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Comparison of Basic Dye Crystal Violet Removal from Aqueous Solution by Low-Cost Biosorbents

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Abstract: The removal of basic dye crystal violet by low-cost biosorbents was investigated in this study using a batch experimental system. The adsorption of crystal violet onto various adsorbents was solution pH-dependent and the maximum removal occurred at basic pH 10.0. The kinetic experimental data were analyzed using pseudo-first-order and pseudo-second-order equations to examine the adsorption mechanism and the intraparticle diffusion model to identify the potential rate controlling step. These results suggested that the adsorption of crystal violet onto various adsorbents was best represented by the pseudo-second-order equation. The suitability of the Langmuir and Freundich adsorption isotherms to the equilibrium data was also investigated at various temperatures for all four sorbents and the adsorption isotherms exhibited Freundlich behavior. The Freundlich constant K_f was 1.55 for alligator weed, 2.33 for *Laminaria japonica*, 9.59 for rice bran and 5.38 $(mg/g)/(mg/L)^{1/n}$ for wheat bran, respectively at adsorbent concentration 5 g/L, pH 10.0 and 20°C. The thermodynamic parameters (ΔH, ΔG, and ΔS) were calculated and the results showed that the adsorption process for various adsorbents was spontaneous, endothermic, with an increased randomness, respectively. The particle size and the reaction temperature exhibited an insignificant impact on the adsorption equilibrium of crystal violet. The adsorbents investigated could serve as low-cost adsorbents for removing the crystal violet from aqueous solution.

Keywords: Adsorption, basic dye, isotherms, kinetics, low-cost biosorbents, wastewater treatment

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INTRODUCTION

Dyes are widely used in industries such as textiles, rubber, paper, plastics, cosmetics, etc. to color their products. As a result, a considerable amount of colored wastewater is generated. At present, one of the more pressing environmental problems associated with the textile industry is the removal of color from textile effluent prior to discharge into the environment. The molecules present in the textile effluent belong to very diverse chemical classes. Hence textile wastewater presents a challenge to conventional physico-chemical and biological treatment technology (1). Basic dyes are the brightest class of soluble dyes used by the textile industry (2). In many developed countries such as the UK and EU countries, environmental policies have required that zero synthetic chemicals should be released into the marine environment (3). Various techniques have been employed for the removal of dyes from wastewaters, which include adsorption, nanofiltrtion, electrokinetic coagulation, coagulation and precipitation, advanced chemical oxidation, electrochemical oxidation, ozonation, supported liquid membrane, liquid-liquid extraction, and biological process (4). The advantages and disadvantages of some dye removal processes mentioned above from wastewater were reviewed (1,4,5). The adsorption process is one of the efficient methods to remove pollutants from wastewaters (5). Amongst all the sorbents proposed, activated carbon is the most popular due to its large surface area, micro-porous structure, high adsorption capacity, etc. In particular, the effectiveness of adsorption on commercial activated carbons (CAC) for removal of a wide variety of dyes from wastewaters has made it an ideal alternative to other treatment options. However, activated carbon also presents several disadvantages. It is quite expensive, and the higher the quality, the greater the cost. The regeneration of saturated carbon is also expensive, not straightforward, and results in loss of the adsorbent (5,6). These have led to search for cheaper substitutes. Several low-cost adsorbents have been investigated for the adsorption of dyes with varying success. These include hard wood (7), banana pith (8), Indian rosewood (9), waste coir pith (10), bagasse pith (11), barley husk (12), cassava peel (13), rice husk and Mahogany sawdust (6), plant oils (4), tree ferns, wheat bran (2), etc. New economical, easily available, and highly effective adsorbents are still needed.

Crystal violet is a triphenyl methane dye, which is most widely used for coloring purpose, amongst all other dyes of its category. The aim of this study was to investigate the potential of using locally abundantly available non-living biomass of marine algae (*Laminaria japonica*) and freshwater macrophyte (Alligator weed) and agricultural by-products (rice bran and wheat bran) as low-cost adsorbents for the removal of the basic dye crystal violet from aqueous solution. The effects of solution pH, contact time, particle size, adsorbent concentration, reaction temperature, and ionic strength on crystal violet adsorption were studied. The Langmuir and Freundlich adsorption isotherms were employed to quantify the adsorption equilibrium. Several kinetic equations (i.e. pseudo-first-order equation, pseudo-second-order equation, and intraparticle diffusion model) were applied to investigate the adsorption mechanisms and potential rate controlling step. These results will be useful for further application of crystal violet in color removal from wastewater.

MATERIALS AND METHODS

Adsorbent

The untreated adsorbents Alligator weed (denoted as A-W), *Laminaria japonica* (brown algae, denoted as L-J), were washed with deionized water to eliminate the remains of sediments and particulate matter, dried in an oven at 105°C for a period of 24 h, and then ground and sieved to get two size fractions of 150–250 µm and $<$ 150 µm. Similarly, the untreated rice bran (denoted as R-B) and wheat bran (W-B) were dried in an oven at 105°C for a period of 24 h, and then ground and sieved to get fractions of 150–250 µm and $<$150 µm. Unless otherwise stated, the 150–250 fraction for various adsorbents were used for subsequent adsorption experiments.

