

Removal of the Pesticide Imidacloprid from Aqueous Solution by Biochar Derived from Peanut Shell

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Biochar is a carbon-rich product generated from the incomplete combustion of biomass through pyrolysis. Biochar plays an important role in removing pollutants from the environment. In this study, biochars were obtained from peanut shell agricultural waste by the limited-oxygen method at 300, 500, and 700 °C. The adsorption capacity of imidacloprid onto the biochar was increased with the increasing pyrolysis temperature. The solution temperature and biochar dosage had positive effects on the adsorption of imidacloprid. The adsorption capacity of the biochar on imidacloprid was increased with the increasing of pH in acid and neutral solution but slightly decreased in weak base solution (pH 9). An analysis of adsorption kinetics showed that the adsorption of imidacloprid on the biochar perfectly followed pseudo-first-order and pseudo-second-order models with R² coefficients above 0.97. Furthermore, the Langmuir and Freundlich models highly correlated with the sorption isotherm data. In summary, this study confirmed that peanut shell biochar is an efficient adsorbent for the removal of the pesticide imidacloprid.

Keywords: Biochar; Peanut shell; Imidacloprid; Removal; Adsorption

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INTRODUCTION

Currently, pesticides application in worldwide agricultural production is a common practice to protect crops. However, with the increasing application of pesticides, adverse effects are a growing concern. Pesticide residue can be released into water environments and can produce negative effects on non-target organisms through leaching, surface runoff, spray drift, improper pesticide disposal, leakage from storage containers, and accidental spillage (Tişler *et al.* 2009; Tiryaki and Temur 2010). Therefore, it is very important to develop effective technologies to remove pesticides from aqueous solutions to decrease their effects on water environments. Imidacloprid [1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine] is one of most widely used neonicotinoid insecticides in the world. It is used in agricultural production to control pest insects (*e.g.*, aphids, Japanese beetles, lacebugs, leafhoppers, thrips, whiteflies, and termites), as a foliar treatment for a variety crops (*e.g.*, cotton, vegetables, fruits, and others), or as a seed dressing for soil treatment (Pons and Albajes 2002; Nauen and Denholm 2005; Szczepaniec and Raupp 2007; Held and Parker 2011). Imidacloprid can be transported into aquatic ecosystems through spray runoff, leach, spray drift, or accidental spills, resulting in local point-source contamination (Felsot and Ruppert 2002; Jemec *et al.* 2007). Morrissey *et al.* (2015) tracked the water monitoring literature in 29 studies from nine countries, finding that imidacloprid can be detected in most surface water at a concentration of 0.001 to 320 µg/L.

Moreover, imidacloprid can exert significant lethal and sub-lethal effects on many aquatic organisms such as mayflies, *Daphnia magna* and *Danio rerio* (Jemec *et al.* 2007; Roessink *et al.* 2013; Ge *et al.* 2015). The degradation dynamics and effecting factors of imidacloprid in water environments has been widely reported (Liu *et al.* 2006; Tişler *et al.* 2009; Thuyet *et al.* 2011). However, little research has been conducted concerning the elimination of this insecticide from contaminated aqueous solutions using agricultural wastes.

Biochar is a carbon-rich compound obtained by oxygen-limited pyrolysis of organic feedstocks; it is used in soil for agricultural gains and carbon sequestration (McHenry 2009; Galinato *et al.* 2011). Due to it is low cost, wide availability, and favorable surface characteristics, biochar used as an adsorbent to remove chemical contaminants in water, including heavy metals and organic pollutants, has attracted much attention in recent years. For example, Xu *et al.* (2013) reported that dairy manure-derived biochar removes Cu, Zn, and Cd from aqueous solutions. Xi *et al.* (2014) showed that brewer's spent grain can be converted into biochar to remove the pesticide pymetrozine from water. Taha *et al.* (2014) reported that the biochar made from rice and corn-straw can effectively remove 15 different pesticides from water solution except oxamyl. However, the ability of biochar derived from plant material to remove imidacloprid from water is currently unknown.

In this study, biochars from peanut shell agricultural waste was prepared at three pyrolytic temperatures under oxygen-limited conditions, and the adsorption removal of imidacloprid from water by these biochars was evaluated. The effects of solution pH value and temperature on imidacloprid adsorption onto biochar were investigated. The kinetics and equilibrium isotherms of imidacloprid sorption onto biochar were also measured.

