactive azo dye such as procion orange (PO) by surfactant-modified coir pith (CPHDTMA) and to determine the applicability of CPHDTMA as adsorbent in the treatment of textile wastewater.

EXPERIMENTAL

Materials

All reagents used were analytical-grade chemicals and were obtained from Merck (Mumbai, India). Stock

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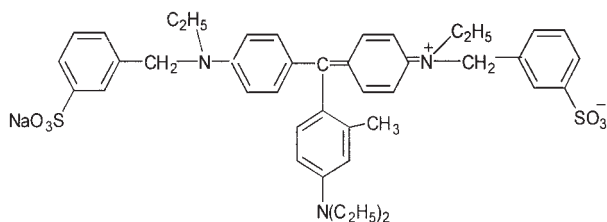


Figure 1 Structure of acid brilliant blue (Acid Blue 15), C.I. No. 42645.

solutions of the test reagent were made by dissolving the dye in doubly distilled water. Dyes were procured from Hindusthan Ciba Geigy (Mumbai, India) and were of >99% purity. The structures of the dyes, acid brilliant blue and procion orange, are shown in Figures 1 and 2, respectively.

Preparation and characterization of surfactant-modified coir pith (CPHDTMA)

Waste coir pith was collected from the nearby coir industries and dried in sunlight. Then it was crushed and sieved to produce particle sizes in the range of 150–250 μm . The coir pith was modified as follows: 10 g of coir pith and 200 mL of 2% HDTMA solution were added to a 500-mL conical flask. The mixture was agitated in a shaker machine for 5 h at 200 rpm. Then the suspension was left undisturbed for the liquid and the coir pith to separate. The liquid was discarded, and the modified coir pith was washed with distilled water several times to remove superficially held surfactant. The modified coir pith was dried in a hot air oven at 60°C for 8 h. Then it was characterized by CHNS analysis and surface area analysis. The pH_{zpc} of the modified coir pith was determined using standard methods.²¹ A suspension of 100 mg of adsorbent in 50 mL of an electrolyte solution of 0.001M sodium nitrate was prepared. Aliquots of suspension were adjusted to various pH values with dilute NaOH and HNO₃ solutions. After 1 h of agitation at 175 rpm in an orbital shaker machine, the initial pH values were measured. Then 1 g of NaNO₃ was added to each aliquot to bring final electrolyte concentration to about 0.45M. After one hour of additional agitation, the final pH was measured. The results were plotted with ΔpH (final pH – initial pH) against final pH. The pH at which ΔpH was equal to zero was defined as the pH_{zpc} of the adsorbent. Leaching of the surfactant was studied by agitating a known weight of the adsorbent with 50 mL of different pH-adjusted distilled water for 2 h. After agitation, the supernatant was decanted, and the adsorbent was filtered using Whatman filter paper and washed gently with water to remove any superficially held surfactant. Then it was dried in a hot air oven and

analyzed for the percentages of C, H, and N using a CHNS analyzer.

The pH measurements were made using a pH meter (model LI-107, Elico, Hyderabad, India). The surface area was measured by a Quantasorb model surface area analyzer. A CHNS analyzer (Vario EL III, Germany) was used to determine carbon and nitrogen contents. Absorbance measurements were made on a UV-vis spectrophotometer (Hitachi, model U-3210, Tokyo, Japan). An orbital shaker machine (Rotek LSA, Pelican Equipments, Chennai, India) was used for the adsorption studies.

Adsorption studies

The adsorption experiments were carried out by agitating 50 mg of adsorbent with 50 mL of a dye solution of the desired concentration and pH at 200 rpm using an orbital shaker machine. Dye concentration was estimated spectrophotometrically by monitoring the absorbance at 550 nm for ABB and 492.6 nm for PO using a UV-vis spectrophotometer. The pH was measured using a pH meter. The samples were withdrawn from the shaker at predetermined time intervals, and the dye solution was separated from the adsorbent by centrifugation at 10,000 rpm for 30 min. The absorbance of the supernatant solution was measured. The effect of pH was studied by adjusting the pH of the dye solutions using dilute HCl and NaOH solutions. The pH was not maintained during adsorption. The effect of the adsorbent dose was studied by agitating different adsorbent doses and 50 mL of dye solutions at equilibrium time. Langmuir and Freundlich isotherms were employed to study the adsorption capacity of the adsorbent.

