Jute (*Corchorus olitorius*) stick charcoal as a low-cost adsorbent for the removal of methylene blue dye from aqueous solution

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Abstract

Removal of methylene blue (MB) dye from aqueous solution was studied using jute stick charcoal (JSC), prepared from jute (*Corchorus olitorius*) stick: an affordable and available agricultural by-product, as a low-cost adsorbent. All the experiments were carried out in batch mode. Controlling factors of the system, including contact time, solution pH, JSC dose and initial MB concentration, were investigated to study their effects on MB adsorption. JSC was characterized by Fourier transform infrared spectroscopy and field emission scanning electron microscope. Adsorption equilibrium data fitted well with Freundlich and Halsey adsorption isotherms that describe the multilayer adsorption on heterogeneous surface. The maximum adsorption capacity calculated by the Langmuir isotherm was 29.32 mg/g. The MB adsorption process was well described by the pseudo-second-order kinetic model, and the MB diffusion in JSC was the potential rate-controlling step. Finally, JSC is a promising adsorbent for the adsorption of MB from aqueous solution.

Keywords Adsorption · Jute stick charcoal · Methylene blue · Dye

1 Introduction

Water pollution by dyes from the industries such as textile, printing, plastic, dye synthesis, pulp and paper mill, leather, electroplating, food, cosmetic, pigments, petroleum, rubber, pesticide is posing a serious threat to aquatic ecosystems as well as to human health. The presences of very small amount of dyes in water affect photosynthetic activity by preventing light penetration and upset the biological metabolism processes in aquatic life. Dyes produce microtoxicity for fish and other aquatic organisms by chelating metal ion [1]. Therefore, much attention should be given to treatment of dyes containing effluent before discharge. Methylene blue (MB), an organic cationic dye, has extensive applications including dyeing of cotton or wool or silk, leather dyeing, plastics coloring, paper coloring, manufacturing of paints and printing ink [2] and also in the treatment of fungal infection and

determination of microbial load in milk [3]. MB causes various adverse effects on human health such as increased heart rate, vomiting, nausea, diarrhea, breathing difficulties (dyspnea), cyanosis, convulsions for inhalation, eye injury, fever, headache, dizziness, mental confusion, cancer and hypertension [4–6]. MB removal is difficult due to its complex atomic structure, xenobiotic properties, high light visibility, stability and oxidation reaction [4, 7]. Different types of methods such as coagulation/flocculation, membrane separation, oxidation/ozonation, reverse osmosis, photocatalysis, ultrafiltration, electrochemical and adsorption [8–12] have been applied for the removal of MB from wastewater or aqueous solution. Among these methods, adsorption has been found to be superior than others due to its simplicity of design and operation, low cost, high efficiency, source abundance and insensitivity to toxic substance [13, 14]. A variety of bioadsorbents such as bagasse, peanut hull, banana peel, pineapple stem, garlic

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peel, coconut bunch waste, coffee husk, rubber seed shell, fallen phoenix tree's leaves, ground hazelnut shells, walnut sawdust, yellow passion fruit waste, rice husk, cherry sawdust, coconut coir, neem leaf powder, spent rice biomass, pine fruit shell carbon, walnut shell carbon, oil palm shell carbon, wood apple rind carbon, plant leaf powder, coal fly ash, duckweed, algal waste, green alga, dead fungus [15], brown linseed deoiled cake-activated carbon [16], chitosan-bamboo sawdust composite [17], custard apple fruit shell [18] and modified pea peels [19] has been used for dye removal from aqueous solution. It has been found that bioadsorbent derived from different parts of jute plants is effective for dye removal, such as jute processing wastes for dye wastewater treatment [20], jute stick powder for Congo red and rhodamine B dye [4], activated carbon of jute stick for brilliant green dye [21], but the utilization of JSC for MB removal is still hindered by lack of information. Raw jute crop is an important cash crop to the farmers in jute-producing countries. Jute sticks are by-product of jute plant after jute fiber collection and mainly used as fuel for earthen stoves and sometimes for making fences in jute-growing rural areas. The total production of jute stick in the world is around 6 million tons per year [22]. This research intend to investigate the applicability of JSC for MB removal from aqueous solution with different experimental conditions: contact time, pH, adsorbent dose and initial MB concentration. Adsorption isotherms and kinetics model were also investigated. The information obtained may be useful for modeling and designing the adsorption processes.