EXPERIMENTAL

Materials

Preparation of biochars and chemicals

Peanut shell materials were collected from a local agriculture field in Qingdao city, China, after harvesting. The shells were washed thoroughly with distilled water to remove soil and dust and then dried in the sun. The dried shells were crushed into fine powder. The powder was stacked in ceramic crucibles with a lid and pyrolyzed in a muffle furnace under limited oxygen conditions at 300, 500, and 700 °C for 4 h to carbonize, respectively. The biochars were ground to pass a 60-mesh sieve. The ash specimens were removed by shaking the sieved biochars for 10 h with 1 M HCl (10:1, solution: biochar mass ratio) and by washing them with deionized water several times to remove residual acid and soluble salts until the solution pH was neutral (Zhang *et al.* 2013). The resulting biochars were oven dried at 100 °C, placed in amber glass bottles, and stored in a desiccator. Based on the heated temperature, the biochars were referred to as PB300, PB500, and PB700.

The insecticide imidacloprid (CAS No. 138261-41-3, purity 97.1%) was obtained from Qingdao Hansen Biologic Science Co., Ltd., Qingdao, China. Its molecular formula, molecular weight, dissociation constant (pK_a value), and water solubility are $C_9H_{10}ClN_5O_2$, 255.66, 1.56, and 0.61 g/L, respectively. All other chemicals are of analytical grade.

Methods

Characterization of biochars

The C, H, O, and N contents of the biochars were determined using an elemental analyzer (Elementar Vario EL III, Hanau, Germany). The surface and pore volume were

analyzed with a Micromeritics Gemini apparatus (ASAP 2020 M+C, Micromeritics, Norcross, GA, USA) using N₂ adsorption method. The functional groups were determined using a Fourier transform infrared (FTIR) spectroscopy (FT-IR200 spectrometer, Thermo Fisher Scientific, Waltham, USA). The surface morphology was examined by a field emission scanning electron microscope (SEM) equipped with an energy dispersive spectroscopy (JSM-7500F, JEOL, Tokyo, Japan).

Batch adsorption experiments

First, the adsorption ability of biochar produced at different pyrolysis temperatures to imidacloprid was determined at room temperature (25 °C). According to a published method (Zhang *et al.* 2013), the appropriate amount of biochar (2 g/L) was weighed into a glass tube that contained 20 mL of deionized water. The water solution contained 5 mM CaCl₂ to maintain a constant ionic strength. After 24 h of pre-equilibration, ten microliters of imidacloprid (40 g/L, acetone solution) was spiked into each tube, reaching the final concentration of 20 mg/L. The solution without biochar was the control. Each treatment was repeated three times. All tubes were sealed with Teflon film and shaken at 180 rpm in the dark. At 0, 0.5, 1, 2, 3, 4, 5, and 6 h, 1 mL of solution was sampled from each tube. The sampled solution was filtered into a liquid vial through 0.22 µm filter membranes for determination of imidacloprid by high performance liquid chromatography (HPLC). A Shimadzu LC-2010A HPLC system (Kyoto, Japan) equipped with an ultraviolet detector and a reverse phase column (Thermo ODS Hypersil, 250 mm × 4.6 mm × 5 µm, Waltham, MA, USA) was employed to detect imidacloprid. The mobile phase, flow rate, detection wavelength, and injection volume were methanol:water (80:20, v/v), 0.8 mL/min, 270 nm, and 20 µL, respectively. The results of control samples without biochar showed that the loss of imidacloprid was less than 2%.

After obtaining the above results, the biochar with strongest adsorption ability was selected to perform the following experiments. The adsorption kinetics of different dosages of biochar on imidacloprid were investigated. Varied dosages of biochar (1, 2, and 3 g/L) were added into water solution that contained 20 mg/L of imidacloprid. The following procedures including sampled time and determination method were the same as the above mentioned. Moreover, the appropriate pH was investigated.

Finally, adsorption isotherms for optimal biochar were determined at five initial solution concentrations (2.5, 5, 10, 20, and 30 mg/L) at temperatures of 25, 35, and 45 °C. After shaking for 4 h, the concentration of imidacloprid was determined by HPLC.

Data analysis

Data analysis was carried out using SPSS16.0 software (SPSS Inc., Chicago, IL, USA). The data are expressed means ± standard deviation. Differences between the treatments were evaluated by two analysis of variance (ANOVA) and identified significant at $p < 0.05$.

