

# METHANE ADSORPTION OF LANDFILL COVER SOIL IMPROVED WITH HYDROPHOBIC BIOCHAR

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**Abstract:** Biochar can be amended to landfill cover soils to enhance CH<sub>4</sub> adsorption and oxidation. However, biochar increases soil permeability, which will lead to infiltration of rainwater and increased leachate. Improving landfill cover soil with hydrophobic biochar can simultaneously achieve CH<sub>4</sub> reduction and prevent rainwater infiltration that increases leachate. In this study, kinetic and thermodynamic adsorption models were used to investigate the effects of different initial CH<sub>4</sub> concentration and different (hydrophobic) biochar addition on the CH<sub>4</sub> adsorption performance of the cover layer, to reveal their adsorption behaviors and patterns. The results show that the addition of hydrophobic biochar significantly improved the adsorption capacity of soil for CH<sub>4</sub>. The pseudo-second-order equation and Freundlich isothermal adsorption model were more suitable to describe the adsorption process of CH<sub>4</sub> by modified soil with different (hydrophobic) biochar additions.

## INTRODUCTION

Methane (CH<sub>4</sub>) is the most abundant greenhouse gas except carbon dioxide in the atmosphere. The radiation intensity of CH<sub>4</sub> is 0.97W/m<sup>2</sup>, second only to 1.68W/m<sup>2</sup> of CO<sub>2</sub>, and much higher than N<sub>2</sub>O (0.17W/m<sup>2</sup>) and fluorinated greenhouse gases (0.18W/m<sup>2</sup>)<sup>[1]</sup>. Also, CH<sub>4</sub> is a very important pollutant (ozone) precursor, and the contribution of precursor emissions to ozone pollution is 85%, of which CH<sub>4</sub> accounts for about 13%<sup>[2, 3]</sup>. Since the industrial revolution, the increase in CH<sub>4</sub> in the atmosphere means that the CH<sub>4</sub> of man-made emissions is 340 ±50TgCH<sub>4</sub>/yr, contributing about 20% to climate warming<sup>[4, 5]</sup>. CH<sub>4</sub> emissions from landfills are the third largest anthropogenic source of emissions after agricultural production and coal mining<sup>[6]</sup>. In Europe, landfills account for 23.6% of total anthropogenic CH<sub>4</sub> emissions<sup>[7]</sup>. Based on a global landfill volume of 1.5 billion tons per year, the corresponding landfill CH<sub>4</sub> production rate is estimated at 75 billion m<sup>3</sup>, of which

less than 10% is captured and utilized<sup>[8]</sup>. CH<sub>4</sub> released into the atmosphere has a lifetime of about 12 years<sup>[9]</sup>, so reducing the level of CH<sub>4</sub> in the atmosphere can have an immediate effect on mitigating the greenhouse effect.

At present, the CH<sub>4</sub> emission reduction technologies of landfills can be divided into three categories: recycling, end control and in-situ emission reduction<sup>[10-13]</sup>. Only the large-scale sanitary landfill CH<sub>4</sub> has the potential of energy recovery. At the same time, due to the lack of management, the economically feasible landfill CH<sub>4</sub> energy recovery projects are few, the return is low, and it is difficult to implement. And end control such as flare incineration require expensive equipment and the addition of auxiliary fuels when CH<sub>4</sub> concentrations are insufficient<sup>[14]</sup>. China's waste is characterized by a high proportion of food waste, CH<sub>4</sub> production is fast and short-lived, the peak of gas production often ends quickly after landfill closure, then the release rate and concentration of CH<sub>4</sub> will drop significantly and the basic conditions for energy recovery and flare incineration may no longer be

available. The gas collection rate of the ongoing CH<sub>4</sub> recovery project in several landfills in China is estimated to be 55%-68%<sup>[15]</sup>, which means that even if CH<sub>4</sub> gas is collected for resource utilization or end treatment, 32%-45% of CH<sub>4</sub> from landfills in China will still be uncontrolled released into the atmosphere, the escape emission of CH<sub>4</sub> is still a problem that can not be ignored<sup>[16]</sup>. In the current dual-carbon context, China is under increasing pressure to reduce greenhouse gas emissions, and reducing CH<sub>4</sub> emissions from landfills is crucial for countries with high greenhouse gas emissions like China. Most of the landfills in China are small and medium-sized, which do not have the conditions for energy recovery, and it is not realistic to be equipped with expensive terminal treatment facilities<sup>[17, 18]</sup>.