2 Materials and methods

2.1 Preparation and analysis of test water

MB was purchased from Sigma-Aldrich, USA. The formula of MB is $C_{16}H_{18}ClN_3S \cdot xH_2O$, molecular weight 319.9 g/mol, solubility 43×10^3 mg/L at 25 °C, pK_a 3.8 [23] and purity 88%. The stock solution of MB (100 mg/L) was prepared by dissolving the required amount of MB powder in double-distilled water. Then, the desired working solution was prepared from the stock solution by diluting with double-distilled water. The pH of experiment solution was adjusted by adding 0.1 N HCl/0.1 N NaOH and measured by using a digital pH meter (EZdo 6011, Taiwan). The concentration of MB was measured by UV-visible spectrophotometer (HACH DR 3900, USA) at 665-nm wavelength. All the chemicals in this work were of analytical grade.

2.2 Preparation and characterization of adsorbent

Jute sticks were collected from local farmer, Jashore, Bangladesh. After collection, the sticks were cut into small pieces (5 inches long) and then washed with tap water to remove dirt and jute fiber, then further washed with double-distilled water, dried in an oven (Labtech LDO-150F, Korea) at 80 °C for 24 h, cooled in room temperature and carbonized into a muffle furnace (SXT-10, Shanghai Shuli Instrument and Meters Co., Ltd. China) at 300 °C for 30 min. After that crushed by a mortar and pestle, 0.5–1.0 mm size particles were collected through sieved. Finally, JSC was stored in airtight borosilicate glass bottles and used for experiments as needed. FTIR (Fourier transform infrared spectroscopy) spectra of JSC were recorded before and after adsorption of MB on a FTIR-4600, spectrophotometer, JASCO Corporation Ltd., Japan. The surface morphology of JSC was observed before and after adsorption of MB by using a field emission scanning electron microscope (FE-SEM, Zeiss Sigma, Carl Zeiss, Germany).

2.3 Batch adsorption experiments

The batch adsorption experiments were carried out in 500-mL beakers with 150 mL working solution and adsorbent. In this test, 150 mL of a known MB solution (prepared from the dilution of 100 mg/L stock solutions) was poured into each beaker, the pH was adjusted, a given mass of JSC was added to the solution, and stirring speed was kept at 200 rpm. The effects of experimental conditions: Contact time (1–180 min), pH (3–9), adsorbent dose (1–9 g/L) and initial MB dye concentration (10–100 mg/L) on MB removal by JSC were studied. Upon completion, a sample of the suspension was taken from the beaker and filtered through Whatman® glass microfiber filter (grade GF/B) to remove adsorbent particles. The filtrate was diluted and analyzed for residual MB. All batch experiments were conducted in a Jar-test instrument (JLT4, VELP Scientifics, Italy) and performed in duplicate. Under the experimental conditions, the amount of MB adsorbed and the percentage removal of MB at equilibrium was calculated using Eqs. (1) and (2), respectively:

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (1)$$

$$R(\%) = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (2)$$

where C_0 and C_e are the initial and at equilibrium MB concentrations in mg/L, respectively. q_e is the equilibrium MB

adsorbed in mg/g. V is the volume of solution (L), and m is the mass of adsorbent (g).

2.4 Adsorption isotherms

In adsorption isotherm experiments, MB adsorption onto JSC was conducted at the optimum conditions with an equilibrium contact time of 120 min at pH 9 using initial MB concentration of 10, 20, 50, 70 and 100 mg/L and a fixed JSC dose of 3 g/L. All other operational parameters were the same as batch adsorption experiments. In this study, four equilibrium adsorption isotherm models (Langmuir, Freundlich, Elovich and Halsey) were used. Langmuir isotherm [24] expresses monolayer adsorption on finite site of adsorbent surface, where only one adsorbate molecule can hold a single vacant space and no further overlapping at that sites. The linearized form of Langmuir isotherm is presented in Eq. (3).

$$\frac{C_e}{q_e} = \frac{1}{q_{\max}b} + \frac{C_e}{q_{\max}} \quad (3)$$

where C_e is the equilibrium concentration of remaining MB in the solution (mg/L), q_e is the amount of MB adsorbed at equilibrium (mg/g), $q_{\max}$ is the amount of MB at complete monolayer coverage (mg/g), and b (L/mg) is Langmuir constant related to adsorption capacity and rate of adsorption. The Langmuir parameters can be determined from the slope and intercept, when plotting C_e/q_e versus C_e .