The adsorption content (q_t , mg/g) and remove rate (w) of biochar on imidacloprid were calculated by Eq. 1 and Eq. 2, respectively,

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

$$w (\%) = \frac{(C_0 - C_t)}{C_0} \times 100 \quad (2)$$

where C_0 and C_t are the initial imidacloprid concentration and at time t in the solution, respectively (mg/g); V is the volume of the solution (mL); m is the weight of biochar (g).

For adsorption kinetics, pseudo-first-order model (Eq. 3), pseudo-second-order model (Eq. 4), and Elovich model (Eq. 5) were employed to fit the data,

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (3)$$

$$\frac{t}{q_t} = \frac{t}{q_e} + \frac{1}{k_2 q_e^2} \quad (4)$$

$$q_t = k_3 t^{0.5} + C \quad (5)$$

where q_t and q_e are the amount of imidacloprid adsorbed at time t and at equilibrium, respectively (mg/g), and k_1 , k_2 , and k_3 are the first-order, second-order, and Elovich model apparent adsorption rate constants, respectively.

For sorption isotherms, the Freundlich model (Eq. 6) and Langmuir model (Eq. 7) were used to fit data,

$$q_e = K_F C_e^{1/n} \quad (6)$$

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \quad (7)$$

where q_e and q_m are the amount of imidacloprid adsorbed at equilibrium and the maximum sorption capacity, respectively (mg/g); C_e is the imidacloprid concentration equilibrium of the solution (mg/L); K_F and K_L are the affinity coefficient, and n is the Freundlich exponential coefficient.

For understanding the influence of temperature on the adsorption of imidacloprid onto biochar, three thermodynamic parameters including Gibbs free energy (ΔG°), entropy (ΔS°), and enthalpy (ΔH°) were calculated according to Eq. 8 and Eq. 9.

$$\Delta G^\circ = -RT \ln K_L \quad (8)$$

$$\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ \quad (9)$$

In these equations K_L is the adsorption equilibrium constant in Langmuir model, R is the gas constant (8.314 J/mol K), and T (K) is the absolute temperature. The values of ΔS° and ΔH° were obtained from intercept and slope of the plot of ΔG° versus T .

RESULTS AND DISCUSSION

Characterization of Biochars

The elemental composition, surface area, and pore volume parameters of biochar are listed in Table 1. The peanut shell biochar was rich in C (57.8 to 83.5%), which increased with increasing pyrolysis temperature, while the H, N, and O contents decreased. This result indicated that H, N, and O were lost due to ashing as pyrolysis temperature increased, resulting in the accumulation of C content (Zhang *et al.* 2013; Deng *et al.* 2014). Some amorphous carbon can be transformed into aromatic carbon in plant tissue at higher temperatures. The atomic ratios of H/C, O/C, and (O+N)/C are usually used as indices to evaluate the aromaticity and polarity, respectively (Chen *et al.* 2005). In this study, according to the changes of these indices, aromaticity of the peanut shell biochar increased, and polarity decreased with increasing pyrolysis temperature. The surface area and pore volume of biochars increased as pyrolysis temperature increased (Table 1). This increase

was attributed to a greater transformation in the elemental composition with increasing temperature. At low temperature, pores are not well formed since amorphous carbon is the main carbon in plant tissues. Moreover, some pores are obstructed by aliphatic or volatile constituents, which also reduce surface area. With increasing temperature, amorphous carbons condense to crystalline carbons, more pores are developed, and aliphatic and volatile constituents are removed, resulting in biochar with high surface area and pore volume at higher temperature (Keiluweit *et al.* 2010). Previous studies have also confirmed that the surface area and pore volume of biochar is largely dependent on pyrolyzing temperature (Martins *et al.* 2007; Keiluweit *et al.* 2010; Zhang *et al.* 2013).

Table 1. Elemental Composition, Surface Area, and Pore Volume Parameters of Biochars

Sample	Surface Area (m ² /g)	Pore volume (cm ³ /g)	Elemental Composition (%)				Atomic Ratio		
			C	H	N	O	H/C	O/C	(N+O)/C
PB300	4.52	0.007	57.83	4.14	1.68	25.35	0.92	0.33	0.36
PB500	134.32	0.042	75.32	2.92	1.32	17.14	0.51	0.17	0.19
PB700	534.83	0.287	83.48	1.43	0.96	12.46	0.23	0.11	0.12

Figure 1 shows the SEM images of the surface morphologies of the biochars produced from peanut shell at three pyrolysis temperatures. The PB300 was slightly rough and had fewer small holes. With the increasing pyrolysis temperature, however, the structure of biochar became rougher. Especially in PB700, there was a clearly rough surface and porous structures. The increase in the number of holes indicated an increase in surface area and total pore volume which were confirmed by the data in Table 1.