Desorption studies

The adsorbent that was used for the adsorption of dye solution was separated from the dye 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

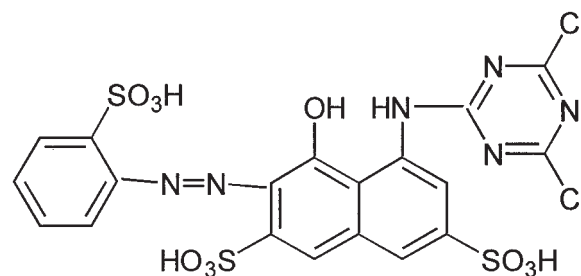


Figure 2 Structure of procion orange (reactive azo dye), C.I. No. 18260.

TABLE I
Elemental Composition of Raw Coir Pith, CPHDTMA,
and CPHDTMA After Leaching at Different pHs

Sample	C (%)	H (%)	N (%)
Raw coir pith	40.68	5.134	0.436
CPHDTMA	53.21	7.313	1.232
CPHDTMA after leaching at:			
pH 2	53.17	7.358	1.181
pH 7	53.61	7.492	1.197
pH 11	53.22	7.461	1.240

samples were prepared. Then the spent adsorbent was agitated with 50 mL of distilled water, at different pH values adjusted using dilute HCl and NaOH solutions, for equilibrium time for the dye concentration of 40 mg/L. The desorbed dye was estimated as before.

Temperature studies

Adsorption of 40 mg/L of dye by 50 mg of adsorbent was carried out at 35°C, 40°C, 50°C, and 60°C in the thermostated rotary shaker machine.

RESULTS AND DISCUSSION

Characterization of adsorbent

The percentages of C, H, and N in the modified and unmodified coir pith are given in Table I. These increased percentages are a result of the adsorption of HDTMA, calculated as 198.93 mg/g, onto the coir pith surface. The BET surface area of CPHDTMA (1.9 m²/g) was smaller than that of unmodified coir pith (2.3 m²/g). Sorption of HDTMA on coir pith caused a decrease in the surface area relative to the unmodified coir pith. Apparently, the adsorption process leads to a constriction of the pore channels, as a result of attachment of the surfactant moieties to the internal framework surfaces. A similar reduction in the BET surface area also was observed during modification of montmorillonite with HDTMA.²² The percentages of C, H, and N in CPHDTMA before and after leaching were found to be same, which showed that no leaching of the surfactant occurred in the pH range of 2.0–11.0. The percentages of C, H, and N in CPHDTMA before and after agitation with distilled water adjusted to different pHs are shown in Table I.

Effects of agitation time and concentration of dye on adsorption

The amount of dye adsorbed (mg/g) increased with increased agitation time and reached equilibrium after 10, 20, 30, 30, and 40 min for dye concentrations of 20, 40, 60, 80, and 100 mg/L, respectively, for ABB (Fig. 3);

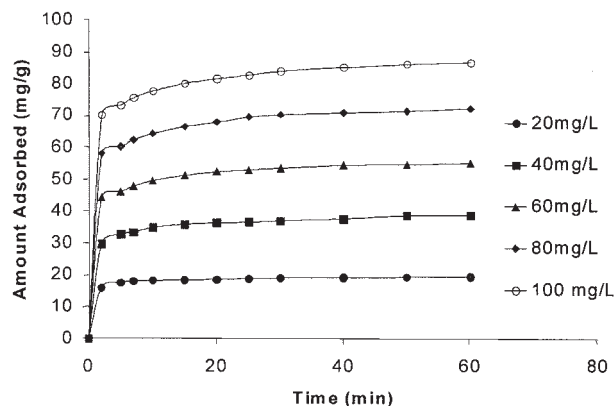


Figure 3 Effect of agitation time on the adsorption of acid brilliant blue onto CPHDTMA.

and 5, 20, 30, 60, and 60 min for dye concentrations of 20, 40, 60, 80, and 100 mg/L for PO (Fig. 4), used in this study. The amount adsorbed (mg/g) increased with increased dye concentration.

