



Synthesis and characterization of iodo polyurethane foam and its application in removing of aniline blue and crystal violet from laundry wastewater

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Available online 14 July 2014

Abstract

A new sorbent was prepared by treating polyurethane foam with HCl and replacing the amino functional groups with iodine atoms. The properties of iodo-polyurethane were studied with infrared, ultraviolet and visible spectroscopy, bulk density, pH_{ZPC} and elemental and thermal analysis. Removal of aniline blue and crystal violet dyes from water with iodo-polyurethane were investigated with the batch technique. Maximum removal was achieved at pH 7–12. The effect of the initial dye concentration on the equilibrium adsorption from aqueous solutions with iodo-polyurethane was found to have a good correlation, with $r^2 = 0.995$ and an intercept of 0.039 when analyzed in the Langmuir and Freundlich isotherm models. The capacity of iodo-polyurethane for aniline blue and crystal violet were 0.24 and 0.45 mmol g^{-1} , respectively (188.9 and 183.6 mg g^{-1}). The values of ΔG and ΔH were -7.7 kJ mol^{-1} and $-26.1 \text{ kJ mol}^{-1}$, respectively, indicating that sorption is spontaneous and exothermic. The sorption rate of the dyes onto iodo-polyurethane was rapid, with 50% removal within 50 s. The pseudo-second order equation best described the kinetics of absorbed aniline blue and crystal violet ($r^2 = 0.994$). A modified equation ($y = ax^{0.1}$) was used to treat deviation from the Morris–Weber model for the sorption diffusion mechanism of crystal violet onto iodo-polyurethane. Use of iodo-polyurethane for removing aniline blue and crystal violet contamination from laundry wastewater is thus possible.

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Keywords: Aniline blue; Crystal violet; Iodo-polyurethane; Wastewater

1. Introduction

Laundry involves washing, usually with water containing detergents or other chemicals, agitation, rinsing, drying and ironing. Washing is often done above room temperature to increase the activity of any chemicals used, to increase the solubility of stains and to kill any microorganisms that may be present on the fabric. Various chemicals can be used to increase the solvent power of water, such as the compounds in soap root or ash lye.

Textile laundry wastewater is among the major sources of hazardous dyes in the environment [1]. Some

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dyes are carcinogenic and hazardous for aquatic organisms [2] and can cause health disorders, such as severe damage to the kidneys and the central nervous system [3]. Aniline blue and crystal violet dyes are extensively used in the textile industry [4]; these dyes are toxic to mammalian cells and are mitotic poisons and proven potent carcinogens [5]. Removal of dyes from wastewater before its discharge into the environment is important to avoid polluting underground water.

Many methods are used to treat wastewater before discharge into natural water, including adsorption [6], oxidation [7], microfiltration [8], coagulation [9] and degradation [10]. Adsorption is the most effective technique because it is easy, inexpensive, can treat concentrated dyes, and the spent sorbent can be regenerated for further use [11]. The sorbents used to remove dyes from wastewater include polyurethane [12–16] organo-bentonite [17], carbon [18], Zn_2Al-NO_3 [19] and miswak [20].

Polyurethane foam is a good sorbent for some organic and inorganic pollutants in wastewater [21,22]. As its high basicity decreases its sorption capacity, low basicity polyurethane must be prepared. In previous studies, we developed polyurethane containing a polyhydroxyl functional group, which has high sorption capacity [23,24]. Polyhydroxy polyurethane foam was prepared from commercial polyurethane by replacing the primary amine with a hydroxyl group. In the work reported here, we prepared iodo-polyurethane foam by treating the matrix of polyurethane with HCl, diazotizing the amino functional groups with $NaNO_2$ and then replacing the azo groups with iodine atoms. Iodo-polyurethane is inexpensive, stable and has high sorption capacity for removing aniline blue and crystal violet dyes from wastewater. The compound can also be recycled many times with no significant decrease in sorption capacity.

2. Experimental

2.1. Materials

Aniline blue ($C_{37}H_{32}N_5O_9S_3$, 786.9 g/mol) and crystal violet ($C_{25}H_{30}N_3Cl$, 407.98) were purchased from BDH (Poole, England), and stock solutions (1 mg mL^{-1}) were prepared by dissolving 0.1 g of dye in 100 mL of H_2O . A series of 25 mL of dye standard solutions ($0.4\text{--}8.0\ \mu\text{g mL}^{-1}$ dye) were used to determine the calibration curve.