The biochar-amended landfill cover can oxidize and adsorb CH<sub>4</sub><sup>[19]</sup>, which can reduce landfill CH<sub>4</sub> gas escape and achieve in-situ emission reduction. Karhu<sup>[20]</sup> added biochar to agricultural soil and increased the adsorption capacity of CH<sub>4</sub> to 96%. Yaghoubi<sup>[21]</sup> obtained the maximum CH<sub>4</sub> adsorption capacity of 32,346,59 and 82mL/kg respectively by studying the CH<sub>4</sub> adsorption capacity of soil, biochar, soil containing 10% and 20% biochar, and the maximum CH<sub>4</sub> adsorption capacity of the cover layer increased with the increase of biochar content. The adsorption conforms to Lagergren pseudo-second-order model and Langmuir isothermal adsorption model. As a biological covering medium, biochar can not only improve the CH<sub>4</sub> oxidation capacity of soil, but also increase the CH<sub>4</sub> adsorption capacity with its large specific surface area, but the pore structure of biochar increase the permeability coefficient of soil and promote the migration and diffusion of . And affect the adsorption of CH<sub>4</sub> by the cover layer. The study shows that the landfill cover soil with 10%-20% moisture content has the best absorption effect of CH<sub>4</sub><sup>[22-24]</sup>. The large specific surface area and porosity of biochar are conducive to the transport and diffusion of CH<sub>4</sub> and O<sub>2</sub>, promote CH<sub>4</sub> adsorption, but it increased the permeability coefficient of soil, promoted the transport and diffusion of, affected the adsorption of CH<sub>4</sub>, and increased the leachate.

Therefore, it is necessary to study the adsorption of CH<sub>4</sub> by hydrophobic biochar which can not only promote the diffusion of CH<sub>4</sub> and O<sub>2</sub>, but also prevent from entering the coating.

To better understand the effect of hydrophobic biochar on the CH<sub>4</sub> adsorption properties of soil, in this study, hydrophobic biochar was added to landfill cover soil to form hydrophobic biochar modified landfill cover soil (HBS), and biochar modified landfill cover soil (BS) was used as a control. The adsorption properties of CH<sub>4</sub> with different initial CH<sub>4</sub> concentration and different amount of (hydrophobic) biochar were studied by kinetic and thermodynamic adsorption experiments. The results of the adsorption experiments were quantitatively analyzed by combining the pseudo-first-order model, pseudo-second-order model, Freundlich isothermal adsorption model and Langmuir isothermal adsorption model to reveal the adsorption behaviors and laws of CH<sub>4</sub> and provide a theoretical basis for the application of HBS.

## EXPERIMENTAL

### Materials

The cover soil used in the experiment was a silty clay soil obtained from the Shankou landfill in Guilin, which is screened by # 10 screen. Biochar, purchased from Desheng carbon Industry Co., Ltd., is made from rice straw by pyrolysis at 500 °C and screened by # 40-60 sieve. Hydrophobic biochar was modified with purchased biochar by the method of Zhang et al<sup>[25]</sup>.

Prior to use for testing, soil was autoclaved at 121°C for 30 min for two days to eliminate microbial oxidation<sup>[26, 27]</sup>. Biochar (B) and hydrophobic biochar (HB) were evenly mixed with soil (S) at mass ratios of 1:19, 1:9, 3:17 and 1:4, respectively, to obtain 5%, 10%, 15%, 20% biochar-amended soil (BS<sub>5</sub>, BS<sub>10</sub>, BS<sub>15</sub>, BS<sub>20</sub>) and hydrophobic biochar-amended soil (HBS<sub>5</sub>, HBS<sub>10</sub>, HBS<sub>15</sub>, HBS<sub>20</sub>).

## Kinetics study

In this experiment, a 500 mL volumetric flask with a butyl rubber stopper was used as a CH<sub>4</sub> adsorption device. In this experiment, the partial pressure of adsorbent gas is changed indirectly by directly controlling the concentration of adsorbate in the system<sup>[28]</sup>. A synthetic gas was used to simulate landfill gas, consisting of 50% CH<sub>4</sub> and 50% CO<sub>2</sub><sup>[29-31]</sup>.