Adsorption dynamics

Adsorption rate constant

The adsorption kinetics described by first-order rate expression was given by Lagergren²³:

$$\log(q_e - q) = \log q_e - k_1 t / 2.303 \quad (1)$$

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 (1/min). Values of k_1 were calculated from the plots of $\log(q_e - q)$ versus t (figures not shown) for different concentrations of dyes. The experimental q_e values do not agree with the calculated ones, obtained from the linear plots (Tables II and III). This shows that the

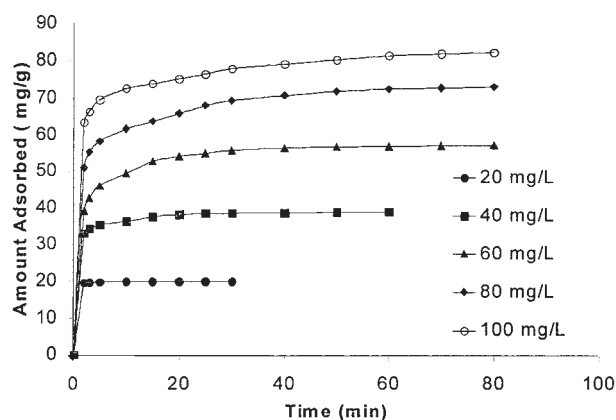


Figure 4 Effect of agitation time on the adsorption of procion orange onto CPHDTMA.

TABLE II
Comparison of First- and Second-Order Adsorption Rate Constants and Calculated and Experimental q_e Values for Different Initial Dye Concentrations and Temperatures for ABB

Parameter	First-order kinetic model				Second-order kinetic model		
	q_e (exp) (mg/g)	k_1 (1/min)	q_e (cal) (mg/g)	R^2	k_2 (g mg ⁻¹ min ⁻¹)	q_e (cal) (mg/g)	R^2
Initial ABB concentration (mg/L) ^a							
20	18.3	0.49	6.3	0.995	0.14	19.0	0.999
40	36.3	0.20	10.4	0.996	0.04	37.2	0.999
60	53.5	0.11	12.3	0.965	0.03	56.5	0.999
80	70.2	0.12	17.7	0.983	0.02	71.7	0.999
100	85.2	0.08	17.0	0.998	0.01	85.5	0.999
Temperature (°C) ^b							
35	36.3	0.20	10.4	0.996	0.04	37.1	0.999
40	36.8	0.16	7.5	0.992	0.06	37.2	0.999
50	39.0	0.16	6.4	0.991	0.09	38.6	0.999
60	39.4	0.26	2.1	1.000	0.24	39.8	1.000

^a Conditions: adsorbent dose, 50 mg/50 mL; pH, 6.5; temperature, 32°C.

^b Conditions: dye concentration, 40 mg/L; adsorbent dose, 50 mg/50 mL; pH, 6.5.

adsorption of dye onto CPHDTMA is not a first-order reaction.

The second-order kinetic model²⁴ is expressed as:

$$t/q = 1/k_2q_e^2 + t/q_e \quad (2)$$

where k_2 (g/mg/min) is the rate constant of second-order adsorption. The second-order rate constants, k_2 and q_e , were calculated from the intercept and slope, respectively, of the plots of t/q versus t (Figs. 5 and 6). The linear plots of t/q versus t showed good agreement between the experimental and the calculated q_e values using the second-order kinetic model for different initial dye concentrations. The correlation coefficients also were good (Tables II and III). These indicate that the adsorption system belongs to the second-order kinetic model. Similar phenomena have been

observed in the sorption of congo red by coir pith carbon,¹⁸ acid blue 9 by a mixture of activated clay and activated carbon sorbents,²⁵ and methylene blue on KOH-impregnated activated carbon.²⁶