Iodo-polyurethane was prepared as follows: 5.0 g of commercial polyurethane foam were soaked in 0.5 L of HCl (2 mol L^{-1}) for 24 h and then washed with distilled H_2O . The preparation was diazotized with $NaNO_2$

(50 mL of 2 mol L^{-1}) in an ice bath, and the diazonium salts were washed with ice-cold water and coupled with 2 mol L^{-1} KI. The orange iodo-polyurethane was washed with H_2O and then dried in air.

2.2. Apparatus

All spectrophotometric measurements were performed with a Shimadzu Model UV-1800 (Shimadzu Corporation, Japan). pH was measured with a pH meter from Microprocessor pH Meter (HANNA Instruments).

2.3. Recommended procedure

An aliquot of 0.1 g of iodo-polyurethane was mixed with 25 mL of dye solution ($1\ \mu\text{g mL}^{-1}$) then shaken for 30 min, and the aniline blue and crystal violet concentrations remaining in solution were measured at $\lambda = 599$ and 592 nm, respectively. The percentage of removed dye and the capacity of iodo-polyurethane (Q , mmol g^{-1}) were calculated from $\%E = ((C_o - C)/C_o) \times 100$ and $Q = (C_o - C)V/m$.

To determine the iodo-polyurethane surface acid sites, 25 mL of 0.05 mol L^{-1} NaOH solution were added to 0.1 g of iodo-polyurethane, and the solution was shaken for 24 h. Then, 10.0 mL of the residual solution were titrated with HCl (0.05 mol L^{-1}) in the presence of methyl orange as the indicator, and the basic sites were back-titrated with 0.05 mol L^{-1} NaOH and HCl solutions.

To determine the pH_{ZPC} of iodo-polyurethane, a series of flasks containing 25 mL of solution at pH 1–13, adjusted with HCl and NaOH, were prepared, and the solution was added to 0.1 g of iodo-polyurethane. After 24 h, the final pH (pH_f) of the solutions was measured, and the difference between the initial and final pH values ($\Delta pH = pH_f - pH_i$) was plotted against the pH_i . The pH_{ZPC} was noted as the pH at which the initial pH equalled the final pH.

3. Results and discussion

3.1. Characterization of iodo-polyurethane

The pH_{ZPC} of polyurethane and iodo-polyurethane (Fig. 1) were 8.9 and 6.9, respectively, showing that iodo-polyurethane is less basic than polyurethane. The surface sites of iodo-polyurethane are positively charged at pH lower than 6.9 and become negatively charged at pH greater than pH 6.9. The negatively charged iodo-polyurethane surface is due to free unshared electron pairs of iodine and ether oxygen. Iodo-polyurethane is therefore suitable for extracting basic species at

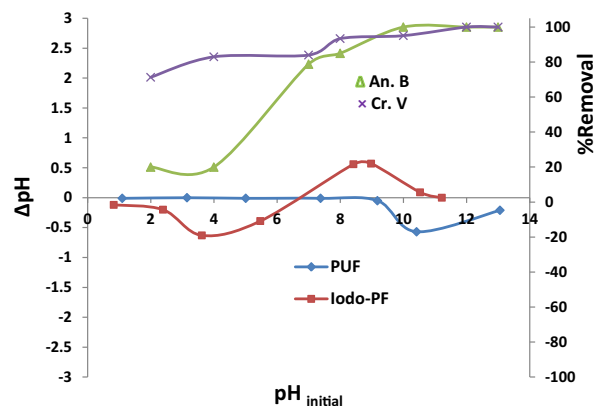


Fig. 1. pH_{ZPC} of iodo-polyurethane and effect of initial pH on the sorption of aniline blue and crystal violet.

$\text{pH} \geq 6.9$. The amounts of acidic and basic surface sites on iodo-polyurethane were $1.1 \text{ mmol H}^+ \text{ g}^{-1}$ and $0.4 \text{ mmol OH}^- \text{ g}^{-1}$, respectively, indicating that most sites are acidic. Accordingly, sorption of positively charged species should be favoured.