Weigh 10 g of adsorbent material with an electronic balance and pour it into the adsorption device, cork the bottle and wrap it with tape to prevent air leakage. The initial concentrations of CH<sub>4</sub> of 4%, 7% and 10% were obtained by withdrawing 40, 70 and 100 mL of gas from the flask with a syringe and then injecting an equal amount of simulated gas and sealing the needle holes with a silicone pad. The experiment was carried out at room temperature (298.15-300.15K). Each group set up a blank test to check the initial concentration, and all data were subjected to the averages of triplicate experiments to ensure the experimental repeatability and improve the data accuracy<sup>[32]</sup>. The timing begins when the simulated gas is injected into the bottle by the syringe, when the gas enters the bottle and comes into contact with the test material, and the gas sample is taken with a 5mL syringe every 2, 4, 6, 10, 20, 30, 60 and 120min when the material comes into contact with the gas. The gas samples obtained were analyzed by GC-7890 gas chromatograph.

In this experiment, the adsorption process of CH<sub>4</sub> by improved soil with different CH<sub>4</sub> concentration and different addition of (hydrophobic) biochar was investigated, the adsorption speed of CH<sub>4</sub> by (hydrophobic) biochar modified soil was studied, and the relationship between CH<sub>4</sub> adsorption amount and adsorption time was clarified. The kinetic adsorption was fitted by pseudo-first-order kinetic equation and pseudo-second-order kinetic equation<sup>[33]</sup>:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (1)$$

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

where  $q_e$  (mol/kg) is the equilibrium adsorption capacity,

$q_t$  (mol/kg) is the unit adsorption amount at time  $t$  (min),  $K_1$  (min<sup>-1</sup>) and  $K_2$  (kg · mol<sup>-1</sup> · min<sup>-1</sup>) are the pseudo-first-order and the pseudo-second-order adsorption rate constant.

## Isotherm study

The adsorption isotherms of CH<sub>4</sub> in (hydrophobic) biochar modified soils with different mass ratios (5%, 10%, 15%, 20%) were determined under low pressure, to clarify the relationship between CH<sub>4</sub> adsorption capacity and equilibrium pressure, and to explain the CH<sub>4</sub> adsorption behavior and law. The adsorption temperature is 273.15K and the adsorption pressure is 0-101kPa.

The isothermal adsorption is fitted by Langmuir equation and Freundlich equation, both of which can be applied to chemical adsorption and physical adsorption. Langmuir adsorption model is a monolayer adsorption model, which holds that the adsorbate is not adsorbed on the whole surface of the adsorbent, but on a specific point on the surface of the adsorbent<sup>[34]</sup>. Freundlich isotherm is an empirical equation. It is generally believed that the smaller  $1/n$  the better the adsorption performance,  $1/n$  in 0.1~0.5, it is easy to adsorb,  $1/n > 2$  is difficult to adsorb<sup>[35]</sup>. Langmuir equation and Freundlich equation are as follows:

$$q_e = \frac{k_L q_m c_e}{1 + k_L c_e} \quad (3)$$

$$q_e = K_F c_e^{1/n} \quad (4)$$

where:  $q_e$  (mol/kg) is the equilibrium adsorption amount;  $q_m$  (mol/kg) is the saturation adsorption amount;  $C_e$  (kPa) is the equilibrium pressure;  $K_L$  (1/kPa) is the Langmuir adsorption characteristic constant;  $K_F$  and  $n$  are the Freundlich characteristic constants.

## RESULT AND DISCUSSION

### CH<sub>4</sub> adsorption kinetics

#### Effect of initial CH<sub>4</sub> concentrations

Pseudo-first-order and pseudo-second-order kinetic

models were used to study the adsorption of S, B, HB, BS<sub>20</sub> and HBS<sub>20</sub> at different initial CH<sub>4</sub> concentrations (4%, 7% and 10%), respectively. All the adsorption curves increased sharply in a short time, followed by a slow rise to the last basically unchanged, as shown in Fig. 1 and Fig. 2.