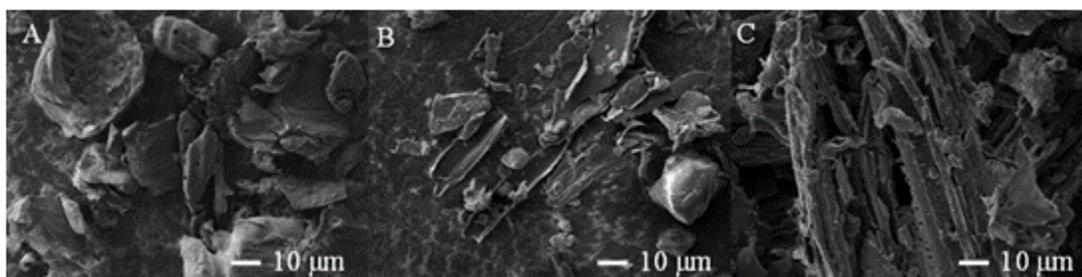


Fig. 1. Scanning electron micrographs: A, 300 °C; B, 500 °C; and C, 700 °C

Figure 2 shows the FTIR spectra of the biochars derived at three pyrolysis temperatures. Although the spectra were similar for most of the wavenumbers, the band transmittances show obvious differences, which confirms that the structure of biochars underwent significant changes under different pyrolysis temperature. The band at around 3650 cm⁻¹ indicates the stretching vibration of the hydroxyl group (Zhang *et al.* 2013). In this study, the decrease in transmittances of PB500 and PB700 at band 3650 cm⁻¹ suggested that hydroxyl was oxidized, and cellulose and lignin were transformed into aromatic carbon (Deng *et al.* 2014). This result was also confirmed by the changes of smaller band intensities at 500 to 700 cm⁻¹, which indicate the presence of aromatic compounds (Liu *et al.* 2015). Compared with PB300, the decrease in transmittances of band 2940 cm⁻¹, 2100 cm⁻¹, and 1740 cm⁻¹ in PB500 and PB700, indicated that long-chain aliphatic carbon was destroyed in lignin at a higher temperature (Zhang *et al.* 2013). The bands at around 1500

to 800 cm^{-1} were attributed to high aromaticity and corresponded to the presence of alkyl and alkene from the stretching of aromatic rings (Xi *et al.* 2014). In this study, the transmittances within these ranges of band decreased with the increasing of pyrolysis temperature, indicating that higher temperature can increase the aromaticity of peanut shell biochar.

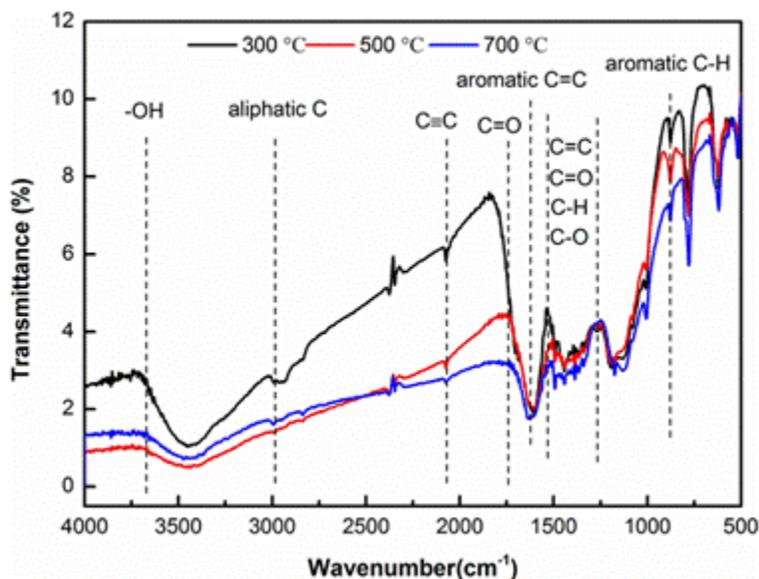


Fig. 2. FTIR spectra of peanut shell biochar at 300 °C, 500 °C, and 700 °C pyrolysis temperatures