The carbon, hydrogen and nitrogen composition of iodo-polyurethane is lower than that of polyurethane due to partial hydrolysis (Table 1). The proportion of iodine in iodo-polyurethane was about 6.3% due to addition of an iodo group.

The infrared spectra of polyurethane and iodo-polyurethane were tested with the thin film technique. The spectrum of polyurethane showed several strong band stretches at 3310.8 , 3280.6 , 2865.7 , 2242.8 and 1596.8 cm^{-1} due to free $-\text{NH}_2$, aliphatic hydrocarbon ($-\text{CH}$), free isocyanate ($-\text{NCO}$) and urethane ($-\text{NHCOO}-$) groups, respectively (Fig. 2a). The absorption bands at 3310.8 and 3280.6 cm^{-1} characteristic of $-\text{NH}_2$ groups had disappeared in the infrared spectrum

Table 1
Comparison between the properties of PF and iodo-PF.

Property	PF	Iodo-PF
pH_{ZPC}	8.9	6.9
Total acidity, mmol g^{-1}	–	1.1
Total basisty, mmol g^{-1}	–	0.4
Elemental analysis		
C, H, N, and I %	64.5, 9.1, 7.3 and 0.0	59.4, 8.4, 6.8 and 6.3
IR spectra		
ν $-\text{C}-\text{I}$ aromatic, cm^{-1}	3310.8 and 3280.6	409, 420, 450 and 454
UV–Vis spectra		
max, nm	Nil	700, 425.5 and 281
Colour	White	Orange

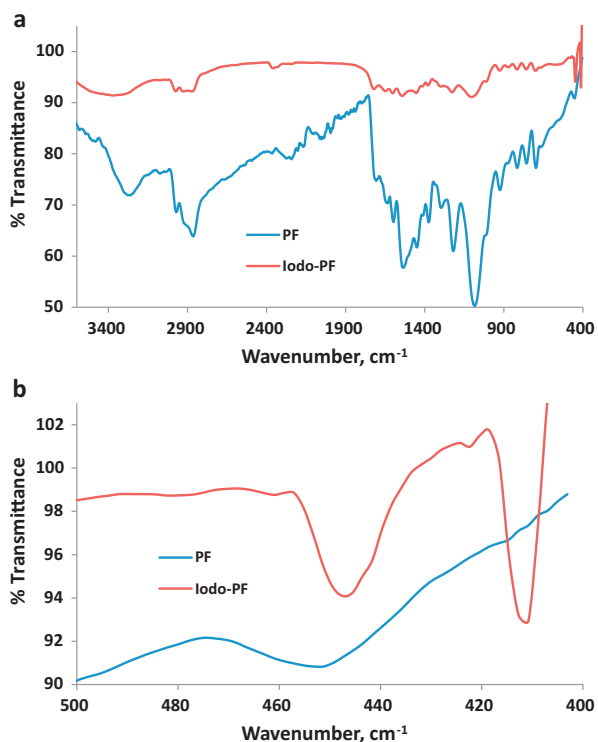


Fig. 2. Infrared spectra of polyurethane foam (polyurethane) and iodo-polyurethane foam.

of iodo-polyurethane, and four new absorption bands appeared at 409 , 420 , 450 and 454 cm^{-1} , characteristic of the aromatic $\text{C}-\text{I}$ groups in the spectrum of iodo-polyurethane (Fig. 2b). The results indicate replacement of the amino functional groups by iodine atoms in the matrix of iodo-polyurethane.

For ultraviolet–visible spectrophotometry, a thin film of iodo-polyurethane was placed in the path of light against polyurethane in H_2O . Three peaks appeared at 700 , 425.5 and 281 nm in the iodo-polyurethane spectrum.

3.2. Optimum conditions for removing aniline blue and crystal violet dyes

The effect of pH on removing aniline blue and crystal violet dyes with iodo-polyurethane is shown in Fig. 1. Removal was low at $\text{pH} \leq 2.0$ and increased with increasing pH, reaching 80–100% at pH 7–13 due to electrostatic interaction between dye and sorbent ($\text{pH}_{\text{ZPC}} = 6.9$). Polyurethane removed 38.4% of aniline blue and 57.5% of crystal violet, indicating that the iodo-polyurethane is more efficient than polyurethane.

