



Adsorption of cadmium (II) ions from aqueous solution by a new low-cost adsorbent—Bamboo charcoal

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ABSTRACT

Batch adsorption experiments were conducted for the adsorption of Cd (II) ions from aqueous solution by bamboo charcoal. The results showed that the adsorption of Cd (II) ions was very fast initially and the equilibrium time was 6 h. High pH (≥ 8.0) was favorable for the adsorption and removal of Cd (II) ions. Higher initial Cd concentrations led to lower removal percentages but higher adsorption capacity. As the adsorbent dose increased, the removal of Cd increased, while the adsorption capacity decreased. Adsorption kinetics of Cd (II) ions onto bamboo charcoal could be best described by the pseudo-second-order model. The adsorption behavior of Cd (II) ions fitted Langmuir, Temkin and Freundlich isotherms well, but followed Langmuir isotherm most precisely, with a maximum adsorption capacity of 12.08 mg/g. EDS analysis confirmed that Cd (II) was adsorbed onto bamboo charcoal. This study demonstrated that bamboo charcoal could be used for the removal of Cd (II) ions in water treatment.

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1. Introduction

The increasing use of heavy metals over the past few decades has inevitably led to an increased flux of metallic substances in ground water and surface water, as well as drinking water, and posed serious ecological and health risks. Cadmium (Cd) is considered to be an extremely toxic metal without known biological function. Contamination of drinking water may occur as a result of the presence of Cd (II) as an impurity in the zinc of galvanized pipes or Cd-containing solders in fittings, water heaters, water coolers and taps. Cd can accumulate in the human body especially in kidneys, thus leading to disfunction of the kidney. Thus, Cd has been included in the red list of priority pollutants by the Department of Environment, UK and in the black list of Dangerous Substance Directive in European Economic Community. US Environment Protection Agency has also classified Cd as group B1 carcinogen. The permissible limit for Cd in drinking water in China, as well as the drinking water guideline value recommended by World Health Organization, is 0.005 mg/L. It is of great importance for water purification to develop efficient procedures for the removal of Cd from aquatic environments.

Among numerous clean-up techniques for water treatment, adsorption techniques are widely used for the removal of diverse contaminants. Commercial activated carbon is a preferred adsorbent used to remove impurities from liquid solutions; however,

its widespread use is restricted due to the high cost. As such, alternative non-conventional low-cost adsorbents have been investigated and natural, industrial as well as synthetic materials have been tested for the removal of heavy metals from water [1–3].

Bamboo charcoal is produced from the rapidly growing moso bamboo plants, which is distributed widely in China. Currently, the area of bamboo forests is 4.84 million hm^2 in China. The annual growth of bamboo area averages 126,000 hm^2 , according to the statistics of the Sixth National Forest Resources Survey. The bamboo charcoal is low cost, and its price is only about 1/3 to 1/5 of that of activated carbon in China. It has been applied for many roles in various fields, such as to supply negative ions, to emit far-infrared rays, to prevent oxidation, to remove microbes from water, as a humidity regulator and a rich source of minerals, in China, Japan and Korea [4]. Bamboo charcoal burnt at high temperatures (over 800 °C) is characterized by a high density, a porous structure and a huge specific surface area [4]. Its adsorption capacity has attracted more attention in recent years [5,6]. Several studies have found that activated bamboo charcoal has excellent adsorption capacity for a wide variety of substances, such as nitrate-nitrogen [7], heavy metals [8,9], dibenzothiophene [10] and phenol [11], harmful gases [6], and can be potentially used for the purification of water or air. Therefore, as a new, innovative and cost-effective adsorbent, bamboo charcoal may provide an alternative option and be used to partly replace the activated carbon, and decrease the consumption of wood. As a low-cost adsorbent, the use of bamboo charcoal may deserve more attentions in water treatment.

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Numerous studies have found that Cd (II) can be adsorbed and easily removed by activated carbon, activated carbon fibers, or other low-cost adsorbents, such as agricultural waste [1–3,12,13]. However, the adsorption characteristics of Cd (II) ions by bamboo charcoal still remain unclear, and the potential use of this adsorbent in the removal of Cd (II) ions deserves study. In the present experiment, the adsorption characteristics of Cd (II) ions onto bamboo charcoal were investigated under varying experimental conditions, such as contact time, solution pH, initial concentration, and adsorbent dosage. The kinetic and equilibrium data for the adsorption studies, as well as energy-dispersive spectrometry analysis, were processed to understand the adsorption mechanism.