Effect of temperature

Temperature plays an effective role in the adsorption of dyes on CPHDTMA. As the temperature of the solution increases, the extent of adsorption increases. The changes in standard free energy (ΔG^0), enthalpy (ΔH^0), and entropy (ΔS^0) of adsorption were calculated using the following equations:

$$\Delta G^0 = -RT \ln K_c \quad (3)$$

TABLE III
Comparison of First- and Second-Order Adsorption Rate Constants and Calculated and Experimental q_e Values for Different Initial Dye Concentrations and Temperatures for PO

Parameter	First-order kinetic model				Second-order kinetic model		
	q_e (exp) (mg/g)	k_1 (1/min)	q_e (cal) (mg/g)	R^2	k_2 (g/mg)	q_e (cal) (mg/g)	R^2
Initial PO concentration (mg/L) ^a							
20	19.7	0.62	1.2	1.000	0.84	20.0	1.000
40	38.2	0.15	6.6	0.962	0.07	38.3	0.999
60	55.7	0.13	19.9	0.985	0.02	57.1	0.999
80	72.4	0.07	23.0	0.987	0.01	73.0	0.999
100	81.4	0.05	17.3	0.988	0.01	81.3	0.999
Temperature (°C) ^b							
35	38.6	0.11	5.6	0.954	0.08	38.7	0.999
40	38.9	0.12	5.6	0.958	0.09	38.5	1.000
50	39.3	0.13	5.4	0.999	0.11	38.6	0.999
60	39.3	0.15	3.7	0.992	0.16	39.1	1.000

^a Conditions: adsorbent dose, 50 mg/50 mL; pH, 5.5; temperature, 32°C.

^b Conditions: dye concentration, 40 mg/L; adsorbent dose, 50 mg/50 mL; pH, 5.5.

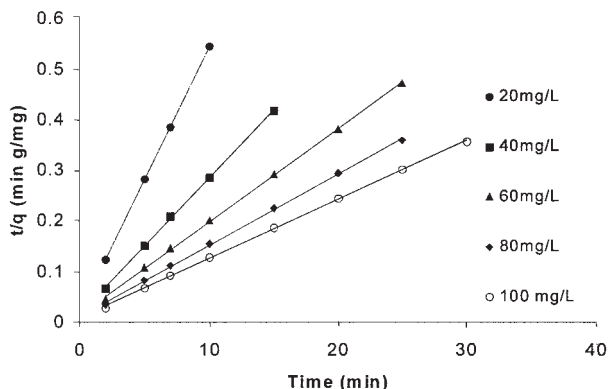


Figure 5 Second-order plot for the adsorption of acid brilliant blue onto CPHDTMA.

where R is the gas constant, K_c is the equilibrium constant, and T is the temperature in K . And according to the van't Hoff equation,

$$\log_{10}K_c = \Delta S^0/2.303R - \Delta H^0/2.303RT \quad (4)$$

The plots of $\log K_c$ versus $1/T$ are linear (Fig. 7). The values of ΔH^0 and ΔS^0 were evaluated from the slope and intercept, respectively, of the van't Hoff plots (Table IV). The negative values of ΔG^0 at 35°C, 40°C, 50°C, and 60°C clearly indicate that the adsorption processes were spontaneous for dyes with a high affinity for CPHDTMA. A similar trend was observed for the adsorption of four dyes on neem sawdust.²⁷ The positive values of ΔH^0 suggest endothermic adsorption. The positive value ΔS^0 indicates the increased randomness at the solid/solution interface during the adsorption of dye on CPHDTMA. The energy of activation (E_a) was calculated using the Arrhenius equation and found to be 57.70 and 20.73 kJ/mol for ABB and PO, respectively. The first-order rate constants of adsorption (k_1) were evaluated from the plots of $\log(q_e - q)$ versus t for different tempera-