At the initial CH<sub>4</sub> concentration of 4% for 2 min, the adsorption of CH<sub>4</sub> by S, B, HB, B<sub>20</sub>, and HB<sub>20</sub> was 0.25 mol/kg, 0.41 mol/kg, 0.48 mol/kg, 0.46 mol/kg, and 0.41 mol/kg, respectively, with the lowest adsorption rate of S and the highest adsorption rate of HB, followed by BS<sub>20</sub>, B and HBS<sub>20</sub>, which shows that HB has a faster onset adsorption rate compared to S and B. The reason may be that the hydrophilic group-OH on the surface of B is replaced by hydrophobic group, which forms an organic cover layer on the surface of biochar by chemical bonding, which reduces the agglomeration of biochar and makes its pores easier to capture adsorbate<sup>[36]</sup>. As shown in Fig. 1 (a), all the adsorption curves have basically reached a stable state when the adsorption was carried out for 60 min. The adsorption of B on CH<sub>4</sub> was the highest, the difference between HB, BS<sub>20</sub> and HBS<sub>20</sub> was not significant, and the adsorption of S was the lowest. When the initial concentration of CH<sub>4</sub> is 7% and 10%, each adsorption curve basically reaches a stable state at 60min. Compared with 4% CH<sub>4</sub> initial concentration, the adsorption capacity of S, B, HB, BS<sub>20</sub> and HBS<sub>20</sub> in 7% CH<sub>4</sub> initial concentration was increased, and the adsorption capacity of B was the highest and that of S was the lowest. Compared with the initial concentration of 7% CH<sub>4</sub>, the adsorption capacity of B, HB, BS<sub>20</sub> and HBS<sub>20</sub> in the initial concentration of

10% CH<sub>4</sub> was increased except that the adsorption capacity of S was decreased.

The adsorption of B was the highest and S the lowest at different initial CH<sub>4</sub> concentrations. Both the addition of biochar and hydrophobic biochar significantly increased the adsorption capacity of soil to CH<sub>4</sub>, with the addition of biochar having the most significant effect. As the initial concentration of CH<sub>4</sub> increased, the adsorption capacity of B, HB, BS<sub>20</sub> and HBS<sub>20</sub> on CH<sub>4</sub> increased accordingly, while the adsorption of S on CH<sub>4</sub> change little because the adsorption capacity of S on CH<sub>4</sub> was weak and had reached its highest point when the CH<sub>4</sub> concentration reached 7%, and did not change much after increasing the concentration. As seen in Table 1, Fig. 1 and Fig. 2, the pseudo-second-order model has a best correlation. Compared with other materials, the fit of S was lower, probably because the adsorption amount of S on CH<sub>4</sub> was smaller than 1/2 that of B, making the regularity between the measured adsorption value and adsorption time poor. The equilibrium adsorption capacity fitting value of the pseudo-second-order kinetic equation is closer to the actual equilibrium adsorption capacity measured by the experiment, so the pseudo-second-order kinetic equation is more suitable to describe the adsorption process of CH<sub>4</sub> on improved soil with different (hydrophobic) biochar content, which indicates that the adsorption process is mainly controlled by chemical action and its rate of CH<sub>4</sub> adsorption is influenced by both adsorbate concentration and adsorbent properties<sup>[37, 38]</sup>.

TABLE 1 Kinetic equation parameters of the adsorption by S, B, HB, BS<sub>20</sub> and HBS<sub>20</sub> at different initial CH<sub>4</sub> concentrations

materials	initial concentrations of CH <sub>4</sub>	Pseudo-first-order kinetics			Pseudo -second-order kinetics		
		k <sub>1</sub> (1/min)	q <sub>e</sub> (mol/kg)	R <sup>2</sup>	k <sub>2</sub> (kg/mol/min)	q <sub>e</sub> (mol/kg)	R <sup>2</sup>
S	4%	0.92	0.49	0.957	2.62	0.38	0.942
	7%	0.68	0.80	0.954	1.59	0.84	0.973
	10%	0.08	0.81	0.923	0.09	0.96	0.924

B	4%	0.38	0.69	0.987	0.92	0.73	0.992
	7%	0.92	1.29	0.980	1.63	1.33	0.994
	10%	0.37	1.92	0.972	0.28	2.06	0.984
HB	4%	0.69	0.62	0.958	2.43	0.64	0.961
	7%	0.91	1.15	0.994	2.21	1.18	0.994
	10%	0.46	1.26	0.907	0.55	1.35	0.970
BS <sub>20</sub>	4%	0.61	0.61	0.976	1.95	0.64	0.990
	7%	1.16	0.89	0.973	3.02	0.92	0.989
	10%	0.61	1.57	0.992	0.82	1.63	0.974
HBS <sub>20</sub>	4%	0.61	0.56	0.970	1.94	0.59	0.990
	7%	0.43	0.95	0.992	0.80	0.99	0.993
	10%	0.71	1.30	0.974	1.10	1.35	0.995