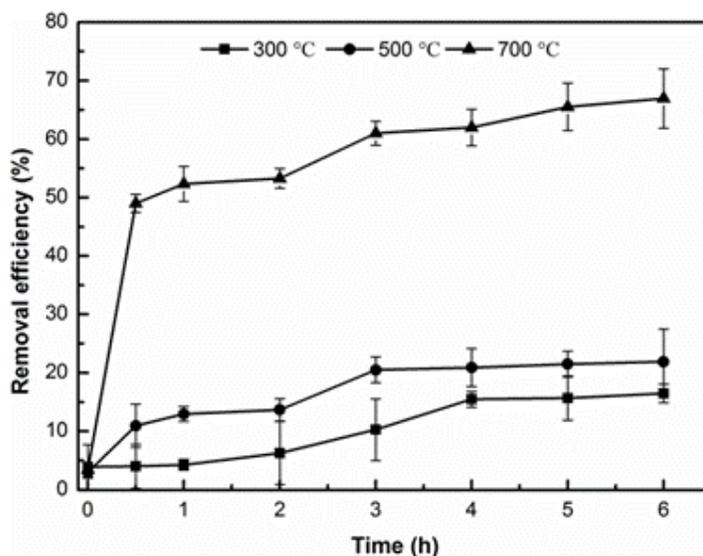


Fig. 3. Removal effects of peanut shell biochar produced by different pyrolysis temperatures on Imidacloprid. Biochar amount: 2 g/L; Initial imidacloprid concentration: 20 mg/L. Error bars represent standard deviation of triplicate samples.

Effects of Pyrolysis Temperature on Biochar Sorption of Imidacloprid

As shown in Fig. 3, the adsorption capacities reached saturation after 3 h, the removal rates of PB300, PB500, and PB700 on imidacloprid were 10.3%, 20.5%, and 62.0%, respectively, indicating that the adsorption capacities of peanut shell biochar on

imidacloprid were increased with increasing pyrolysis temperature. According to the results of biochar surface area and pore volume (Table 1), surface adsorption and pore-filling effects were mechanisms involved with imidacloprid adsorption onto the peanut shell biochar. However, in this study, there was little difference between the removal efficiency of PB300 and PB500 (Fig. 3), although surface area, pore volume, and FTIR spectra of PB300 exhibited significant differences with PB500 and PB700. This indicated that there are other effects which control the adsorption of imidacloprid onto the biochar. Previous studies have reported that strong adsorption of hydrophobic organic chemicals on micro- and mesoporous carbon is usually driven by specific interaction (Lohmann *et al.* 2005; Zhang *et al.* 2011). In this study, the chlorine substituent in imidacloprid has an electron-withdrawing nature, making the associated aromatic π -structure an electron acceptor, which can interact with the aromatic carbon (electron-donors) on the biochar surface through π - π electron donor-accepter interactions (Zhang *et al.* 2013). Therefore, the specific interactions between imidacloprid and the biochar surface may be the major reason why biochar produced from higher pyrolysis temperature has the higher adsorption affinity to imidacloprid. Based on the adsorption ability of three biochars, in this study, PB700 was selected as the adsorption material for further experiments.

Adsorption Kinetics

As shown in Fig. 4A, the concentrations of imidacloprid quickly decreased in the first 30 min once the three contents of biochar were added into the aqueous solutions.