The essential feature of the Langmuir isotherm can be expressed in terms of dimensionless constant separation factor (R_L) that is used to predict whether an adsorption system is "favorable" or "unfavorable" [25]. The separation factor is presented in Eq. (4).

$$R_L = \frac{1}{1 + bC_0} \quad (4)$$

The adsorption process as a function of R_L may be described as $R_L > 1$; unfavorable, $R_L = 1$; linear, $0 < R_L < 1$; favorable, and $R_L = 0$; irreversible.

Freundlich isotherm explains the heterogeneous surfaces of adsorbent [26] and also the exponentially distribution and dynamisms of active sites of adsorbent. The linearized form of Freundlich model is presented in Eq. (5):

$$\log q_e = \log K_F + 1/n \cdot \log C_e \quad (5)$$

where K_F and n are Freundlich constant that represent adsorption capacity and adsorption intensity, respectively. Therefore, a plot of $\log q_e$ against $\log C_e$ gives a straight line; K_F and $1/n$ are determined, respectively, from the intercept and slope. Values of n , between 1 and 10, indicate a favorable adsorption process, while higher K_F value indicates an easy uptake of adsorbate from the solution.

Elovich model is defined on the basis of kinetic principle, where adsorption processes are increased exponentially with increasing adsorption sites, which is known as multilayer adsorption [27], and the linearized form of this equation is given in Eq. (6).

$$\ln \frac{q_e}{C_e} = \ln k_e q_m - \frac{q_e}{q_m} \quad (6)$$

where q_m is the Elovich maximum adsorption capacity (mg/g) and k_e is Elovich constant, which can be calculated from slope and intercept of $\ln(q_e/C_e)$ versus q_e plot, respectively.

Halsey isotherm model describes the multilayer adsorption at a relative distance from the surface [28]. The linearized form of this equation is given in Eq. (7).

$$\log q_e = \frac{1}{n_H} \log K_H - \frac{1}{n_H} \log C_e \quad (7)$$

where K_H and n_H are the Halsey constants, which can be obtained from the intercept and slope of $\log q_e$ versus $\log C_e$ plot, respectively.

2.5 Adsorption kinetics

The adsorption kinetic experiments of MB were conducted at optimum pH 9 with a fixed MB concentration of 20 mg/L with JSC dose of 3 g/L at 200 rpm at 25 ± 2 °C. Samples were drawn from the solution mixture at time intervals of 1, 2, 5, 7, 10, 15, 30, 60, 90, 120, 150 and 180 min and analyzed for kinetics study. The four kinetic models (Lagergren pseudo-first-order model, Ho's pseudo-second-order model, intraparticle diffusion model and Boyd model) were used to investigate the adsorption dynamic. Lagergren pseudo-first-order model is used to determine the adsorption performance of adsorbate onto adsorbent. The linearized form of Lagergren pseudo-first-order model [29] is shown in Eq. (8).

$$\log (q_e - q_t) = \log (q_e) - \frac{K_1}{2.303} t \quad (8)$$

where K_1 is the pseudo-first-order rate constant (min^{-1}) and q_e and q_t are the amount of MB dye adsorbed (mg/g) at equilibrium and time t . K_1 and q_e can be obtained, respectively, from the slope and intercept of a linear plot of $\log(q_e - q_t)$ versus t .

Ho's pseudo-second-order kinetic model determines the adsorption rate of adsorbate, which are proportional to the available active sites onto the adsorbent surface. The linearized form of Ho's pseudo-second-order model [30] is presented in Eq. (9).

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e} (t) \quad (9)$$

where K_2 is the pseudo-second-order rate constant (g/mg/min). Replacing the $K_2 q_e^2$ by H in Eq. (9), we have Eq. (10).

$$\frac{t}{q_t} = \frac{1}{H} + \frac{1}{q_e} (t) \quad (10)$$

where H is the initial adsorption rate (mg/g/min) constant.

The intraparticle diffusion model was explored by Weber and Morris equation [31]. This model indicates the presence of the intraparticle diffusion during adsorption process. The intraparticle diffusion model is expressed as Eq. (11).

$$q_t = K_{\text{diff}} t^{0.5} + C \quad (11)$$

where K_{diff} is the intraparticle diffusion rate constant (mg/gmin^{0.5}) that can be calculated from the slope of a linear plot of q_t versus $t^{0.5}$, and C is intercept that represents the thickness of boundary layer.