Adsorbate

The adsorbate crystal violet (Molecular Weight: 407.99; CAS number: 603–48-5; Colorant: Triarylmethane; C.I. 42555; λ_{max} : 580 nm) utilized was commercial salt, which was widely used in the textile industry. Its structure is as illustrated in Fig. 1.

Preparation of Dye Solution

Deionized water was used in all experiments. The dye was made up in stock solution of concentration 1000 mg/L and was subsequently diluted to the required concentrations. The dye solution was prepared immediately before use, and exposure to light was minimized.

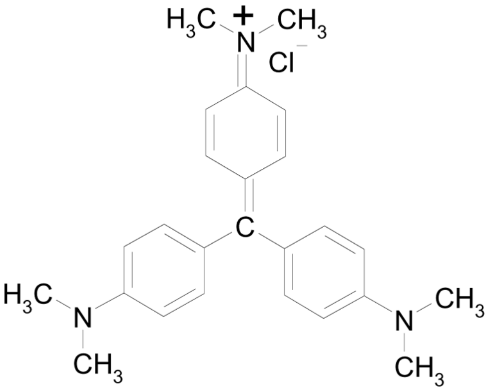

Figure 1. The molecular structure of crystal violet.

Pretreatment of Glassware for Dye Solution

Basic dyes are strongly adsorbed by glass. To minimize this effect, all glassware to be used in contact with dye solutions was steeped before use for at least 1 hr (usually overnight) in a solution (1000 mg/L) of a cationic surface-active agent, cetyl trimethylammonium bromide, which is preferentially adsorbed. The glass surfaces were then thoroughly rinsed with water before use (14).

Experimental

Batch kinetic experiments were carried out at constant pH 10.0 with initial concentration of 80 mg/L and adsorbent concentration of 5 g/L at a temperature of 20°C. After shaking, the solution samples were withdrawn at pre-determined time intervals.

Batch equilibrium experiments were conducted using 125-ml conical flask at a total sample volume of 50 mL for each adsorption run. The samples were agitated in a reciprocating shaker to reach equilibrium. At the end of the reaction time, a known volume of the solution was removed and centrifuged for analysis.

The effect of pH on adsorption of adsorbate onto various adsorbents was investigated by varying the solution initial pH from 3.0 to 10.0. The impact of adsorbent concentrations on uptake was then examined. Finally, sodium chloride (NaCl) was employed as background electrolyte to investigate the influence of ionic strength on solute uptake. The effects of particle sizes and reaction temperature (20, 30, 40°C) on the adsorption equilibrium were also investigated. Temperature control was provided by the water bath shaker units. The solution pH was adjusted with strong acid (HNO_3) and/or strong base (NaOH) and recorded with a pH meter (PHS-3C).

Analysis of Dye Solutions

The calibration curve for this dye was prepared by recording the adsorbance values for a range of known concentrations of dye solution at the wavelength to maximum adsorbance of the dye. The value of $\lambda_{\max}$ was used in all subsequent investigations. All measurements were made on an UV/Vis spectrophotometer (UNICO-7200).

Calculation

The amount of dye adsorbed at time t, q_t, and the removal efficiency (%) were calculated according to the following equations

$$q_t = \frac{(C_0 - C_t)V}{m} \tag{1}$$

$$\text{Removal } (\%) = \frac{C_0 - C_e}{C_0} \times 100 \tag{2}$$

where q_t and q_e are the amount of solute adsorbed onto the unit mass of the adsorbent at time t (min) and at equilibrium (mg/g), respectively; C_0, C_t, and C_e the concentration of the solute in the initial solution and in the aqueous phase at time t, and at equilibrium (mg/L), respectively; V the solution volume of the aqueous phase (L); and m the amount of adsorbent used (g).

Error Analysis

In order to quantitatively compare the applicability of different models in the present study, the correlation coefficient (R^2), was calculated in the following form

$$R^2 = \frac{\sum (q_{cal} - q_{\exp})^2}{\sum (q_{cal} - \bar{q}_{\exp})^2 + \sum (q_{cal} - q_{\exp})^2} \tag{3}$$

where q_{exp} and q_{cal} (mg/g) are the experimental and the calculated values, respectively. $\overline{q_{\text{exp}}}$ the average of q_{exp}.

RESULTS AND DISCUSSION

Effect of PH

The effect of solution pH on the percentage of crystal violet removal from aqueous solution by various adsorbents is illustrated in Fig. 2. The result shows the maximum percentage removal of the crystal violet taking place at basic pH (pH 10). Lower adsorption at low pH is probably due to the presence of excess hydrated H_3O^+ ions competing with the cation species on the dye for the adsorption sites. It should be noted that the percentage removal of the crystal violet considered in this study remained almost constant in the pH range from 9 to 10.