2. Materials and methods

2.1. Bamboo charcoal

Bamboo charcoal was provided by the Department of Material Science and Engineering, Tsinghua University. Before use, carbonized bamboo was boiled in distilled water for 1 h to remove some ash and impurities, and then oven-dried at 105 °C for 24 h. Then they were ground and passed through 200 mesh (i.e., 0.074 mm) and stored in desiccators. The BET surface area is 1120 m²/g and the bulk volume is 0.538 cm³/g. The pH_{ZPC} of bamboo charcoal is 7.15 and the iodine number is 811 mg/g, determined according to Zhang et al. [14] and ASTM D4607-94 (1999) [15], respectively.

2.2. Preparation of solutions

Stock solution of Cd (II) ions with a concentration of 1000 mg/L was prepared by dissolving Cd(NO₃)₂·4H₂O (analytical reagent grade) in distilled water. The desired Cd (II) concentrations were prepared from the stock solution by making fresh dilutions for each sorption experiment.

2.3. Adsorption procedure

All adsorption experiments were performed on a mechanical shaker equipped with a thermostatic water bath at 120 rpm using 250 mL conical flasks. A series of adsorption experiments were carried out at room temperature (25 °C). The first experiment was to investigate the effect of adsorbent contact time and equilibrium time. Cd (II) solution (150 mL, 100 mg/L) and 0.5 g bamboo charcoal were added into the flasks and then agitated at 120 rpm for contact times ranging from 5 min to 8 h. The second experiment was to study the pH of the adsorbate solution. The pH values of Cd (II) solutions were adjusted to 2.0, 4.0, 5.93 (initial pH), 8.0, 10.0, and 12.0 respectively with HCl (0.1 M) or NaOH (0.1 M) solutions. Then 100 mL Cd (II) solution (100 mg/L) and 0.5 g bamboo charcoal were added into the flasks and then agitated for 6 h (equilibrium time) at 120 rpm. The third experiment was to study the effect of adsorbent dosage. Bamboo charcoal at different doses, i.e. 0.2, 0.5, 0.8, 1.5, 3.0, and 5.0 g, respectively, were added into the flasks with 100 mL of Cd (II) solution (100 mg/L), and then agitated for 6 h at 120 rpm. The fourth experiment was to study the isotherm and the effect of initial Cd (II) concentration. Solutions of Cd (II) at different concentrations of 20, 40, 60, 100 mg/L were prepared and then treated as the procedure in the first experiment. All solution samples were taken with a syringe and filtered through 0.45 μm filter membrane for analysis. Cd (II) concentrations in samples were determined by an IRIS Intrepid IIXSP inductively coupled plasma atomic emission spectroscopy.

2.4. Calculation of removal percentage and adsorption capacity

The removal percentage (A%), the amount of adsorbate adsorbed per unit mass of adsorbent at time *t* (*q_t*, mg/g), and the amount of adsorbate adsorbed per unit mass of adsorbent at equilibrium (*q_e*, mg/g), were calculated from the following equations:

$$A\% = \frac{C_0 - C_e}{C_0} \times 100 \quad (1)$$

$$q_t = V \times \frac{C_0 - C_t}{m_s} \quad (2)$$

$$q_e = V \times \frac{C_0 - C_e}{m_s} \quad (3)$$

where *C₀* and *C_e* (mg/L) are the initial and the final concentrations of adsorbates in flasks, respectively, *C_t* (mg/L) is the concentrations of adsorbates at time *t*. *V* is the volume of the solution (L) and *m_s* is the mass of dry adsorbent used (g).

2.5. Kinetic models

The sorption kinetics of Cd (II) were tested using pseudo-first-order and pseudo-second-order sorption equations. The pseudo-first-order equation is shown below:

$$\log(q_e - q_t) = \log q_e - k_1 t \quad (4)$$

where *k₁* (g/mg min) is the rate constant of the pseudo-first-order sorption, which can be calculated by plotting log(*q_e* - *q_t*) versus *t*.

The pseudo-second-order equation can be written as:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (5)$$

where *k₂* (g/mg min) is the rate constant of the pseudo-second-order sorption.

2.6. Sorption isotherm models

The sorption equilibrium data of Cd (II) on bamboo charcoal were analyzed in terms of Langmuir, Freundlich and Temkin isotherm models. The linear form of Langmuir's isotherm model is given by the following equation:

$$\frac{C_e}{q_e} = \frac{1}{b q_m} + \frac{C_e}{q_m} \quad (6)$$

where *b* (L/mg) is the Langmuir constant related to the rate of adsorption.