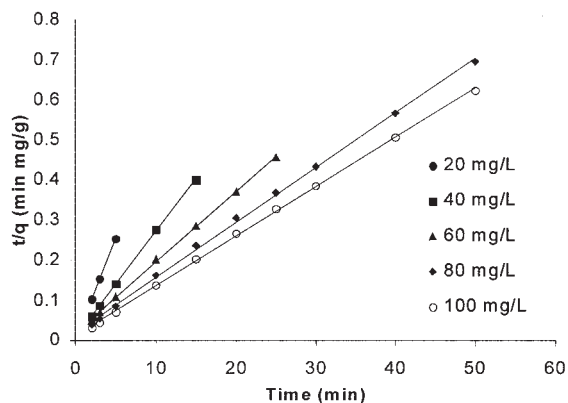


Figure 6 Second-order plot of the adsorption of procion orange onto CPHDTMA.

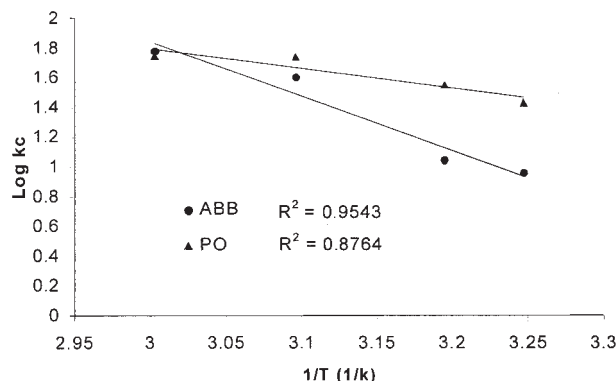


Figure 7 van't Hoff plots for the adsorption of dyes onto CPHDTMA.

tures using the Lagergren first-order rate expression (figures not shown). The calculated q_e values obtained from the first-order kinetic model did not agree with the experimental q_e values (Tables II and III). This shows that the adsorption of dye on coir pith carbon at different temperatures does not follow the first-order kinetic model. The adsorption data were fitted into the second-order kinetic model. The calculated values of q_e showed very good agreement with the experimental data. This indicates that adsorption followed a second-order kinetic model at different temperatures used in this study.

Adsorption isotherms

The equilibrium adsorption isotherm is fundamental in describing the interactive behavior between adsorbates and adsorbent and is important in the design of adsorption systems. The Langmuir isotherm is represented by the following equation²⁸:

$$C_e/q_e = 1/Q_0b + C_e/Q_0 \quad (5)$$

where C_e is the concentration of dye solution (mg/L) at equilibrium, the constant Q_0 is the adsorption ca-

TABLE IV
Thermodynamic Parameters

Temperature (°C)	K_c	ΔG^0 (kJ/mol)	ΔH^0 (kJ/mol)	ΔS^0 (J/mol/k)
ABB				
35	9.08	-5.65	70.09	245.64
40	11.53	-6.36		
50	40.33	-9.93		
60	60.82	-11.37		
PO				
35	26.91	-8.43	25.69	111.52
40	35.63	-9.30		
50	55.17	-10.77		
60	56.03	-11.15		

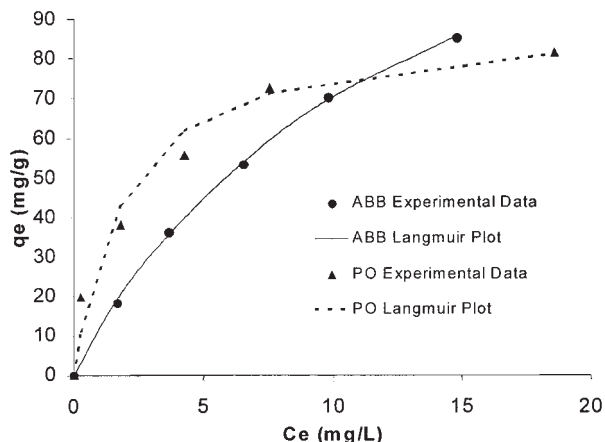


Figure 8 Plot of q_e versus C_e for the adsorption of dyes onto CPHDTMA.