Uptake Kinetics

Figure 3 shows the adsorption kinetics of crystal violet by various adsorbents by plotting the amounts adsorbed, q_t, versus time t at the initial concentration of 80 mg/L. The removal of crystal violet by adsorption onto various adsorbents was found to be rapid at the initial period of contact time and then to slow down with the increase of contact time. Consequently, the removal of crystal violet was carried out in two distinct

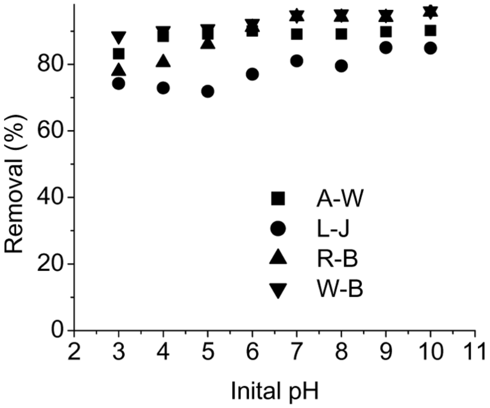

Figure 2. The effect of initial pH on the crystal violet uptake for various adsorbents (temperature 20°C; adsorbent concentration 5 g/L; initial concentration 80 mg/L).

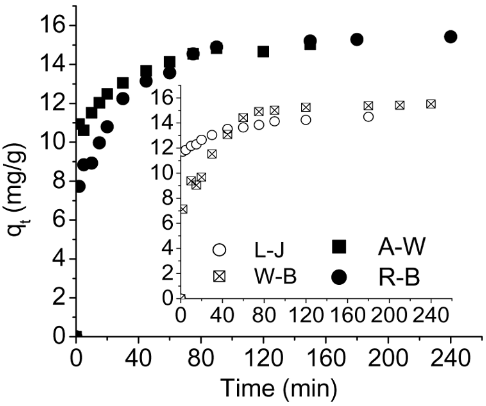

Figure 3. Plots of q_t versus t for adsorption of crystal violet onto various adsorbents (temperature 20°C; pH 10.0; adsorbent concentration 5 g/L; initial concentration 80 mg/L).

stages: a relatively rapid one followed by a slower one. At the beginning, the dye was possibly adsorbed by the external surface of the adsorbent, so the adsorption rate was very fast. When the adsorption of the external surface reached saturation, the dye species entered into the pores within the adsorbent and was adsorbed by the internal surface binding sites. When the dye species entered in the pore of the adsorbent, the diffusion resistance increased and correspondingly resulted in the reduction of diffusion rate.

Kinetic Modeling

In order to analyze the adsorption kinetics of crystal violet onto various adsorbents, the pseudo-first-order (15) and pseudo-second-order (16) equations were applied to the experimental data. These two equations are written in the following forms

$$\log(q_{e,1} - q_t) = \log(q_{e,1}) - \frac{k_1}{2.303}t \tag{4}$$

$$\frac{t}{q_t} = \frac{1}{q_{e,2}^2 k_2} + \frac{1}{q_{e,2}}t \tag{5}$$

where $q_{e,1}$ and q_t (mg/g) are the amounts of adsorbed crystal violet onto the adsorbents at equilibrium and at time t (min), respectively, k_1 (1/min) the rate constant of the pseudo-first-order equation, $q_{e,2}$ (mg/g) the

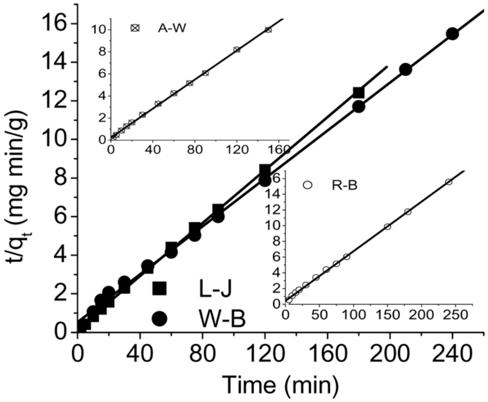

Figure 4. Pseudo-second-order plots for adsorption of crystal violet onto various adsorbents (temperature 20°C; pH 10.0; adsorbent concentration 5 g/L; initial concentration 80 mg/L).

adsorbed amounts of crystal violet at equilibrium, and k_2 (g/(mg min)) the rate constant of the pseudo-second-order equation.

Literature review has shown that most adsorption studies reported can be represented as pseudo-first–order rate mechanism. However, of all the systems studied here, this model is restricted only to a limited range of reactions (not shown) and this is in agreement with earlier finding (17).