To distinguish between the pore and film diffusion step involved in the adsorption process, the kinetic experimental results were further analyzed using the Boyd model [32]. The Boyd model can be expressed as Eq. (12).

$$F = \frac{q_t}{q_e} = 1 - \frac{6}{\pi^2} \exp(-Bt) \quad (12)$$

where F is the fraction of solute adsorbed at different time t and B_t is the function of F . The B_t value can be calculated at different contact time, t , by using Eq. (13):

$$B_t = -0.4977 - \ln(1 - F) \quad (13)$$

where B_t is calculated for each q_t and then plotted against t . If the Boyd linear plot pass through the origin, then rate-limiting step in adsorption process is particle diffusion. Otherwise, film diffusion is rate-limiting step [33].

3 Results and discussion

3.1 Characterization of JSC

FTIR analysis finds the functional groups, existing on the adsorbent surface and also the changes of functional group vibrational frequency. The percentage transmission for various wave numbers and the adsorption bands identified in the spectra of JSC is presented in Fig. 1a, and this discloses the presence of several functional groups for binding MB molecules onto the JSC. The adsorption peak at 3398 cm⁻¹ (H-bonded OH group, mostly found in cellulose) and 2987 cm⁻¹ (C–H stretching vibration of –CH₂–, usually found in lignin, cellulose

and hemicellulose) was the primal peak of JSC [4, 23]. Carboxyl acid groups and different types of hemicellulose were presented in 1701 cm⁻¹ peak [4, 21]. The peak at 1596 cm⁻¹ indicates stretching vibration of benzene ring of lignin. The other peak at 1231, 988 and 893 cm⁻¹ reflects the stretching vibration C–O, C=C and C–H groups, respectively (Fig. 1a). MB-loaded FTIR spectrum found at 3398 and 1701 cm⁻¹ indicates that hydroxyl and carboxyl groups, respectively, were effective for MB adsorption onto JSC. Similar results were found in other studies where MB was removed by *Ficus carica* bast [9] and white pine sawdust [23]. The morphology and surface characteristics of JSC, before (Fig. 1b) and after (Fig. 1c) adsorption of MB, were observed using FE-SEM. The surface of the unloaded JSC (before MB adsorption) showed rough, irregular pores of different sizes and shapes (Fig. 1b), which are capable for ensnaring the MB during adsorption process. The surface of MB-loaded JSC (Fig. 1c) was smooth, i.e., enclosed by MB molecules.

3.2 Effect of contact time and pH on MB adsorption

The adsorption capacities of MB onto JSC were carried out with contact time variation ranging from 1 to 180 min and are presented in Fig. 2a. The maximum adsorption capacity and removal efficiency were 5.43 mg/g and 81%, respectively (Fig. 2a). This adsorption process occurred by the following two steps. In the first step, adsorption increased significantly in the first 5 min (69%) due to available active sites on the surface of adsorbent and high concentration of MB dye. During the second step, adsorption increased slowly, because most of the active sites were filling up by the MB ions with time progress and finally equilibrium was reached at 120 min (Fig. 2a). Similar trend was found by Han et al. [34].

The aqueous solution pH is an important controlling parameter in dye adsorption processes. The removal of MB as a function of varying pH in the range of 3–9 is given in Fig. 2b. As the varying pH increased from 3 to 9, the adsorption of MB onto JSC increased and maximum removal was 90% at pH 9; hence, it was taken as the optimum pH value for further experiments. This is due to the fact that the solution pH influences the cationic MB dye as well as the ionization of the functional groups onto the adsorbent surfaces. As MB is a cationic dye, the presence of excess H⁺ ions at acidic pH competes with the cation groups on the dye for adsorption sites of JSC. However, at higher pH, the electrostatic repulsion between the cationic MB dye and the surface of the JSC is lower, which may lead in an increase in the rate of adsorption. As a result, it is expected that Coulombic interaction plays an important role in the adsorption of MB onto JSC.