The essential characteristics of the Langmuir isotherm can also be expressed in terms of a dimensionless constant separation factor or equilibrium parameter, *R_L*, which is defined as:

$$R_L = \frac{1}{1 + b C_0} \quad (7)$$

where *b* is the Langmuir constant and *C₀* is the initial concentration of Cd (II) ions. The value of *R_L* indicates the type of the isotherm to be either unfavorable (*R_L* > 1), linear (*R_L* = 1), favorable (0 < *R_L* < 1) or irreversible (*R_L* = 0).

The Freundlich isotherm equation can be written in the linear form as given below:

$$\log q_e = \log k_f + \frac{1}{n} \log C_e \quad (8)$$

where *k_f* [(mg/g) (L/g)^{1/*n*}] and *n* are the Freundlich constants that are related to the adsorption capacity and intensity, respectively. The Freundlich constants *k_f* and *n* can be calculated from the slope and intercept of the linear plot, with log *q_e* versus log *C_e*.

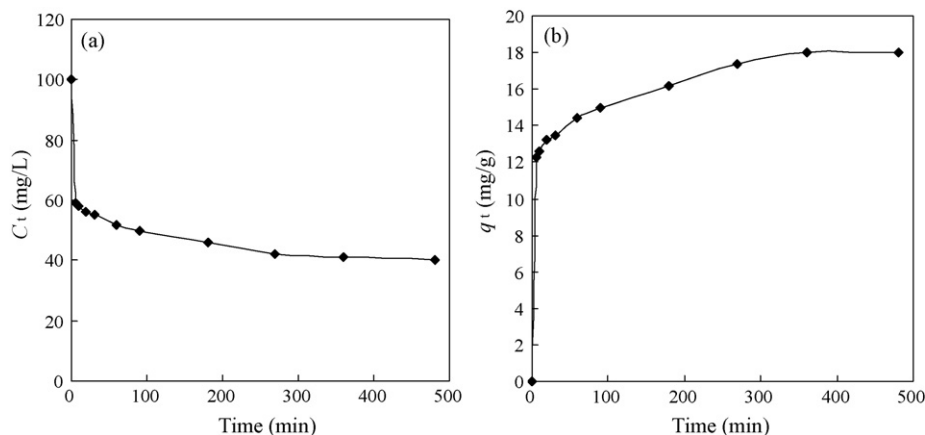


Fig. 1. Effect of the contact time on the adsorption of Cd (II) by bamboo charcoal.

The linear form of Temkin isotherm can be expressed as:

$$q_e = B \log k_t + B \log C_e \quad (9)$$

where $B = RT/b$ represents heat of adsorption, T is the absolute temperature in Kelvin and R is the universal gas constant, $1/b$ indicates the adsorption potential of the adsorbent while k_t (L/mg) is the equilibrium binding constant corresponding to the maximum binding energy. The plot of q_e versus $\log C_e$ enables the determination of isotherm constants k_t and B .

2.7. Energy-dispersive X-ray spectrometry analysis

The element analysis of bamboo charcoal before and after adsorption of Cd (II) ions is carried out by the energy-dispersive X-ray spectrometry (EDS) detector attached on the scanning electron microscopy (SEM) (JEOL-6301F).

3. Results and discussion

3.1. Effect of contact time

The results in Fig. 1 show that the adsorption rate was very fast initially; about 40% of total Cd (II) was removed within 5 min. Thereafter, the adsorption capacity increased slowly with the contact time before reaching a plateau value after the contact time of 6 h, and then remained constant. Thus, equilibration time was considered as 6 h, which was considered as sufficient for the removal of Cd (II) ions by this adsorbent. Consequently the contact time was set to 6 h in the following experiments to ensure adsorption equilib-

rium. The time curves in Fig. 1 are smooth and continuous, leading to saturation suggesting the possibility of monolayer coverage of Cd (II) ions on the adsorbent surface. The amount of adsorbed Cd (II) ions by bamboo charcoal (q_e) from an initial concentration of 100 mg/L after a 6 h equilibration time was 18.20 mg/g.

Obviously, the initial high adsorption rate is due to the abundance of free binding sites. The meso-pores become almost saturated with Cd (II) ions during the initial stage of adsorption process. Thereafter, the Cd (II) ions have to traverse farther and deeper into the micro-pores encountering much larger resistance, thus leading to decreased driving force and adsorption rate. Additionally, with the process of adsorption, desorption rate increased, adsorption–desorption equilibrium is also affected around equilibrium.