Using Eq.(5), t/q_t was plotted versus t for various adsorbents and the parameters ($q_{e,2}$ and k_2) values were determined from the slope and intercept of the plots (Fig. 4). The values of parameters k_2 and $q_{e,2}$ and of correlation coefficients ($R^2 \sim 0.99$) are also presented in Table 1. The

Table 1. The pseudo-second-order equation constants of adsorption crystal violet onto various adsorbents (temperature 20°C; pH 10.0; adsorbent concentration 5 g/L; initial concentration 80 mg/L, unit of k_2 is g/(mg min), respectively; unit of q_e, $q_{e,2}$ are mg/g, respectively)

Adsorbents	Exp. q_e	Pseudo-second-order $q_{e,2}$	$k_2 \times 10^2$	R^2
A-W	15.0	14.5	2.6	0.99
L-J	14.5	16.1	0.7	0.99
R-B	15.4	15.2	1.9	0.99
W-B	15.5	15.8	0.8	0.99

correlation coefficient R^2 had an extremely high value, and the theoretical $q_{e,2}$ values agreed very well with the experimental values in the case of pseudo-second-order model. These results suggested the adsorption of crystal violet onto various adsorbents was best represented by the pseudo-second-order equation, which is based on the assumption that the rate-limiting step may be the adsorption (17).

Mass Transfer Analysis

Adsorption, whether physical or chemical, involves the mass transfer of a soluble species (adsorbate) from bulk solution to the surface of a solid

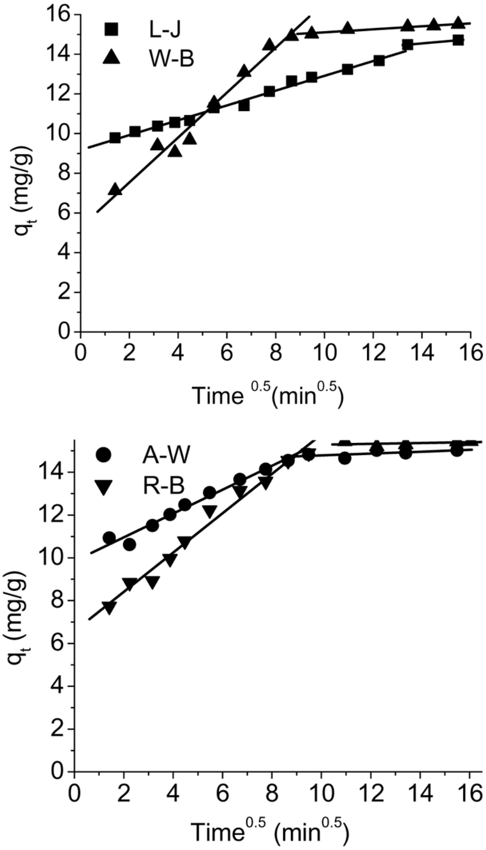

Figure 5. Intraparticle diffusion plots for adsorption of crystal violet onto various adsorbents (temperature 20°C; pH 10.0; adsorbent concentration 5 g/L; initial concentration 80 mg/L).

phase (adsorbent). For a porous adsorption media, the transport of adsorbate to adsorbent will occur through four subsequent steps: bulk solution transport, external (film) resistance to transport (external diffusion), internal (pore) transport (intraparticle diffusion) and adsorption.

It is essential to understand these mass transfer mechanisms in order to design a cost effective and efficient adsorption system. Bulk transport and adsorption are rarely, if ever, rate-limiting steps. The transport mechanisms of concern, therefore, are external film diffusion and intraparticle diffusion. In this work, the intraparticle diffusion (18) model was used to investigate the rate-controlling steps of the adsorption process. The equation is defined as follows

$$q_t = k_i t^{0.5} \tag{6}$$

where k_i (mg/g min$^{0.5}$) is the rate constants.

Plots of crystal violet amounts adsorbed, q_t versus time$^{0.5}$, are presented for various adsorbents in Fig. 5. All the plots have the similar general features, initial linear portion followed by a plateau. The initial linear portion was attributed to the intraparticle diffusion. However, such a deviation of the straight line from the origin could likely be due to the difference in the rate of boundary layer diffusion in the initial stage of adsorption. Generally, the intercept of the plot of q_t vs. time$^{0.5}$ gives an idea about boundary layer thickness, the larger the value of the intercept, the greater the boundary layer diffusion effect is. The values of intraparticle diffusion rate constant, k_i, are listed in Table 2.