The effect of the initial dye concentration on extraction of aniline blue and crystal violet with

Table 2
Comparison of maximum sorption capacities of various sorbents for dye removal.

Sorbent	Dye	Q_{\max} (mg g ⁻¹)	Reference
Treated Shorea dasyphylla sawdust	Acid Blue 25	24.4	[25]
TiO ₂ /Ag modified Bi ₅ O ₇ NO ₃	Methyl Orange	24.3 and 25.0	[26]
	Sunset Yellow		
Carbon slurry	Vertigo Blue 49	11.6	[27]
	Orange DNA13	4.5	
Activated carbon (rubber tire)	Acid Blue 113	0.8	[28]
Activated carbon		9.7	
Bentonite	Methylene Blue	151	[29]
Activated carbons (PAC2, F400 and PAC1)	Methylene Blue	588, 476 and 380	[30]
Activated carbon derived from olive-waste cakes	Lanaset Grey G,	108.7	[31]
Treated ginger waste	Crystal violet	227.0	[32]
Grapefruit peel	Crystal violet	254.2	[33]
Miswak	Aniline blue	291.2	[20]
Iodo-PUF	Aniline blue	188.9	This work
	Crystal violet	183.6	

iodo-polyurethane was studied by plotting the amount of dye extracted by 1 g of iodo-polyurethane (Q). The plot revealed a good correlation, with $r^2 = 0.995$ and an intercept value of 0.039 (Fig. 3). The sorption capacity of iodo-polyurethane increased with increasing dye concentration and then reached a plateau at 0.24 mmol g⁻¹ for aniline blue and 0.45 mmol g⁻¹ for crystal violet (188.9 and 183.6 mg g⁻¹). The sorbent thus has greater capacity for absorbing aniline blue than crystal violet, indicating that the sorption capacity depends on the size of the dye molecule. Comparison of the sorption capacity of iodo-polyurethane with that of other sorbents (Table 2) shows that it has better capacity [20,25–33].

The Freundlich (1), Langmuir (2) and Dubinin Radushkevich (3) isotherm models were applied (Fig. 3)

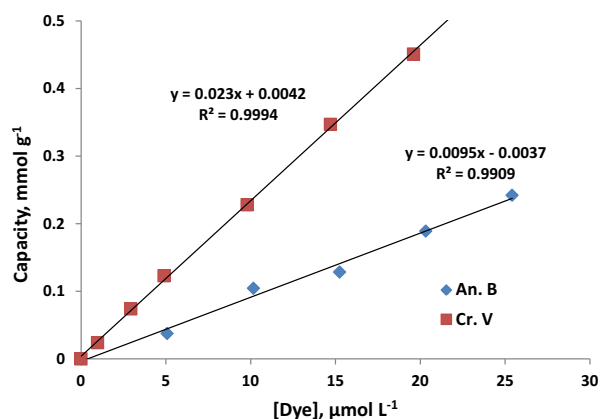


Fig. 3. Effect of initial dye concentration on sorption of aniline blue and crystal violet onto iodo-polyurethane.

to interpret the mechanism of sorption of aniline blue and crystal violet onto iodo-polyurethane.

$$\frac{C_e}{Q_c} = \frac{1}{K_L Q_m} + \frac{C_e}{K_L} \quad \& \quad R_L = \frac{1}{(1 + Q_m C_e)} \quad (1)$$

$$\log Q_c = \log K_F + \frac{1}{n} \log C_e \quad (2)$$

$$\ln Q_c = \ln K_{D-R} - \beta \varepsilon^2 \quad \& \quad \varepsilon = RT \ln \left[1 + \left(\frac{1}{C_e} \right) \right] \quad (3)$$

where C_e is the dye concentration at equilibrium in solution (mmol L⁻¹), K_L is the Langmuir sorption constant, Q_c is the maximum sorption monolayer capacity, and R_L is a dimensionless equilibrium parameter. K_F and n are the Freundlich constants; the value of n indicates how favourable the sorption process is, and K_F (mg g⁻¹) is the sorption capacity. K_{D-R} (mol g⁻¹) represents the maximum sorption capacity of the sorbent, β (mol² J⁻²) is a constant related to sorption energy, while ε is the Polanyi sorption potential.