3.2. Effect of pH

Fig. 2 shows that with an increase in pH, the residual of Cd (II) (C_e) decreased, and adsorbents are effective for the quantitative removal of Cd (II) ions at pH = 8.0. A sudden change occurred at pH ranging from 6.0 to 8.0. At higher pH (>8.0), the adsorption of Cd (II) ions is nearly constant. The maximum removal (A%) and adsorption capacity (q_e) of bamboo charcoal occurred at the pH 12.0.

Similar results with pH have been reported by many studies that adsorption capacity of adsorbents is low at acidic pH while increases at higher pH values [16–19]. When the pH is <6.0, the surface charge on the surface of bamboo charcoal is positive. A significant electrostatic repulsion exists between the positively charged surface and the cationic Cd (II) ions, which inhibits the

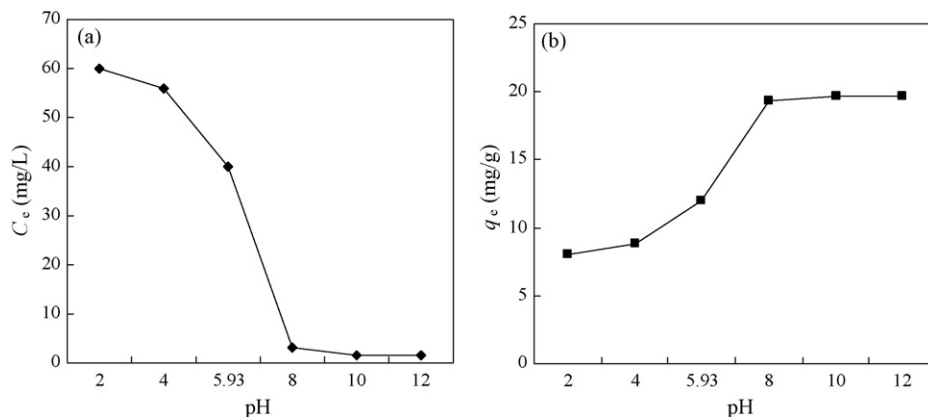


Fig. 2. Effect of pH on the adsorption of Cd (II) ions by bamboo charcoal.

adsorption of Cd (II). Besides, a higher concentration of H^+ in the solution competes with Cd (II) ions for the adsorption sites, resulting in the reduced uptake. The increase in adsorption with the increase in pH can be attributed to the fact that the positively charged metal cations are repulsed less by the oxide surfaces at higher pH values. As the pH of the system increases, the number of positively charged sites decreases and the number of negatively charged sites increases on the surface of adsorbents. Obviously, a negatively charged surface site favors the adsorption of cationic Cd (II) ions due to electrostatic attraction.

Cd species are found to be present in deionized water in the forms of Cd^{2+} , $Cd(OH)^+$, $Cd(OH)_2^0$, $Cd(OH)_2(s)$, etc. [20]. Cd^{2+} is the only ionic species present in the solution at $pH < 6.0$, and the dominant Cd (II) species at $pH < 8.0$ is Cd^{2+} and $Cd(OH)^+$ and at $pH > 8.0$ is $Cd(OH)_2$ [12,19]. In the alkaline range, precipitation plays the main role in the removal of Cd attributed to the formation of precipitate of $Cd(OH)_2(s)$. The precipitation of metal hydroxides into pores or spaces around the adsorbent particles is nearly impossible as the adsorption process is kinetically faster than the precipitation [21,22]. Therefore, it can be stated that Cd (II) removal by bamboo charcoal was dominantly controlled by adsorption at pH values < 8.0 but it could be slightly enhanced by $Cd(OH)_2$ precipitation at $pH > 8.0$.

The effect of pH can also be explained in terms of pH_{zpc} of the adsorbent. The pH_{zpc} of bamboo charcoal is 7.15, and the surface charge of the adsorbent was positive when the pH of the adsorbate solution was below the pH_{zpc} value while it was negative at a pH above the pH_{zpc} ; thus at acidic pH, the surface charge of the bamboo charcoal was also positive and hence the uptake of Cd^{2+} was low. When the pH of the adsorbate solution increased above 7.15, the surface was negatively charged, leading to a higher adsorption of Cd^{2+} . Furthermore, higher pH may change the chemical properties of functional groups, thus further influence the adsorption process. For example, the $-COOH$ groups present in the bamboo charcoal are converted into $-COO^-$, which favors the adsorption of Cd^{2+} .