Fig. 1 **a** FTIR spectra of JSC before (green) and after (red) adsorption of MB; **b** FE-SEM image of JSC before adsorption of MB; and **c** FE-SEM image of JSC after adsorption of MB

Fig. 2 Effect of **a** contact time and **b** pH on removal of MB by JSC [experimental condition: adsorbent dose (3 g/L), rotation speed (200 rpm) and temperature (25 ± 2 °C), initial MB dye concentration (20 mg/L)]

3.3 Effect of adsorbent dose and initial MB concentration on MB adsorption

The adsorption of MB onto JSC was conducted by varying the JSC dose (1–9 g/L) for a fixed MB concentration of 20 mg/L at pH 9. The MB removal efficiency increased from 65 to 97% while increasing the adsorbent dose from 1 to 9 g/L (Fig. 3a). The possible causes are increased surface area and large number of available unsaturated active sites for adsorption process. In contrast, adsorption capacity decreases with increasing adsorbent dose (Fig. 3a) mainly because of unsaturation of adsorption sites through the adsorption process. Adsorption capacity of JSC for MB was decreased from 13.14 to 2.15 mg/g as the JSC dose increased from 1 to 9 g/L, respectively. This is due to the fact that all unsaturated active sites are exposed and filling up by low adsorbent dose and particle aggregation is created by increasing adsorbent dose [34].

The adsorption of MB onto JSC at various concentrations (10, 20, 50, 70 and 100 mg/L) with equilibrium contact time (120 min) is shown in Fig. 3b. The MB removal efficiency gradually decreased (95–74%) with increasing the concentration of MB (10–100 mg/L) at constant adsorbent dose (3 g/L), due to limited numbers of active sites present on adsorbent surface which becomes saturated at certain concentration of MB and excess MB remains unadsorbed due to lacking of binding sites at higher initial concentration of MB (Fig. 3b). On the other hand, the adsorption capacity of JSC increased (3.17–24.74 mg/g) with increasing the concentration of MB (10–100 mg/L) (Fig. 3b).

3.4 Adsorption isotherms

In this study, four isotherm models (Langmuir, Freundlich, Halsey and Elovich) were applied to know the adsorption behavior of MB onto JSC. The adsorption isotherms and fitting results are presented in Fig. 4 and Table 1. The results revealed that the adsorption of MB onto JSC fitted better with the Freundlich ($R^2 = 0.998$) and Halsey ($R^2 = 0.998$) models as compared with the Langmuir ($R^2 = 0.950$) and Elovich ($R^2 = 0.918$) models (Table 1). The Freundlich and Halsey models express the heterogonous distribution of active sites with multilayer adsorption of MB onto JSC. This leads further support to the conclusion that the surface of the JSC is likely made up of small heterogeneous adsorption patches, which are dissimilar to each other in respect of adsorption phenomenon. The value of n (1.934) from Freundlich isotherm model was higher than 1, suggested that JSC is suitable for adsorption of MB from aqueous solution. On the other hand, the values of separation factor (R_L : 0.063–0.404) of Langmuir model lie within 0 and 1, indicating the suitable character of MB adsorption process onto the JSC, and higher K_F value (4.576) also indicates that JSC easily uptakes MB from the aqueous solution (Table 1). Similarly, Langmuir isotherm indicates the maximum adsorption capacity of JSC was 29.32 mg/g (Table 1). The lower adsorption capacity ($q_m = 11.65$ mg/g) and R^2 (0.918) values obtained from Elovich isotherm indicate that this model is inappropriate for describing the adsorption process of MB onto JSC (Fig. 4c). The absorption capacity of JSC that had been compared with other adsorbents reported in the literature is given in Table 2. It shows that the maximum monolayer adsorption capacity of MB onto

Fig. 3 Effect of **a** adsorbent dose and **b** initial MB concentration on removal of MB by JSC [experimental condition: pH (9), contact time (120 min), rotation speed (200 rpm) and temperature (25 ± 2 °C)]

Fig. 4 Adsorption isotherm of MB onto JSC using different isotherm models: **a** Langmuir isotherm, **b** Freundlich isotherm, **c** Elovich isotherm and **d** Halsey isotherm

Table 1 Isotherm parameters of MB adsorption onto JSC for different isotherm models (Langmuir; Freundlich; Elovich; and Halsey)

Models	Parameters	Values
Langmuir	$q_{\max}$ (mg/g)	29.32
	b (L/mg)	0.147
	R_L	0.063–0.404
	R^2	0.950
Freundlich	K_F (mg/g) (L/mg) $^{1/n}$	4.576
	n	1.934
	R^2	0.998
Elovich	q_m (mg/g)	11.655
	K_e	1.176
	R^2	0.918
Halsey	K_H	2.194
	n_H	1.934
	R^2	0.998

JSC is moderate and it is a suitable alternative adsorbent for the cleanup of MB from aqueous solution, because of its low cost, easily available, environmental friendly and does not create secondary pollution.