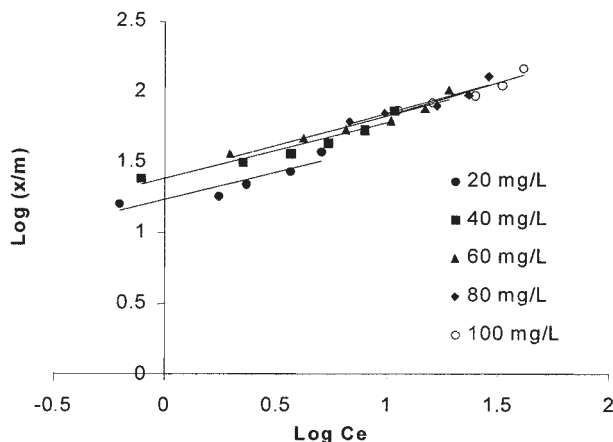


Figure 9 Freundlich plots of adsorption of acid brilliant blue onto CPHDTMA.

capacity (mg/g), and b is related to the energy of adsorption (L/mg). The plot of q_e versus C_e shows the fit of experimental data with Langmuir model (Fig. 8). Values of Q_0 and b are presented in Table V. The applicability of the Langmuir isotherm suggests the monolayer coverage of the dye on the surface of CPHDTMA. The essential characteristics of the Langmuir isotherm can be expressed by a dimensionless, constant called equilibrium parameter, R_L defined by Weber and Chakkravorti²⁹ as

$$R_L = 1 / (1 + bC_0) \tag{6}$$

where b is the Langmuir constant, C_0 is the initial dye concentration (mg/L), and R_L indicate the type of isotherm. Calculated R_L values between 0 and 1 indicate favorable adsorption for all dye concentrations (Table V).

Also applied for the adsorption of dye was the Freundlich isotherm³⁰:

$$\log_{10}(x/m) = \log_{10}k_f + (1/n)\log_{10}C_e \tag{7}$$

TABLE V
Langmuir Constants

ABB concentration (mg/L)	Q_0 (mg/g)	b (L/mg)	R_L
20	159	0.08	0.39
40			0.32
60			0.21
80			0.16
100			0.13
PO concentration (mg/L)	89	0.53	0.09
40			0.05
60			0.03
80			0.02
100			0.02

where x is the amount of dye adsorbed (mg), m is the weight of the adsorbent used (g), C_e is the equilibrium concentration of dye in the solution (mg/L), and k_f and n are constants incorporating all factors affecting the adsorption process (adsorption capacity and intensity of adsorption). Linear plots of $\log_{10}(x/m)$ versus $\log_{10} C_e$ for all the dyes showed that the adsorption also followed the Freundlich isotherm (Figs. 9 and 10). In general, as the k_f value increased, the adsorption capacity of the adsorbent for a given dye increased. Values of k_f and n were calculated from the intercept and slope, respectively, of the plots and are presented in Table VI. The values of the Langmuir and Freundlich constants for the adsorption of some anionic dyes by various adsorbents reported in literature are shown in Table VII. Tables V and VII show that the adsorption capacity of CPHDTMA for the dyes was higher than or comparable to those of other adsorbents reported in literature.

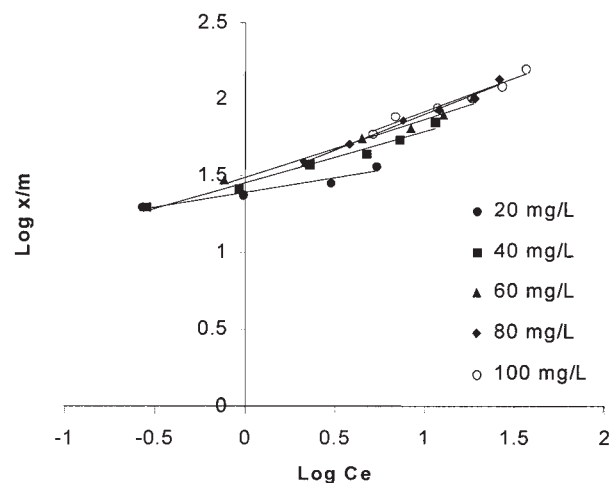


Figure 10 Freundlich plots for adsorption of procion orange onto CPHDTMA.