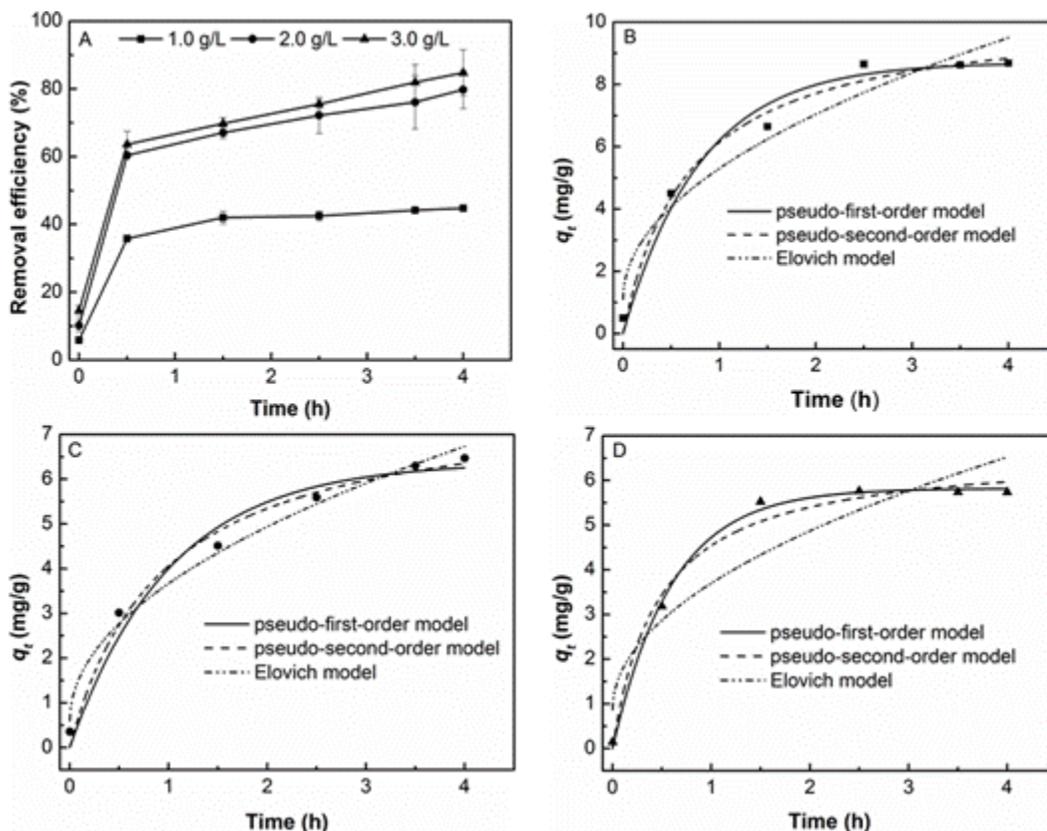


Fig. 4. Removal effects (A) of the different addition ratio of peanut shell biochar PB700 on imidacloprid (20 mg/L) and its sorption kinetics. In A, error bars represent standard deviation of triplicate samples. The amounts of biochar are (B) 1 g/L, (C) 2 g/L, and (D) 3 g/L.

Table 2. Kinetics Constants for Sorption of Imidacloprid on the Peanut Shell Biochar PB700

Biochar (g/L)	$q_{e,exp}$ (mg/g)	Pseudo-First-Order Model			Pseudo-Second-Order Model			Elovich Model		
		$q_{e,cal}$ (mg/g)	K_1 (h ⁻¹)	R ²	$q_{e,cal}$ (mg/g)	K_2 (g/mg·h)	R ²	C (mg/g)	K_3 (g/mg·h)	R ²
1.0	8.68	8.71	1.25	0.9746	10.34	0.14	0.9818	1.10	4.20	0.9450
2.0	6.47	6.38	0.99	0.9782	7.82	0.14	0.9844	0.60	3.07	0.9724
3.0	5.74	5.82	1.67	0.9964	6.67	0.32	0.9821	0.87	2.83	0.8563

At 30 min, 1, 2, and 3 g/L of biochar removed approximately 35.7%, 60.4%, and 63.6% of the imidacloprid, respectively. The concentration of imidacloprid in the aqueous solution then decreased slowly as the contact time increased until the maximum adsorption of the biochar was achieved. The initial rapid removal of imidacloprid may be attributed to the highly hydrophobic surface of biochar, which may preferentially adsorb hydrophobic substances from water (Zheng *et al.* 2010). With increasing contact time, adsorption of imidacloprid onto the biochar changes slowed because it was controlled by intra-particle diffusion (Ghaedi *et al.* 2011). Figure 4A shows that the removal of imidacloprid and the equilibrium adsorbed amount onto biochar increased with the increasing mass of the biochar PB700. However, for PB700 more than 2 g/L, the removal efficiency and adsorbed amount gradually increased slowly, which may be due to the increased number of available sorption sites as the solid mass increased and overlapped the absorbent layers (Xi *et al.* 2014).

In this study, three kinetics models, pseudo-first-order, pseudo-second-order, and Elovich model, were used to describe the time-dependence of imidacloprid adsorption onto different amounts of the peanut shell biochars (Fig. 4B, C, D). The pseudo-first-order and pseudo-second-order models describe the kinetics of a solid-solution system based on mononuclear and binuclear mechanisms, respectively, with respect to the sorbent capacity (Gerente *et al.* 2007), while the Elovich model is an empirical equation regarding the contribution of desorption (Yao *et al.* 2011). The adsorption kinetic data of imidacloprid onto three amounts of biochar were better simulated by all the models (Fig. 4B, C, D), with coefficients of determination (R^2) exceeding 0.85 (Table 2). However, the R^2 values for the pseudo-first-order and pseudo-second-order models ranged from 0.97 to 0.99, which was slightly higher than that of the Elovich model (0.85 to 0.97), suggesting that the pseudo-first-order and pseudo-second-order models provided a good fit to the kinetics of imidacloprid. A previous study also found that the first-order kinetic model, and especially the second-order kinetic model, can provide a good fit to the adsorption of imidacloprid on a granular activated carbon (Daneshvar *et al.* 2007).