Effect of Adsorbent Concentration

Figure 6 shows the crystal violet adsorption as a function of adsorbent concentrations for various adsorbents in a solution at pH 10.0. It is found

Table 2. The intraparticle diffusion rate constants for adsorption of crystal violet onto various adsorbents (temperature 20°C; pH 10.0; adsorbent concentration 5 g/L; initial concentration 80 mg/L, unit of k_i is mg / (g min$^{0.5}$))

	Intraparticle diffusion constant		
Adsorbents	$k_i \times 10$	Intercept	R^2
A-W	5.57	9.84	0.98
L-J	3.73	9.18	0.99
R-B	9.18	6.57	0.99
W-B	11.31	5.27	0.98

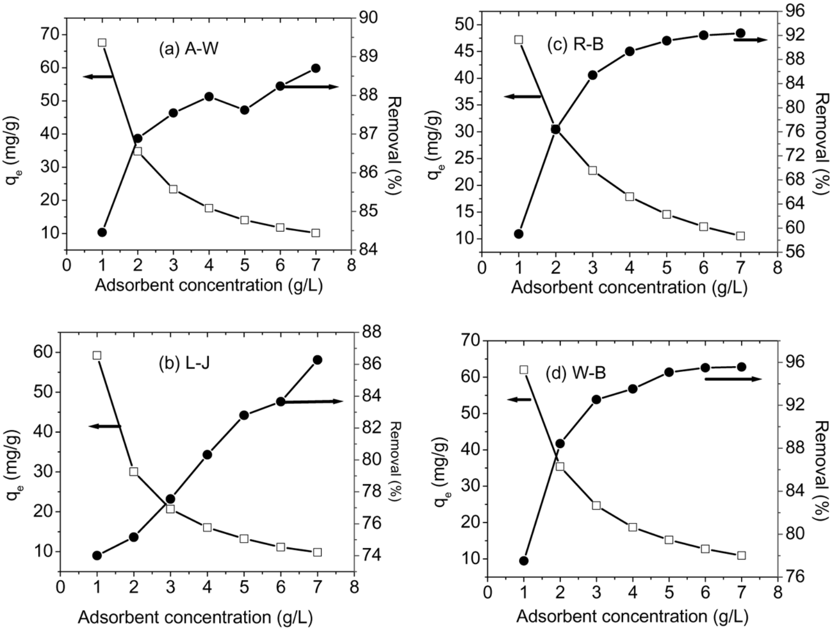

Figure 6. The effect of adsorbent concentration on the crystal violet adsorption onto various adsorbents (temperature 20°C; pH 10.0; contact time 120 min; initial concentration 80 mg/L).

that by increasing the adsorbent concentrations the removal efficiency increased but the adsorption density (i.e. the adsorption amount per unit mass) decreased. This can be attributed to the fact that the number of available adsorption sites increased by an increase in adsorbent and this therefore resulted in an increase in removal efficiency. The decrease in adsorption density with an increase in the adsorbent concentration could be ascribed to the fact that some of the adsorption sites remained unsaturated during the adsorption process. Another reason could likely be due to the inter-particle interaction, such as aggregation, resulting from high adsorbent concentration. Such aggregation would lead to a decrease in the total surface area of the adsorbent and an increase in the diffusion path length.

Effect of Initial Concentration on Distribution Coefficient (K_D)

The distribution coefficient, K_D (mL/g), has been used to indicate the adsorption affinity of a solid adsorbent towards a solute (19). In this work, the K_D is defined as

$$K_D = \frac{C_0 - C_e}{C_e}\frac{V}{m} \tag{7}$$

where C_0 and C_e represent the initial concentration and equilibrium concentration of crystal violet in the solution, respectively. V/m (mL/g) is the ratio of the liquid volume over the mass of adsorbent.

The impact of initial concentration of crystal violet on the distribution coefficients for various adsorbents is shown in Fig. 7. It can be seen that the distribution coefficients for various adsorbents were decreased in different ways as the initial concentration was increased. This could be attributed to the fact that the adsorption sites on the adsorbent surface would become more and more crowded by the increase in the amount of crystal violet adsorbed as the initial concentration of crystal violet was increased.

Adsorption Equilibrium

The adsorption equilibrium curves of crystal violet onto various adsorbents are shown in Fig. 8. The shape of the crystal violet adsorption onto various adsorbents was L2-type according to the classification of Giles et al. (20).

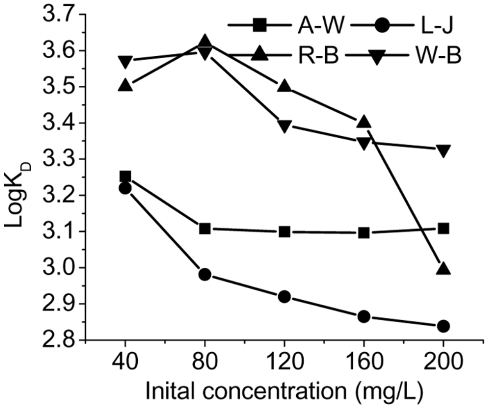

Figure 7. Distribution coefficients (K_D) of crystal violet as a function of initial concentration for various adsorbents (temperature 20°C; pH 10.0; contact time 120 min; adsorbent concentration 5 g/L).