3.3. Effect of initial concentration

The effect of initial concentration on the adsorption of Cd (II) ions by bamboo charcoal was investigated with varying solution concentrations (20, 40, 60, and 100 mg/L) using 0.5 g adsorbent dose (Fig. 3). With increasing concentration of solution, q_e increased, while $A\%$ decreased. At low initial solution concentration, the surface area and the availability of adsorption sites were relatively high, and the Cd (II) ions were easily adsorbed and removed. At higher initial solution concentration, the total available adsorption sites are limited, thus resulting in a decrease in percentage removal of Cd (II) ions. The increased q_e at higher initial concentration can be attributed to enhanced driving force.

3.4. Effect of adsorbent dosage

The $A\%$ increased with an increase in the adsorbent dosage from 0.2 to 1.5 g, but remained almost unchanged when adsorbent dosage ranged from 1.5 to 5.0 g (Fig. 4). The increase in $A\%$ with an increase in adsorbent dosage is due to the availability of larger surface area and more adsorption sites. At adsorbent dosage > 1.5 g, the incremental Cd (II) ion removal becomes very low as the surface

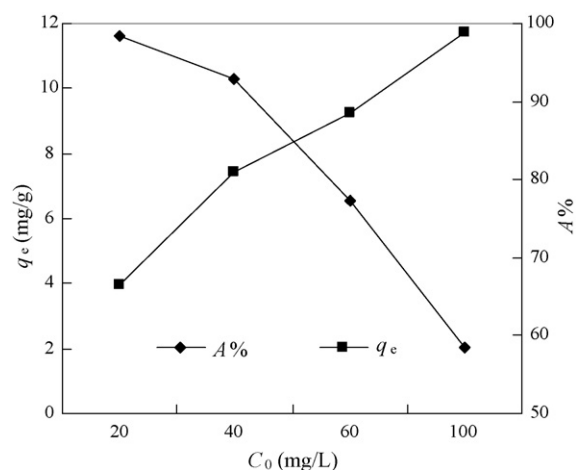


Fig. 3. Effect of initial concentration on the removal and adsorption of Cd (II) ions by bamboo charcoal.

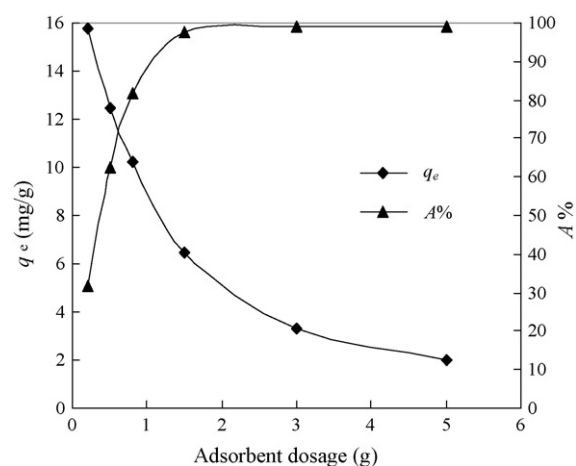


Fig. 4. Effect of adsorbent dose on the removal and adsorption of Cd (II) ions by bamboo charcoal.

metal ions concentration and the solution metal ions concentration come to equilibrium with each other [23]. Thus, increased adsorbent dosage did not enhance the removal percentage of Cd (II).

The decrease in q_e with increase in the adsorbent dose is mainly due to the unsaturation of adsorption sites through the adsorption reaction. Another reason may be due to the particle interactions, such as aggregation, resulting from high sorbent concentration. Such aggregation would lead to a decrease in the total surface area of the adsorbent [24].

3.5. Adsorption kinetics

The adsorption kinetics were investigated in the contact time of 480 min. Kinetic parameters including the first-order rate constant k_1 , second-order rate constant k_2 , calculated equilibrium adsorption capacity $q_{e,cal}$ and experimental equilibrium adsorption capacity $q_{e,exp}$ for Cd (II) ions, and regression coefficients (R^2), were

Table 1
First- and second-order adsorption rate constants and calculated and experimental q_e values.

C_0 (mg/L)	$q_{e,exp}$ (mg/g)	First-order kinetics			Second-order kinetics		
		k_1 (g/mg min)	$q_{e,cal}$ (mg/g)	R^2	k_2 (g/mg min)	$q_{e,cal}$ (mg/g)	R^2
150	18.20	0.0034	6.12	0.9639	0.0049	18.28	0.9983