The plots of C_e/Q_c against C_e and $\log Q_c$ against $\log C_e$ according to the Langmuir and Freundlich models showed a linear relationship, demonstrating that the Freundlich equation provides an accurate description of sorbed aniline blue, which is confirmed by the high determination coefficient (Fig. 3, $r^2 = 0.946$). The r^2 value in the Langmuir model for sorption of crystal violet exceeded 0.998 (Fig. 4), suggesting that the model closely fit the experimental data. These results indicate that sorption depends on the size of the dye molecule.

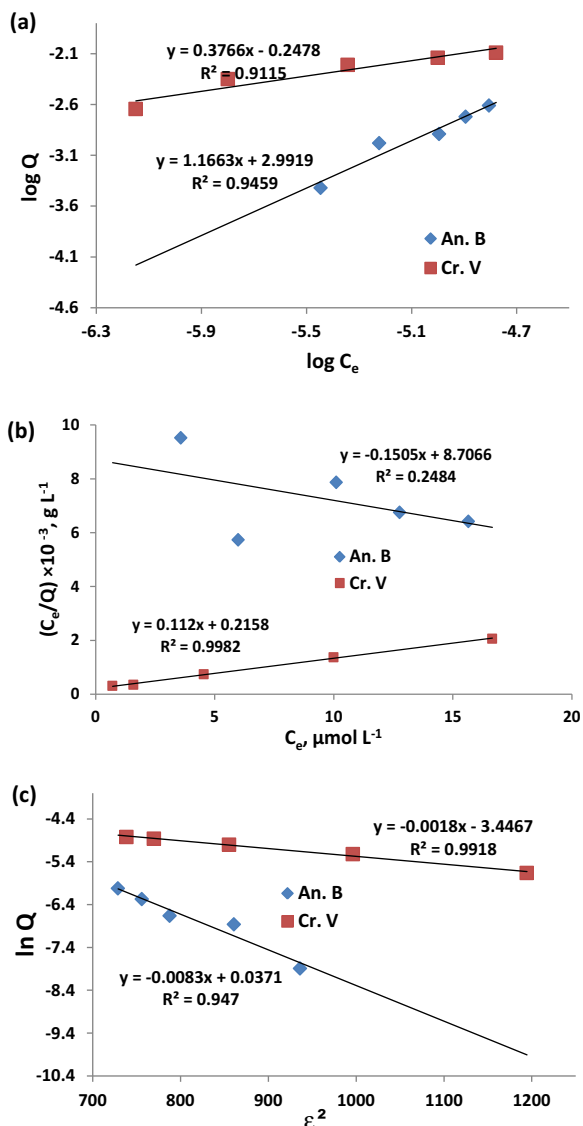


Fig. 4. Freundlich, Langmuir and Dubinin Radushkevich isotherm models for the sorption of aniline blue and crystal violet onto iodo-polyurethane.

The values of β were estimated from the slope of linear plots of $\ln Q_c$ against ε^2 and were -0.0083 and $-0.0018 \text{ kJ}^2 \text{ mol}^{-2}$ for sorbed aniline blue and crystal violet, respectively (Fig. 5). The sorption energy (mean free energy of sorption, ΔE) can be calculated from the equation: $E = 1/\sqrt{-2\beta}$, which gave 7.8 and 16.7 kJ mol^{-1} for sorbed aniline blue and crystal violet, respectively.

Sorption of dye decreased with increasing temperature. The thermodynamic parameters of aniline blue

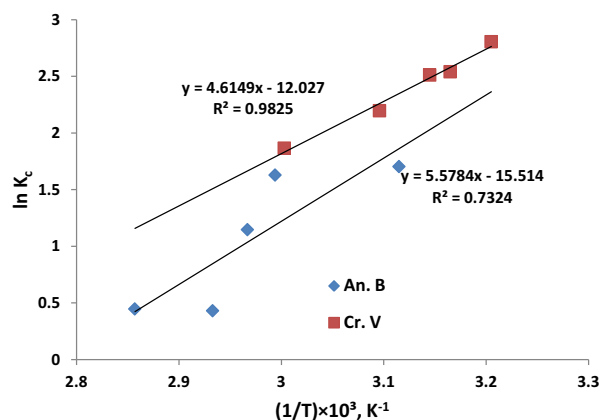


Fig. 5. Effect of temperature on the sorption of aniline blue and crystal violet onto iodo-polyurethane.