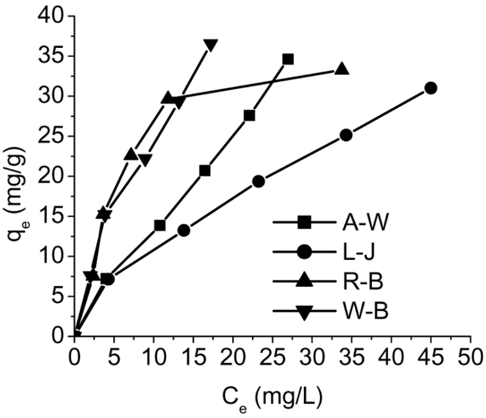

Figure 8. Experimental adsorption isotherms for various adsorbents (temperature 20°C; pH 10.0; contact time 120 min; adsorbent concentration 5 g/L).

The Freundlich and Langmuir equations were applied as follows

$$q_e = K_f C_e^{1/n} \tag{8}$$

$$q_e = Q^0 b C_e / (1 + b C_e) \tag{9}$$

where K_f ((mg/g)/(mg/L)$^{1/n}$) and n (dimensionless), the Freundlich constants characteristics of the system, are indicators of adsorption capacity and adsorption intensity, respectively. Q^0 (mg/g) is the maximum amount of adsorbate per unit weight of adsorbent to form a complete monolayer on the surface and b (L/mg) a constant related to the affinity of the binding sites. The constants can be determined using non-linear analysis (not shown) and the values are listed in Table 3.

The magnitude of K_f and n; the Freundlich constants, suggested easy uptake of crystal violet from aqueous solution with a high adsorptive capacity of R-B. The adsorption capacity is the least for the crystal violet-A-W system. The value of n, which reflects the intensity of adsorption, presents the same trend. Moreover, the values of n are greater than unity, indicating favorable uptake of crystal violet onto various adsorbents.

The value of Q^0 (maximum uptake) appeared to be significantly lower for the crystal violet- R-B system in comparison with the uptake of crystal violet onto the adsorbents L-J and W-B. A large value of b implied strong bonding of crystal violet to the R-B.

Table 3. A comparison of the Freundlich and Langmuir adsorption constants at different temperatures (pH 10.0; contact time 120 min; adsorbent concentration 5 g/L)

	Freundlich constants			Langmuir constants		
Adsorbents	K_f ((mg/g)/ (mg/L)$^{1/n}$)	n	R^2	Q^0 (mg/g)	b (L/mg)	R^2
20°C						
A-W	1.55	1.07	0.99	–	–	–
L-J	2.33	1.48	0.99	66.64	0.01843	0.98
R-B	9.59	2.66	0.91	41.68	0.1528	0.97
W-B	5.38	1.50	0.99	69.15	0.05985	0.98
30°C						
A-W	2.21	1.04	0.99	–	–	–
L-J	3.22	1.59	0.99	59.73	0.0288	0.98
R-B	7.34	2.19	0.98	44.75	0.1013	0.99
W-B	7.21	1.52	0.99	72.76	0.0846	0.99
40°C						
A-W	2.00	0.95	0.99	–	–	–
L-J	2.72	1.45	0.98	82.83	0.0178	0.97
R-B	8.70	2.41	0.97	42.25	0.1407	0.99
W-B	6.39	1.44	0.99	80.37	0.0666	0.99

Effect of Particle Size on Uptake Equilibrium

The effect of particle size on the crystal violet uptake equilibrium for various adsorbents was investigated and the results are shown in Fig. 9. It is evident that the affinity of crystal violet towards three adsorbents of A-W, L-J, and R-B was more for the $< 150\,\mu m$ fraction as compared to the coarser fraction (i.e. 150 to 250 μm). However, the effect of the particle size on the crystal violet uptake onto W-B was negligible as compared to the other three adsorbents.

Effect of Temperature on Uptake Equilibrium

Figure 10 shows the effect of temperature on the crystal violet uptake for various adsorbents. It is found that the crystal violet uptakes for various adsorbents were increased with the rise of reaction temperature only slightly. The Freundlich and Langmuir adsorption constants evaluated form the isotherms at different temperatures with the correlation coefficients are also presented in Table 3. As can be seen in Table 3, the highest K_f and n values were found as 9.59 (mg/g)/(mg/L)$^{1/n}$ and 2.66 for the crystal violet-R-B system, respectively, at the temperature of 20°C.