3.5 Adsorption kinetics

The experimental data and adsorption kinetic models predicted data of MB adsorption onto JSC were compared based on correlation coefficient (R^2) and are presented in Table 3. On the basis of R^2 value, pseudo-second-order model better fitted than the pseudo-first-order model (Fig. 5a and 5b; and Table 3), and the calculated value ($q_{e,cal}$) agreed with the experimental value ($q_{e,exp}$) of pseudo-second-order model (Table 3). So, it confirms that the adsorption process was chemisorption, including sharing or exchange of electrons between MB and adsorbent [42]. Additionally, Weber and Morris's intraparticle diffusion model was used to know the diffusion mechanism of MB adsorption onto JSC. The linear plot of the intraparticle diffusion model (Fig. 5c) did not

Table 2 Comparison of MB adsorption capacity by JSC with respect to other adsorbents

Adsorbents	Maximum adsorption capacity (mg/g)	Optimum dose (g/L)	Concentration range (mg/L)	References
Citrus limetta peel	227.3	2.0	25–250	[35]
<i>Casuarina equisetifolia</i> needle	110.80	0.3	100–400	[36]
Jute stick powder	37.89	20.0	25–300	[37]
Bamboo shoot skin	29.88	2.0	20–200	[14]
Jute stick charcoal	29.32	3.0	10–100	This study
Jute processing waste	22.47	4.0	20–60	[20]
Banana peel	20.80	1.0	10–120	[38]
Orange peel	18.60	1.0	10–120	[38]
Wheat shells	16.56	1.0	100–400	[39]
Coconut coir	15.59	5.0	60–100	[40]
Indian rosewood sawdust	11.8	4.0	50–500	[41]
Neem (<i>Azadirachta indica</i>) leaf powder	8.76	2.0	25–70	[42]
Tamarind fruit shell	1.72	10.0	10–50	[43]

Table 3 Kinetic parameters of MB adsorption onto JSC for different kinetic models (pseudo-first order; pseudo-second order; intraparticle diffusion; and Boyd)

Models	Parameters	Value
Pseudo-first order	$q_{e,exp}$ (mg/g)	5.431
	$q_{e,cal}$ (mg/g)	1.177
	K_1 (min ⁻¹)	0.015
	R^2	0.941
Pseudo-second order	$q_{e,exp}$ (mg/g)	5.431
	$q_{e,cal}$ (mg/g)	5.482
	K_2 (g/mg/min)	0.094
	H (mg/g/min)	2.846
	R^2	0.999
Intraparticle diffusion	$q_{e,exp}$ (mg/g)	5.431
	C (mg/g)	4.457
	K_{diff} (mg/g min ^{0.5})	0.082
	R^2	0.978
Boyd	R^2	0.941

pass through the origin as a result of variation of mass transfer from initial to final stage of adsorption process and higher intercept (4.457 mg/g) confirms that multi-processes (film, pore or surface diffusion) were involved during adsorption of MB onto JSC and that might be occurred simultaneously (Fig. 5c) [44]. Moreover, the

Boyd kinetic plot was tested with the adsorption data of different contact time to know the actual step during adsorption process. Figure 5d shows that the Boyd plot did not pass through the origin, indicating that film diffusion also involved during adsorption process.

4 Conclusions

This study investigates the removal of MB by JSC from aqueous solution. The optimal pH was 9, and the MB removal rate increased with decreased MB concentration and equilibrium achieved at 120 min. This adsorption follows Freundlich and Halsey isotherms very well, and maximum adsorption capacity of MB by JSC was 29.32 mg/g. The adsorption kinetic data were well described by pseudo-second-order kinetic model, and potential rate-limiting steps were chemisorption, film diffusion, external surface and intraparticle diffusion. The FTIR and FE-SEM analysis conformed that different functional groups and more porous active sites are present on the surface of JSC. The JSC has been shown to be a potentially useful adsorbent for the removal of MB from aqueous solution. Moreover, due to low-cost, availability, high adsorptive capacity and favorable kinetics, JSC is an auspicious adsorbent for MB removal from the aqueous solution and can be used economically in the field to treat MB-contaminated wastewater, especially

Fig. 5 Adsorption kinetic of MB onto JSC using different kinetic models: **a** pseudo-first order, **b** pseudo-second order, **c** intraparticle diffusion and **d** Boyd

where centralized wastewater treatment facilities are not accessible.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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