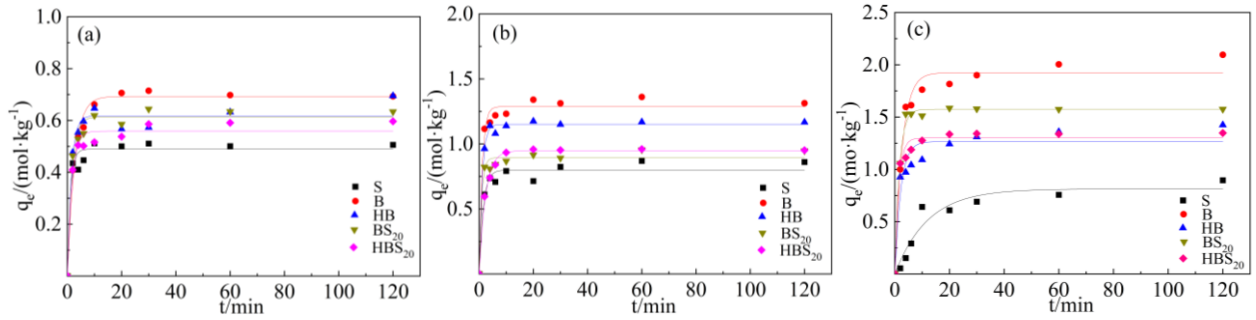


FIG. 1 Adsorption of S, B, HB, BS<sub>20</sub> and HBS<sub>20</sub> at different initial concentrations of CH<sub>4</sub> and their pseudo-first-order kinetic nonlinear fitting curves, respectively (a) 4% CH<sub>4</sub>; (b) 7% CH<sub>4</sub>; (c) 10% CH<sub>4</sub>

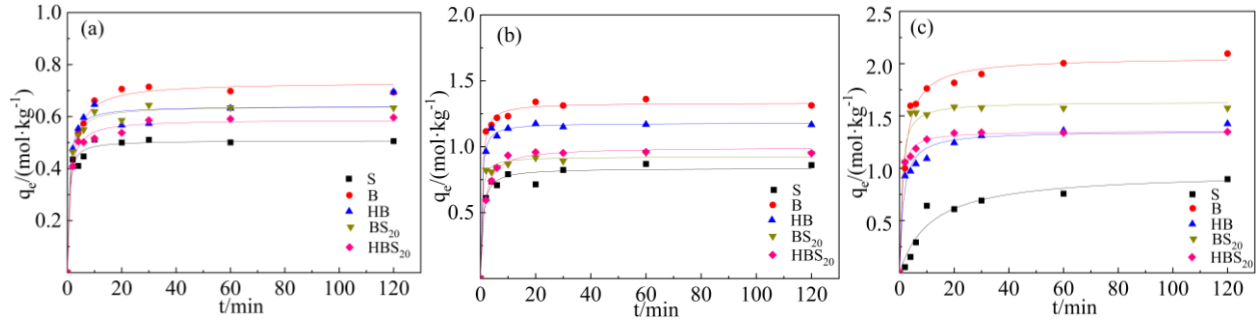


FIG. 2 Adsorption of S, B, HB, BS<sub>20</sub> and HBS<sub>20</sub> at different initial concentrations of CH<sub>4</sub> and their pseudo-second-order kinetic nonlinear fitting curves, respectively (a) 4% CH<sub>4</sub>; (b) 7% CH<sub>4</sub>; (c) 10% CH<sub>4</sub>

### Effect of (hydrophobic) biochar addition

In the experiment, the initial concentration of CH<sub>4</sub> was 4%, and biochar-amended soil (BS<sub>5</sub>, BS<sub>10</sub>, BS<sub>15</sub>) and hydrophobic biochar-amended soil (HBS<sub>5</sub>, HBS<sub>10</sub>, HBS<sub>15</sub>) with mass ratios of 5%, 10%, and 15% were set

up to study the adsorption performance of improved soils at different additions of (hydrophobic) biochar on 4% methane. Fig. 3 show their pseudo-first-order kinetics and pseudo-second-order kinetics fitting curves, respectively.