TABLE VI
Freundlich Constants

Dye concentration (mg/L)	ABB		PO	
	k_f (mg ^{1-1/n} L ^{1/n} g ⁻¹)	n	k_f (mg ^{1-1/n} L ^{1/n} g ⁻¹)	n
20	17.24	2.60	24.65	5.18
40	24.63	2.55	28.49	2.97
60	25.76	2.40	30.88	2.62
80	26.61	2.38	27.22	2.13
100	22.48	2.11	30.30	2.28

Effect of pH

The effect of pH on the removal of dyes is shown in Figure 11. As the pH was increased from 2.0 to 6.5, the percent adsorption of ABB increased from 58% to 88% and then decreased to 63% with pH increasing from 6.5 to 11.0. At low pH, the dye became protonated, and hence the electrostatic repulsion between the protonated dye and positively charged adsorbent sites resulted in decreased adsorption. As the pH was increased above 7.0, the OH⁻ ions competed with the dye anions for adsorption sites and percent adsorption decreased. For procion orange adsorption, percent removal increased from 53% to 90% with an increase in pH from 2.0 to 5.5. Lower removal with a highly acidic pH (2.0) resulted from the electrostatic repulsion between the protonated PO and the positively charged adsorbent sites. As the pH was increased above 5.5, percent adsorption started to decrease and then dramatically dropped to zero at pH 11.0. With a highly alkaline pH (11.0), the OH⁻ ions competed for the adsorption sites, which led to a decrease in dye uptake. Adsorption of dyes onto an adsorbent surface is normally influenced by the surface charge on the adsorbent, which in turn is influenced by the solution pH.³¹ Figure 12 shows the effect of the initial pH on the equilibrium pH (final pH) in the presence and the

absence of dyes. The equilibrium pH for the blank (adsorbent in water in the absence of dyes) was lower than the initial pH. This was a result of the leaching of anions like Cl⁻ anions from the pith and subsequent uptake of OH⁻ ions from the bulk solution. The equilibrium pH of the dye solutions (final pH) was higher than the equilibrium pH for the blank up to pH 11.0 for ABB and up to pH 8.0 for PO. This was because of the uptake of dye anions by the adsorbent and the subsequent release of OH⁻ and Br⁻ ions.

Desorption studies

To make the adsorption process more economical, it was necessary to regenerate the spent adsorbent and dyes, which could be recycled further. Dye desorption is shown in Figure 13. As the desorbing pH was increased from 2.0 to 11.0, the percent desorption of ABB decreased gradually from 13.5% at pH 2.0 to 4% at pH 6.0 and then increased again to 15% at pH 11.0. Only the ion-exchanged ABB was desorbed in a basic pH. The results suggest that chemisorption might be the major mode of ABB removal by the adsorbent. For PO, the percent desorption was within 10% of the acidic pH. As the pH was increased further, desorption increased to 75% at pH 11.0. This is because an OH⁻ ion

TABLE VII
Langmuir and Freundlich Constants for Some Reported Anionic Dyes

Adsorbent	Adsorbate	Q_0 (mg/g)	b (L/mg)	k_f (mg ^{1-1/n} L ^{1/n} g ⁻¹)	n
Raw coir pith ¹⁷	Acid brilliant blue	16.7	0.13	1.00	2.63
Biogas residual slurry ³²	Acid brilliant blue	13.5	0.13	0.50	1.24
Banana pith ³³	Acid brilliant blue	4.4	0.13	1.00	2.63
Red mud ⁸	Procion orange	1.3	0.06	0.16	2.07
Orange peel ³⁴	Procion orange	18.0	0.04	0.86	1.29
Calcined alunite ³¹	Acid blue 40	212.8	0.20	20.26	0.85
Calcined alunite ³¹	Acid yellow 17	151.5	0.03	6.32	1.50
Granular activated carbon ³¹	Acid blue 40	57.5	0.13	7.70	1.68
Granular activated carbon ³¹	Acid yellow 17	133.3	0.15	17.38	1.42
Banana pith ⁹	Acid violet	13.1	0.02	0.50	1.79