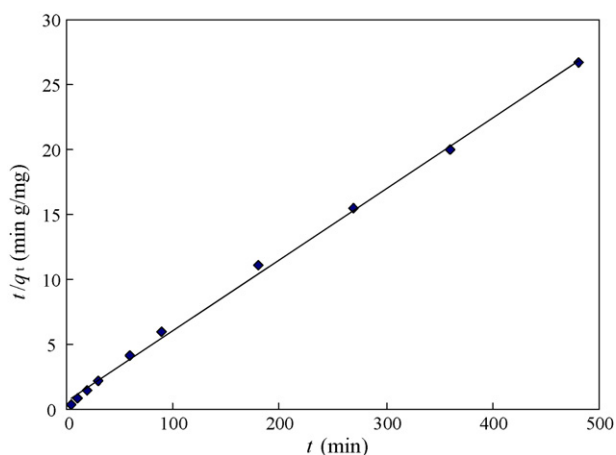


Fig. 5. Pseudo-second-order kinetic model for adsorption of Cd (II) ions on bamboo charcoal.

all shown in Table 1. The dramatic difference between $q_{e,exp}$ and $q_{e,cal}$ from first-order model indicates that the adsorption of Cd (II) ions onto bamboo charcoal does not follow first-order kinetics. The $q_{e,cal}$ using the pseudo-second-order model is in good agreement with the experimental $q_{e,exp}$ values. The R^2 value for the second-order kinetic model is 0.9983, indicating that the system under study is more appropriately described by the pseudo-second-order model (Fig. 5). This confirms that in the adsorption process, concentrations of both adsorbate (Cd^{2+}) and adsorbent (bamboo charcoal) are involved in rate determining step, which may be a chemical sorption or chemisorption [24,25].

Table 2

Equilibrium model parameters for adsorption of Cd (II) ions by bamboo charcoal.

Equilibrium model	Parameter	Value
Langmuir isotherm	q_m (mg/g)	12.08
	b (L/mg)	0.485
	R^2	0.9932
Freundlich isotherm	k_f (mg/g) (L/g) $^{1/n}$	5.32
	$1/n$	0.2173
	R^2	0.9892
Temkin isotherm	k_t (L/mg)	41.93
	b (J/mol)	706.91
	B (L/g)	3.50
	R^2	0.9901

3.6. Adsorption isotherms

The adsorption studies were conducted at a fixed adsorbent dosage (0.5 g) by changing initial concentrations of Cd (II) ions (Fig. 6). The equilibrium data were analyzed using Freundlich, Langmuir and Temkin equilibrium models (Eqs. (6), (8) and (9)) in order to obtain the best fitting isotherm. The isotherms were shown graphically in Fig. 6 and the isotherm parameters were listed in Table 2. All the plots showed a straight line, indicating that the adsorption of Cd (II) ions follows the three isotherms well. Comparison of coefficients indicates that the Langmuir isotherm fitted more precisely ($R^2 = 0.9932$) than the Temkin isotherm ($R^2 = 0.9901$) and the Freundlich isotherm ($R^2 = 0.9892$). The basic assumption of Langmuir adsorption isotherm is based on monolayer coverage of the adsorbate on the surface of adsorbent [26,27], which is an indication of the fact that the adsorption of Cd (II) ions onto bamboo charcoal generates monolayer formation.