As shown in Fig. 1 (a), and (b), all the adsorption curves in the figure follow three processes: a sharp increase in a short period of time, followed by a slow increase and finally essentially no change. The adsorption amounts of S, B and HB on CH<sub>4</sub> were 0.40 mol/kg, 0.70 mol/kg and 0.63 mol/kg, respectively, at an initial methane concentration of 4%. When the adsorption of BS<sub>5</sub> and HBS<sub>5</sub> is carried out for 60min, each adsorption curve has basically reached a stable state, and the adsorption amounts of BS<sub>5</sub> and HBS<sub>5</sub> on CH<sub>4</sub> is 0.49mol/kg and 0.52mol/kg, respectively. The addition of 5% biochar and hydrophobic biochar both improved the adsorption amount of soil on CH<sub>4</sub>. After hydrophobic modification, the adsorption capacity of biochar to CH<sub>4</sub>

basically unchanged, and both the addition of biochar and hydrophobic biochar can increase the adsorption capacity of soil cover, and the adsorption capacity increases with the increase of the addition<sup>[39]</sup>.

As seen in Fig. 3 and Table 2, the pseudo-second-order model has a better correlation. Comparing the experimental values with the fitted values, it can be seen that the equilibrium sorption amount obtained by fitting the pseudo-secondary kinetic equation is closer to the actual equilibrium sorption amount than the pseudo-first-order kinetic equation, so the pseudo-secondary kinetic equation is more suitable to describe the adsorption process of CH<sub>4</sub> by (hydrophobic) biochar modified soil with content.

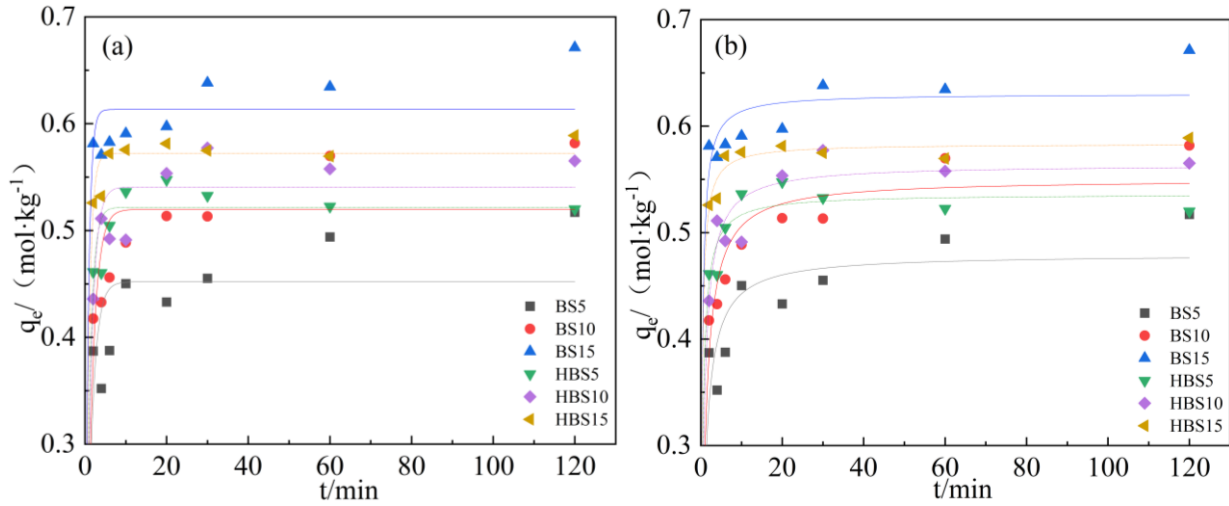


FIG. 3 CH<sub>4</sub> adsorption by improved soils with different (hydrophobic) biochar additions and their nonlinear kinetic fitting curves, respectively (a) pseudo-first-order; (b) pseudo-second-order;

TABLE 2 kinetic equation parameters of CH<sub>4</sub> adsorption by improved soil with different (hydrophobic) biochar additions

Materials	Addition amount	Pseudo-first order kinetics			Pseudo-second order kinetics		
		$k_1$ (1/min)	$q_e$ (mol/kg)	$R^2$	$k_2$ (kg/mol/min)	$q_e$ (mol/kg)	$R^2$
S	-	0.92	0.49	0.957	2.62	0.38	0.942
BS	5	0.70	0.45	0.897	2.50	0.48	0.949
	10	0.65	0.52	0.934	2.09	0.55	0.976
	15	1.40	0.61	0.974	5.90	0.63	0.984