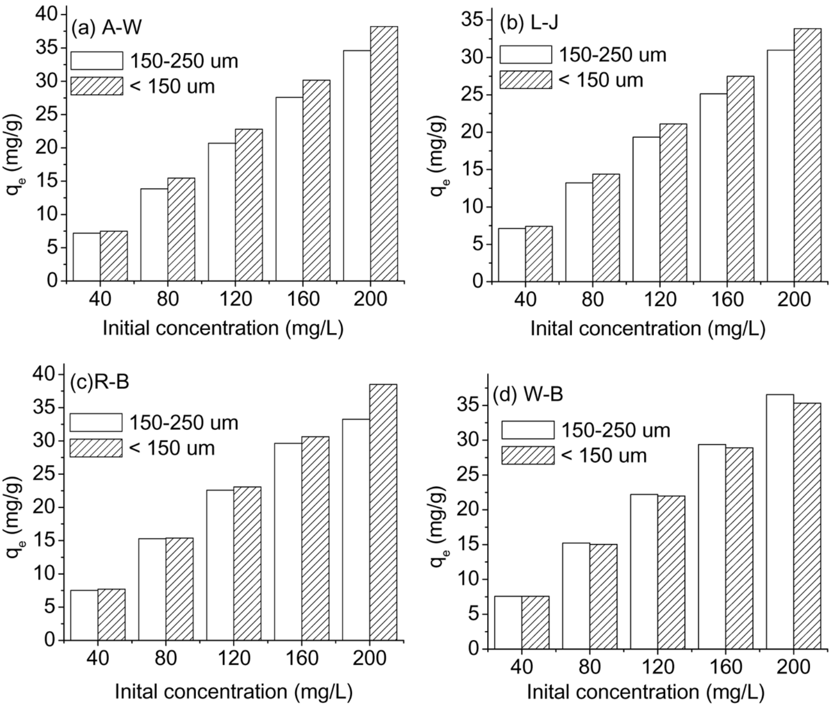

Figure 9. The effect of particle size on the crystal violet uptake for various adsorbents (temperature 20°C; pH 10.0; contact time 120 min; adsorbent concentration 5 g/L).

Table 3 also indicates that n is greater than unity, suggesting that crystal violet was favorably adsorbed by various adsorbents at all the temperatures studied except for the adsorbent of A-W at the temperature of 40°C. The value of Q^0 obtained at 40°C appears to be higher in comparison with the uptakes obtained at the other temperatures for adsorbents of L-J and W-B, respectively. Although the highest Q^0 value for adsorbent R-B was found as 44.75 mg/g at the temperature of 30°C, a large value of b nevertheless implied strong bonding of crystal violet to the R-B at various temperatures as compared to the other three adsorbents.

The thermodynamic parameters for the adsorption process, ΔH (kJ/mol), ΔS (J/mol K), and ΔG (kJ/mol), were evaluated using the following equations (21)

$$\ln K = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \tag{10}$$

$$\Delta G = \Delta H - T\Delta S \tag{11}$$

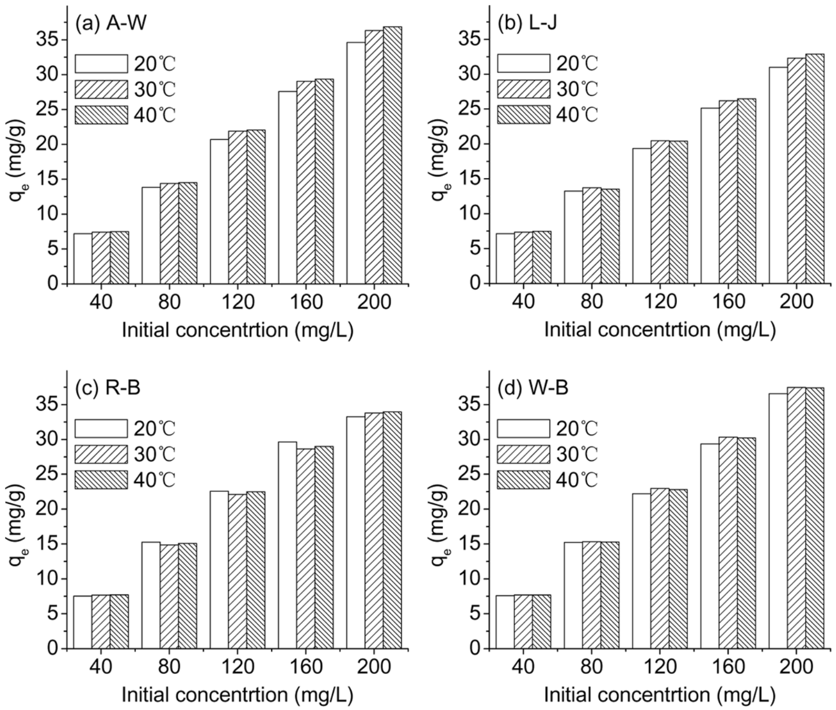

Figure 10. The effect of temperature on the crystal violet uptake for various adsorbents (pH 10.0; contact time 120 min; adsorbent concentration 5 g/L).

where K is the equilibrium constant of the adsrobate ($= q_e/C_e$ in L/g), T the absolute temperature (K), and R the universal gas constant ($= 8.314$ kJ/mol).

The results presented in Table 4 show that the negative values of ΔG as well as the positive values of ΔH and ΔS indicated that the adsorption process for various adsorbents was spontaneous, endothermic, with an increased randomness, respectively. The fact that ΔH values are relatively low was an indication of a diffusion controlled process (22).