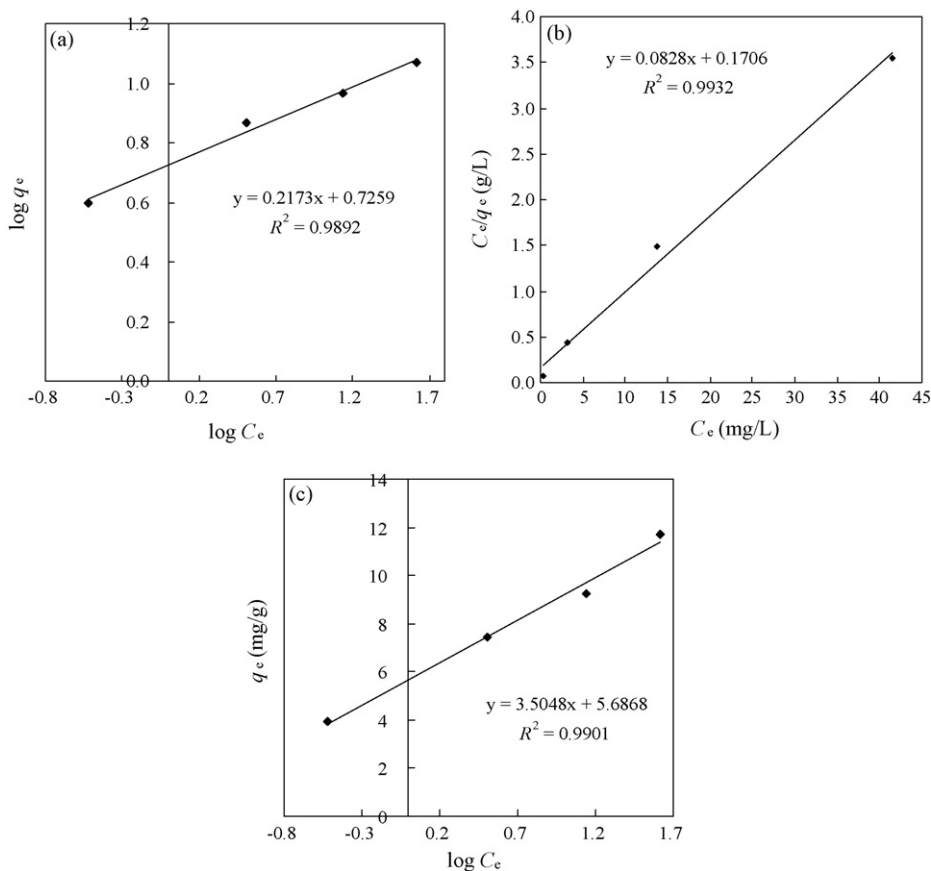


Fig. 6. Freundlich (a), Langmuir (b) and Temkin (c) adsorption isotherms of Cd (II) ions on bamboo charcoal.

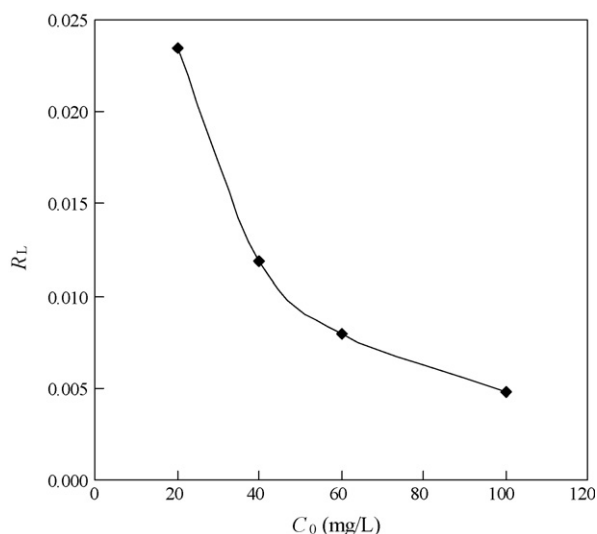


Fig. 7. Plot of R_L against initial Cd (II) ion concentration.

Values of R_L were shown in Fig. 7, confirming that the bamboo charcoal is favorable for the adsorption of Cd (II) ions under conditions used in this study.

Numerous studies have investigated Cd (II) adsorption by activated carbon or various low-cost adsorbents [1–3]. The adsorption capacity of different types of adsorbents used for removal of Cd (II) was compared (Table 3) and it is found that bamboo charcoal may be a highly efficient adsorbent for the removal of Cd (II) ions from water.

3.7. EDS analysis

Fig. 8 shows typical EDS pattern for bamboo charcoal before and after the adsorption of Cd (II) ions. EDS analysis did not show the characteristic signal of Cd (II) ions in the control bamboo charcoal (Fig. 8a), whereas clear signals were observed at about 2.8, 2.95, 3.15, 3.35 and 3.95 keV in the bamboo charcoal absorbed Cd (II) ions (Fig. 8b), which was quite similar to the observations by Saeed et al. [28], who observed clear signals of Cd (II) ions at the same energy in the Cd-loaded mungbean husk. They also found signals for some

Table 3
Comparison of adsorption capacities of Cd (II) ions with some low-cost adsorbents.

Adsorbent	q_m (mg/g)	Reference
Bamboo charcoal	12.08	This work
Coconut copra meal	1.84	[30]
Hazelnut shell	5.42	[31]
Almond shell	3.18	[31]
Rice husk	8.58	[32]
Rice husk	0.89	[33]
Saw dust	0.29	[33]
Rice polish	9.72	[34]
Wheat bran	0.70	[27]
Areca waste	1.32	[35]
Cassava waste	18.05	[36]
Mungbean husk	35.41	[28]
Spent grain	17.3	[37]
Sugar beet pulp	17.2	[13]
Corncoobs	8.89	[13]
Pine Park	14.16	[13]
Olive cake	10.56	[38]
Oak wood char	0.37	[39]
Pine bark char	0.34	[39]
Oak bark char	5.40	[39]
Carbon F-400	8.00	[39]
Bagasse fly ash	6.19	[19]