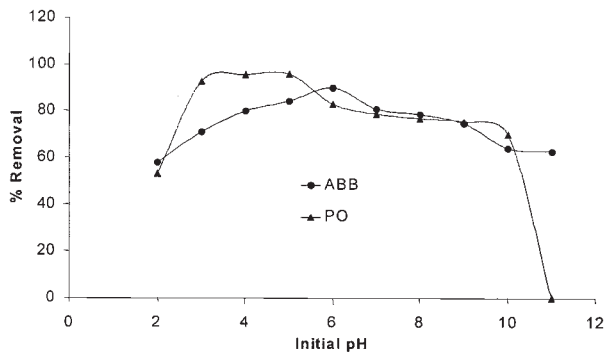


Figure 11 Effect of pH on removal of dyes by CPH-DTMA.

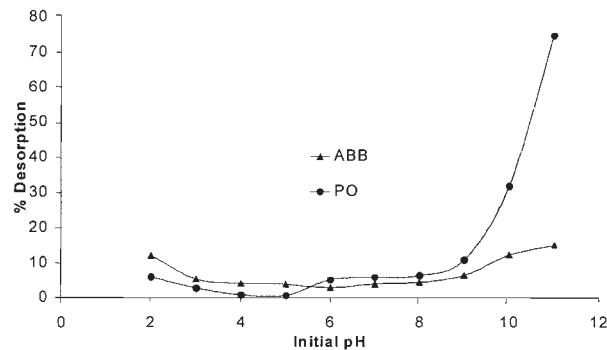


Figure 13 Effect of pH on desorption of dyes from the dye-loaded adsorbent.

displaced the adsorbed PO. The results of both adsorption and desorption studies suggest that PO adsorption occurs predominantly by an ion exchange mechanism.

CONCLUSIONS

The adsorption of anionic dyes onto surfactant modified coir pith was investigated in this study. Coir pith modified with a typical quarternary ammonium surfactant (HDTMA) was made amenable to the adsorption of anionic dyes such as ABB and PO from wastewater. Dye adsorption increased with increased temperature, indicating that the process was endothermic. The adsorption process obeyed second-order kinetics. The results indicate that both the Langmuir and Freundlich models fit the equilibrium data. The adsorption capacities of the ABB and PO dyes on CPH-DTMA were 159 and 89 mg/g, respectively. The effect of pH on adsorption of the dyes shows that ion exchange and chemisorption might be the major modes of the adsorption process for ABB and PO. The raw

material is freely available in large quantities in coir industries, and the treatment method is expected to be economical.

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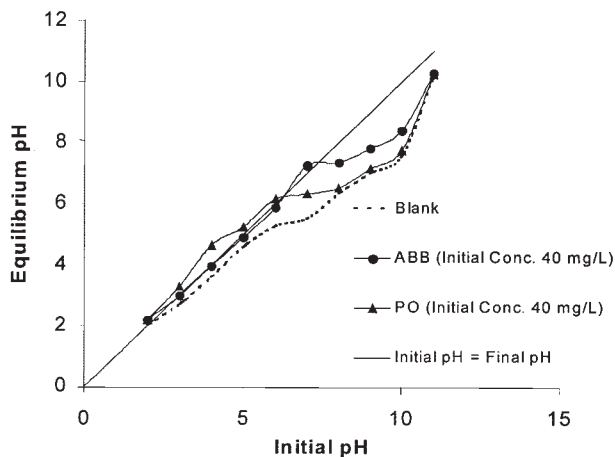


Figure 12 Effect of initial pH on the equilibrium pH on the adsorption of dyes onto CPHDTMA

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