and crystal violet sorbed onto iodo-polyurethane were evaluated from the following equations:

$$\ln K_c = -\frac{\Delta H}{RT} + \frac{\Delta S}{R} \quad (4)$$

$$K_c = \frac{C_a}{C_e} \quad (5)$$

$$\Delta G = \Delta H - T\Delta S \quad (6)$$

where K_c is the distribution coefficient, C_a is the dye concentration on iodo-polyurethane, and C_e is dye concentration in solution (mmol L^{-1}). The slope and intercept of the linear plots of $\ln K_c$ against $1/T$ (Fig. 4) gave the numerical values for enthalpy (ΔH) and entropy (ΔS). ΔH for the sorption of aniline blue and crystal violet was -46.3 and $-38.3 \text{ kJ mol}^{-1}$, respectively, the negative sign indicating an exothermic chemisorption process. ΔS was -128.8 and $-99.8 \text{ J K}^{-1} \text{ mol}^{-1}$, respectively, the negative sign indicating a decrease in randomness at the solid-liquid interface during sorption. The values for free energy (ΔG) were -7.9 and -8.6 kJ mol^{-1} , the negative sign indicating the spontaneous nature of sorption.

The effect of sample volume (10–100 mL) on the removal of aniline blue and crystal violet was studied. The maximum sorption of the dyes in a batch factor ranged from 100 to 250 V/m, and the sorption of the dye decreased from 100% to 52% with increasing volume. Aniline blue and crystal violet can be effectively removed at a batch factor of 250.

Studies of the effect of the eluting agents HCl, NaOH, CH_3OH , $\text{C}_2\text{H}_5\text{OH}$ and CH_3COCH_3 on the stripping of aniline blue and crystal violet dyes from iodo-polyurethane showed that the dyes were completely eluted from iodo-polyurethane with CH_3OH and partially eluted with $\text{C}_2\text{H}_5\text{OH}$ and CH_3COCH_3 . The matrix

of iodo-polyurethane may swell in the presence of methanol, which is good solvent for aniline blue and crystal violet. Iodo-polyurethane was recycled many times after regeneration with CH₃OH then H₂O, without decreasing its capacity.

The rate of sorption of aniline blue and crystal violet onto iodo-polyurethane was measured in batch experiment at intervals of 1–30 min. The time required for sorption of the dyes was 8 min. The rate was fast (67–83% in the first minute) and then slowed with time (17–33% sorption dye after 7 min).

Kinetic modelling of the experimental data with pseudo first-order (7) and pseudo second-order (8) models revealed the potential rate-controlling steps involved in sorption.

$$\log(Q_e - Q_t) = (\log Q_e) - \frac{k_1 t}{2.303} \quad (7)$$

$$\frac{t}{Q_t} = \frac{1}{k_2 Q_e^2} + \frac{t}{Q_e} \quad \& \quad h = k_2 Q_e^2 t_{1/2} = \frac{1}{Ck_2} \quad (8)$$

Comparison of the correlation coefficients showed that the r^2 values of the two models were similar (Fig. 6), with chi-squared values of 0.04 and 0.003 for the first and second order models, respectively. We suggest that the pseudo second-order adsorption mechanism predominates. The amount of dye absorbed at equilibrium (Q_e) can also be calculated from these models, with estimated Q_e values of 20.5 mmol g⁻¹ for aniline blue and 0.04 mmol g⁻¹ for crystal violet in the first-order model and 0.47 and 0.48 mmol g⁻¹ in the second-order model. The experimental capacity of iodo-polyurethane was estimated to be 0.24 mmol g⁻¹ for aniline blue and 0.45 mmol g⁻¹ for crystal violet, indicating that the pseudo second-order adsorption mechanism predominated.

In order to study the diffusion mechanism of the sorption of aniline blue and crystal violet onto iodo-polyurethane, the Morris–Weber [11] equation was applied

$$Q = k_M \sqrt{t} \quad (9)$$

where k_M is the rate constant of interparticle transport.