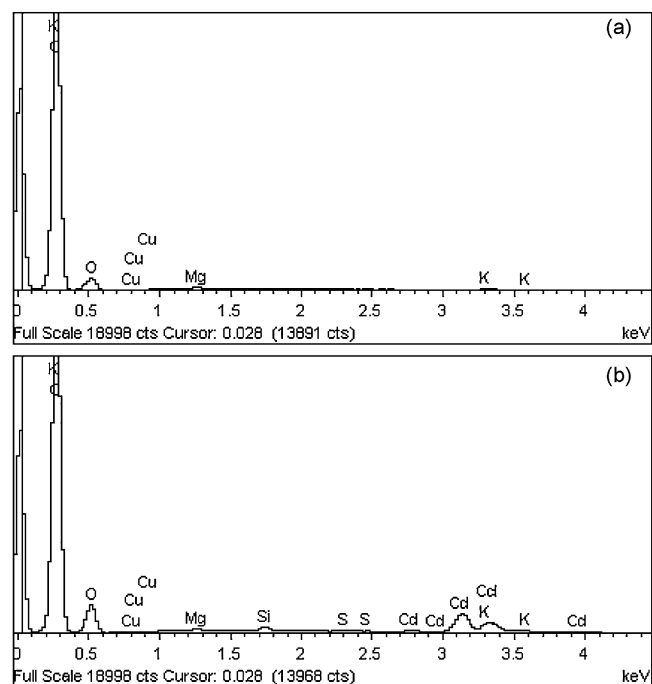


Fig. 8. Energy-dispersive X-ray spectrometry (EDS) analysis of bamboo charcoal: (a) before and (b) after the adsorption of Cd (II) ions.

metal cations such as Ca^{2+} , Mg^{2+} , Na^+ and K^+ disappeared from the EDX spectrum of mungbean husk, and suggested the involvement of ion exchange mechanism for the adsorption of Cd^{2+} by mungbean husk. In our results, we did not observe the exchange between Cd^{2+} and other metal cations (Fig. 8), indicating ion exchange may not be the major mechanism for Cd (II) adsorption by bamboo charcoal.

The mechanisms of biosorption process include chemisorption, complexation, adsorption on surface, diffusion through pores, ion exchange, etc. [2]. The adsorption process and capacity closely correlate to physical and chemical characteristics of adsorbents, such as grain size, exchangeable cation capacity, pore diameter and quantity, specific surface area, surface chemical characteristics. FTIR analysis revealed that $-OH$, $C-H$ bending, $C-O$ stretching vibration and carbonyl functional groups were mainly responsible for Pb (II) biosorption by activated charcoal of bamboo (*Melocanna baccifera* Roxburgh) [9]. Different manufacturing conditions, including carbonization temperature and time, activator, activation temperature and time, significantly influence the adsorption capacity of heavy metals by bamboo charcoal [8]. On the other hand, chemical modifications generally enhance adsorption capacity of natural adsorbents [29]. In future, the adsorption mechanisms of heavy metals by bamboo charcoal, as well as optimization of manufacturing conditions and chemical modifications to increase the adsorption capacity, need further studies for more effective use in water treatment.

4. Conclusions

In the present study, batch adsorption experiments for the adsorption of Cd (II) ions from aqueous solutions have been carried out using activated bamboo charcoal as adsorbent. The adsorption characteristics have been examined at different contact times, pH values, initial Cd (II) ion concentrations, and different adsorbent dosage levels. The obtained results can be summarized as follows:

1. The adsorption rate of Cd (II) ions was very fast initially, and about 40% of total Cd (II) was removed within 5 min. Thereafter, the adsorption capacity increased slowly with the contact time before reaching a plateau value after the contact time of 6 h, and then remained constant.
2. Generally, adsorption capacity of Cd (II) ions by bamboo charcoal increased with an increase in the pH of the adsorbate solution. The optimum pH for Cd (II) removal is 8.0.
3. With an increase in initial Cd (II) ion concentration, adsorption capacity of Cd (II) ions by bamboo charcoal increased but the removal percentage of Cd (II) ions decreased.
4. Increase in adsorbent dosage led to increase in Cd (II) removal but decrease in adsorption capacity.
5. Adsorption of Cd (II) ions by bamboo charcoal was found to follow the pseudo-second-order model.
6. Langmuir adsorption model was better fitted for the adsorption of Cd (II) ions than Temkin and Freundlich isotherms. The highest monolayer adsorption capacity was obtained 12.08 mg/g for the adsorption of Cd (II) ions by bamboo charcoal.
7. Studies on batch adsorption indicate that bamboo charcoal has efficient adsorption capacity for Cd (II) ions and its use may significantly lower the cost of water treatment.

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