Adsorption Isotherms

To further assess the imidacloprid adsorption capacity and understand its mechanism, the Langmuir and Freundlich isotherm models were employed to fit the experimental data (Fig. 5). The Langmuir model assumes monolayer adsorption onto a homogeneous surface with no interactions between the adsorbed molecules. The Freundlich model, however, is often used to describe chemisorption (such as hydrogen chemisorption) onto a heterogeneous surface (Yao *et al.* 2011). As shown in Fig. 5, compared with that at 25 °C, the maximum adsorption capacity of PB700 for 30 mg/L of imidacloprid increased by 14.5% at 35 °C and 16.2% at 45 °C, indicating adsorption of imidacloprid onto the biochar can be affected by temperature. The R^2 values were 0.9925, 0.9603, and 0.9951 for the Langmuir model, and 0.9957, 0.9723, and 0.9931 for the Freundlich model at 25, 35, and 45 °C, respectively (Table 3), suggesting that the Langmuir and Freundlich isotherm models are all well matched with the adsorption of imidacloprid onto the biochar PB700. Moreover, according to Liu and Zhang (2009), this nonlinear adsorption process may be attributed to imidacloprid located at the outer surface area function groups (*e.g.*, hydroxyl, carboxy, methoxy, and phenolic) at low concentrations, while permeating the interior with increasing concentration. Therefore, the adsorption process was very efficient in fitting the Langmuir and Freundlich isotherm models.

As shown in Table 4, the values of ΔG° were negative, indicating that imidacloprid adsorption process was spontaneous. The lower value of ΔG° at higher temperature indicates that the adsorption of imidacloprid onto biochar will be more favorable as increasing temperature. This result was the same as reported by Zhen *et al.* (2018), who also observed a spontaneous adsorption process in removal of methylene blue by rhamnolipid-modified biochar. The positive value of ΔH° implied that imidacloprid adsorption process was endothermic in nature. In this study, the ΔH° value is 5.45 KJ/mol, indicating that hydrophobic character may be an important aspect (Tan *et al.* 2015). According to the results of the FTIR spectra (Fig. 2), the reason may be that the aromaticity of biochar was increased with increasing pyrolysis temperature. The value of ΔS° could reflect the degree of freedom of imidacloprid in the biochar adsorption system. In this study, the ΔS° value is 93.5, suggesting that there was an increase of randomness at solid-solution interface during adsorption.

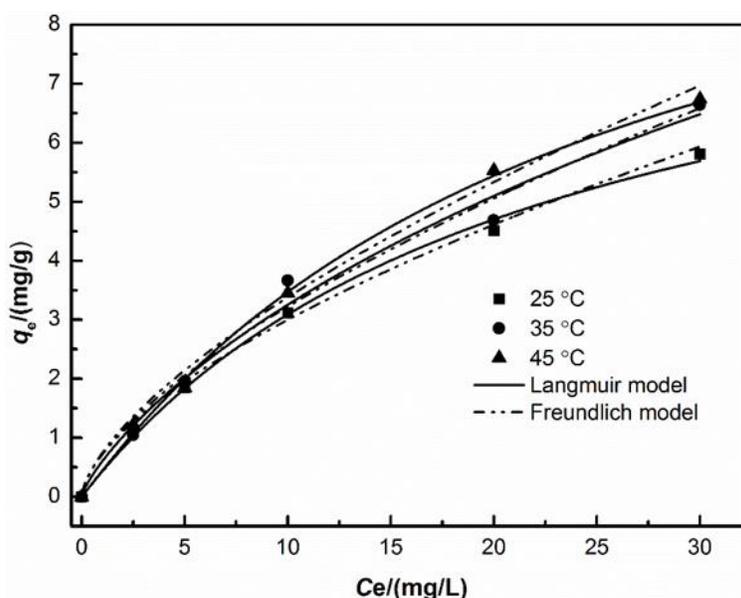


Fig. 5. Sorption isotherms of imidacloprid on the peanut shell biochar PB700

Table 3. Langmuir and Freundlich Parameters for Sorption Isotherms of Imidacloprid on the Peanut Shell Biochar PB700