The plots of Q_t versus $t^{0.5}$ were non-linear, did not pass through the origin and deviated with increasing time. The result shows that the Morris–Weber equation is not applicable and could not explain the diffusion mechanism of the sorption for aniline blue and crystal violet onto iodo-polyurethane.

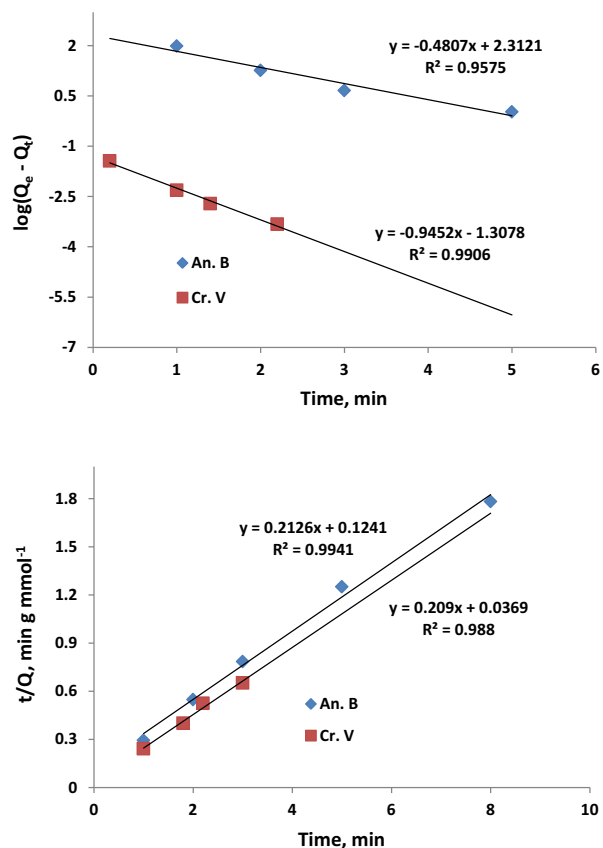


Fig. 6. Pseudo first-order and pseudo second-order kinetic models for the sorption of aniline blue and crystal violet onto iodo-polyurethane.

3.3. Modified particle diffusion model

For crystal violet, the plots of Q_e versus $t^{0.5}$ do not pass through the origin and are nonlinear. We therefore studied the factors affecting the diffusion rate of crystal violet onto iodo-polyurethane, applying different linear models to explain the mechanism.

The effects of pH, initial concentration of crystal violet, amount of iodo-polyurethane, reaction temperature, size of iodo-polyurethane and particle size of crystal violet were investigated. The sorption of crystal violet and the capacity of iodo-polyurethane increased with increasing pH, initial dye concentration, amount of iodo-polyurethane and reaction temperature, decreasing with the size of crystal violet and iodo-polyurethane. The deviation of the linear plot of Q_t against $t^{0.5}$ increased with increasing sorption capacity of iodo-polyurethane. The correlation coefficients decreased with increasing capacity and with decreasing equilibrium sorption time. The intercept values increased with the sorption capacity and decreased the equilibrium sorption time. The deviation of the linear plot and the intercept depend

Table 3
Application of different linear equation on the diffusion mechanism.

Conc., mmol L ⁻¹	Equation	r ²
0.0015	y = 0.000x + 0.001	0.951
0.003	y = 0.001x + 0.001	0.742
0.008	y = 0.001x + 0.054	0.743
0.016	y = 0.001x + 0.133	0.794
0.0015	y = 0.002e0.203x	0.852
0.003	y = 0.009e0.089x	0.628
0.008	y = 0.054e0.020x	0.719
0.016	y = 0.135e0.009x	0.786
0.0015	y = -9E-05x ² + 0.001x + 0.001	0.979
0.003	y = -0.000x ² + 0.003x + 0.005	0.959
0.008	y = -0.000x ² + 0.003x + 0.050	0.958
0.016	y = -0.000x ² + 0.003x + 0.131	0.933
0.0015	y = 0.001 ln(x) + 0.002	0.979
0.003	y = 0.004 ln(x) + 0.009	0.973
0.008	y = 0.004 ln(x) + 0.054	0.974
0.016	y = 0.003 ln(x) + 0.134	0.972
0.0015	y = 0.002x0.45	0.980
0.003	y = 0.009x0.378	0.931
0.008	y = 0.054x0.081	0.968
0.016	y = 0.134x0.024	0.969