Effect of Ionic Strength on Uptake Equilibrium

Dye-laden wastewaters released from different industries contain various types of salts. The presence of these salts leads to high ionic strength, which may significantly affect the performance of the adsorption

Table 4. Thermodynamic data for adsorption crystal violet on to various adsorbents (pH 10.0; contact time 120 min; adsorbent concentration 5 g/L; initial concentration 40 mg/L)

			ΔG (kJ/mol)		
Adsorbents	ΔH (kJ/mol)	ΔS (kJ/mol)	293K	303K	313K
A-W	20.1	73.7	−1.5	−2.2	−2.9
L-J	20.4	74.1	−1.2	−2.1	−2.7
R-B	20.3	79.6	−2.9	−3.7	−4.5
W-B	11.1	49.3	−3.3	−3.8	−4.3

process. Figure 11 shows clearly that the variation of sodium chloride concentration exhibits some effect on the extent of crystal violet uptake by various adsorbents. The uptake of crystal violet was

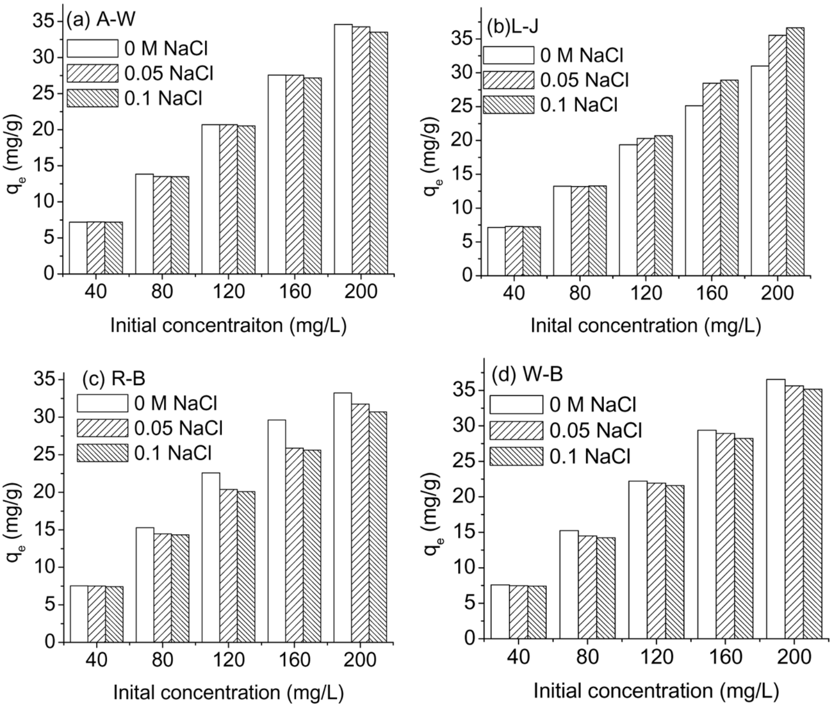

Figure 11. The effect of ionic strength on the crystal violet uptake for various adsorbents (pH 10.0; contact time 120 min; adsorbent concentration 5 g/L; temperature 20°C).

decreased with the increase in ionic strength for the three adsorbents A-W, R-B, and W-B whereas the adsorbent L-J showed the opposite trend. This indicates that the adsorption mechanism of crystal violet onto adsorbent L-J was different from that of the other adsorbents. The fact that the extent of adsorption is sensitive to changes in concentration of supporting electrolyte indicates that electrostatic attraction may be a significant component of the overall adsorption in this system. When the ionic strength was increased, the electrical double layer surrounding the adsorbent surface was compressed and correspondingly resulted in a decrease in crystal violet adsorption on to the three adsorbents.

CONCLUSIONS

The adsorption of basic dye crystal violet on to marine algae (*Laminaria japonica*) and freshwater macrophyte (Alligator weed) and agricultural by-products (rice bran and wheat bran) was investigated in a batch experimental system. The following conclusions were drawn:

1. The removal of crystal violet for various adsorbents was pH-dependent and the maximum removal occurred at basic pH 10.0.
2. The crystal violet adsorption by various adsorbents was very rapid initially. The kinetic data conformed better to the pseudo-second-order equation. The intraparticle diffusion was not the only rate-controlling step.
3. The equilibrium adsorption data by various adsorbents were correlated well by Freundlich isotherms. The particle size and reaction temperature exhibited a very small impact on the crystal violet adsorption equilibrium.
4. The removal efficiency increased and the adsorption density decreased with a rise in adsorbent concentrations for various adsorbents investigated.
5. The uptake of crystal violet was decreased with the increase in ionic strength for the three adsorbents A-W, R-B, and W-B whereas the adsorbent L-J showed the opposite trend.
6. The adsorption process for various adsorbents was spontaneous, endothermic, with an increased randomness, respectively.
7. The adsorbents investigated in this work could serve as low-cost adsorbents for removing the crystal violet from the aqueous solution.

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