Temperature (°C)	Langmuir Model			Freundlich Model		
	q_m (mg/g)	K_L (L/mg)	R^2	K_F (L/mg)	$1/n$	R^2
25	18.17	0.033	0.9965	0.69	0.62	0.9957
35	23.33	0.036	0.9603	0.70	0.65	0.9723
45	23.79	0.038	0.9951	0.71	0.65	0.9931

Table 4. Thermodynamic Parameters for Imidacloprid onto the PB700

Temperature (°C)	$\ln K_L$ (L/mol)	ΔG° (KJ/mol)	ΔS° (J/K·mol)	ΔH° (KJ/mol)
25 (298k)	9.04	-22.40	93.5	5.45
35 (308k)	9.13	-23.38		
45 (318k)	9.18	-24.27		

Effect of pH on Biochar Sorption of Imidacloprid

The pH is a crucial factor affecting the adsorption of organics onto biochar. As shown in Fig. 6, the removal rate of imidacloprid by the biochar PB700 gradually increased from pH 2 to pH 7, then it slightly decreased at pH 9. The differences in the extent of removal rate of imidacloprid at different pH may be attributed to the electrostatic interactions between positive imidacloprid functional groups and negative functional groups of adsorbents (Cui *et al.* 2013). In an acidic environment, the sorption of imidacloprid onto PB700 was reduced with the decreasing of negative charge of PB700 surface. Imidacloprid is readily hydrolysed in alkaline water (Zheng and Liu 1999); however, one cannot predict the individual behavior of imidacloprid in the alkaline environment in this study. Similar results were reported by Daneshvar *et al.* (2007) for the removal ability of imidacloprid from aqueous solutions (pH 1 to 10) by granular activated carbon. The results of this study showed that peanut shell biochar could be used as an efficient adsorbent for the removal of imidacloprid in aqueous solution.

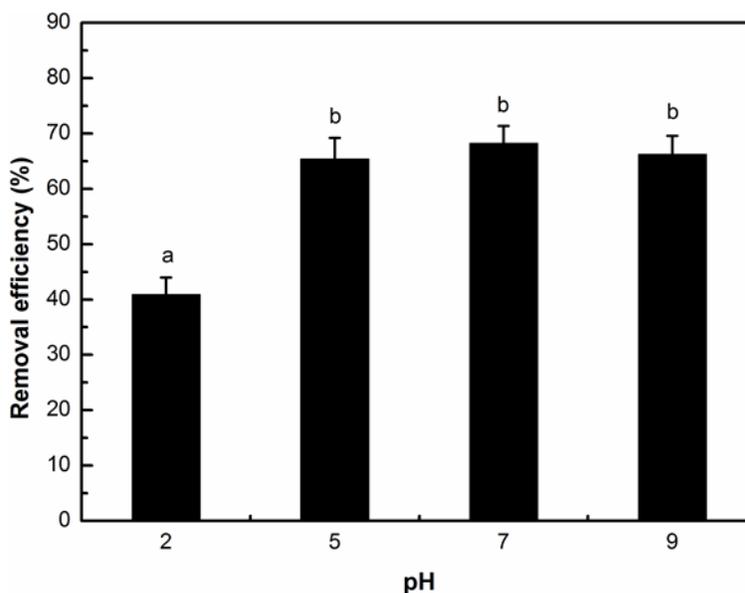


Fig. 6. Effects of pH on removal of imidacloprid. Error bars represent standard deviation of triplicate samples.

CONCLUSIONS

1. The surface area, carbon content, and aromaticity of biochar derived from peanut shell were increased with increasing pyrolysis temperature. The peanut shell biochar produced higher temperature favored the adsorption of the pesticide imidacloprid.
2. The pseudo-first-order and pseudo-second-order models were suitable for fitting the adsorption kinetics of imidacloprid onto the biochar PB700. The isotherm of imidacloprid onto PB700 exhibited relatively nonlinear behavior, and the Langmuir and Freundlich models were employed to describe the adsorption isotherm.
3. The values of thermodynamic parameters indicated that the adsorption was an endothermic process and the adsorption capacity could be increased with increasing of temperature.

4. The temperature of aqueous solution had positive effects on the sorption of imidacloprid onto the biochar PB700. The removal rate of imidacloprid by PB700 increased with increasing pH in acid and neutral environment.

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