on the sorption, the capacity of the sorbent and the equilibrium sorption time; the deviation is directly proportional to sorption capacity and inversely proportional to equilibrium time. We conclude that the deviation depends on the sorption capacity per equilibrium time. We therefore applied linear models (10a–10f) to the deviation plot of the Morris-Weber equation to explain the particle diffusion mechanism of crystal violet onto iodo-polyurethane:

$$y = ax + c \quad (10a)$$

$$y = ax^{0.5} + c \quad (10b)$$

$$y = ae^{nx} \quad (10c)$$

$$y = ax^2 + bx + c \quad (10d)$$

$$y = a \ln x + c \quad (10e)$$

$$y = ax^{0.n} \quad (10f)$$

The correlation coefficients of models (10a), (10b) and (10c) are less than those of (10d), (10e) and (10f). The value of the constant in models (10a), (10d) and (10e) was similar and did not reflect the actual value of the rate diffusion constant. Model (10d) is not a simple form. Model (10f) was the best model for explaining the diffusion mechanism and detecting the rate diffusion constant (Table 3).

We thus applied model (10f) ($y = ax^{0.n}$), which represents a simple explanation of the mechanism of particle diffusion of crystal violet onto iodo-polyurethane. The

Table 4
Removal of crystal violet from wastewater and sea water.

Sample	Add, µg	Found, µg	Recovery %	RSD%
Wastewater	200	180.4	90.2	3.04
Sea water	200	184.8	92.4	4.39

average value of n is 0.272. This depends mainly on the crystal violet concentration (decreased from 0.45 to 0.024 with an increase in concentration from 1.5 to 16 µmol L⁻¹), the amount of iodo-polyurethane and the reaction temperature. The slope increased with increasing pH, initial concentration of crystal violet, reaction temperature and amount and size of iodo-polyurethane and decreased with increasing particle size of dyes. The correlation coefficient depends on the pH and dye particle size.

When we applied equation $y = ax^{0.25}$, the results showed a good correlation coefficient and a lower intercept than that obtained with $Q_t = k_M t^{0.5}$. Nevertheless, the same problem is seen for the rate of diffusion at high capacity.

4. Application

A pilot study was conducted for removal of aniline blue and crystal violet from wastewater samples in El-Dammam, an industrial city, and water from the Arabian Gulf with iodo-polyurethane. Two 25-mL aliquots of water (pH 7.5 and 10) were spiked with 200 µg of the dyes, the solutions were shaken for 15 min, and the concentration of dye remaining in the supernatant was determined. Removal of the dyes from the water samples was 90–92% (Table 4). Iodo-polyurethane is thus a suitable sorbent for removing basic dyes from environmental samples. The relative standard deviation was 3–4%, which is considered acceptable (less than 10%) for real samples, and confirms the accuracy of the method.

5. Conclusion

A new sorbent, iodo-polyurethane, was prepared from polyurethane by replacing -NH₂ groups by iodine atoms. Iodo-polyurethane has useful characteristics, such as rapid extraction, low price and good chemical stability, and it can be used many times without losing its capacity. A pseudo second-order equation is the best model for describing the kinetics of extraction of aniline blue and crystal violet. The rate of sorption of dye onto iodo-polyurethane is rapid, with 50% removal within the first 50 s. The thermodynamic parameters

indicate that extraction of aniline blue and crystal violet is spontaneous and exothermic. The average capacity of iodo-polyurethane is 0.35 mmol g^{-1} for 100% removal of these dyes. A modified Morris–Weber model [18] was used to interpret the particle diffusion mechanism of sorption of crystal violet onto iodo-polyurethane [$y = ax^{0.5n}$ and $a = f(r', r''', pH, T, C, m)$ and $n = f(Q_e)$]. The n value depends on the maximum sorption capacity, $n = f(Q_e)$, the ideal value of $0.5 \leq n \leq 1$. It can be seen from the modified equation that the plot of Q_e against $t^{0.25}$ must give a straight line with the intercept at 0. The sorbent was successfully applied for removing dyes from laundry wastewater samples in Dammam City.

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