	5	0.96	0.52	0.981	4.97	0.54	0.999
HBS	10	0.78	0.54	0.970	2.92	0.56	0.986
	15	1.19	0.57	0.993	7.21	0.58	0.997

### Adsorption isotherms

In this experiment, the adsorption isotherms of CH<sub>4</sub> adsorption on soil, (hydrophobic) biochar and (hydrophobic) biochar with different mass ratios (0,5,10,15 and 20%) were tested under low pressure (0-101kPa), and the results were analyzed using the Langmuir isotherm adsorption equation and Freundlich isotherm adsorption equation. Fig. 4 (a) and (b) shows the isothermal sorption lines of CH<sub>4</sub> by biochar and hydrophobic biochar with different contents, respectively. It can be seen from Fig. 4 (a) and (b) that under the same temperature and pressure conditions, HB has the highest adsorption capacity for CH<sub>4</sub>, followed by B, and S the lowest. And with the increase of (hydrophobic) biochar addition, the adsorption of CH<sub>4</sub> by (hydrophobic) biochar-amended soils also increased.

From the isotherm correlation coefficient  $R^2$  in Table 3, it can be seen that the  $R^2$  of the Freundlich isothermal sorption model was larger than that of the Langmuir isothermal sorption model, and the saturated

sorption amounts fitted by the Langmuir isothermal sorption model were significantly different from those in the actual experiments, indicating that the Freundlich isothermal adsorption model can better fit the adsorption of CH<sub>4</sub> by different amounts of (hydrophobic) biochar modified soil. The parameter  $1/n$  in the Freundlich isothermal adsorption model indicates the binding force or adsorption capacity of the adsorption material to the adsorbate. A smaller  $1/n$  means better adsorption performance, and a value of  $1/n$  between 0.1 and 0.5 means easy adsorption, while more than 2 means difficult adsorption.  $1/n$  of the soil was 1.81, indicating its weak adsorption capacity for CH<sub>4</sub>, while the biochar-amended soils with different additions ranged from 0.34 to 1.12 and the hydrophobic biochar-amended soils with different additions ranged from 0.35 to 1, indicating that the (hydrophobic) biochar had a weak adsorption capacity for CH<sub>4</sub> at low pressure, but the addition of (hydrophobic) biochar improved the adsorption capacity of the soil for CH<sub>4</sub>.

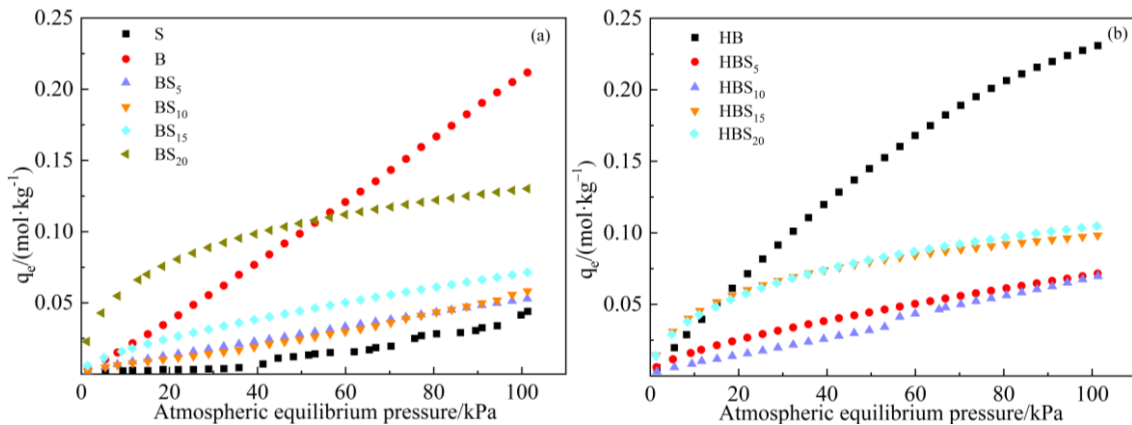


FIG. 4 Isothermal adsorption curve of CH<sub>4</sub> by different amounts of (hydrophobic) biochar modified soil (a) biochar (b) hydrophobic biochar

TABLE 3 Isotherm parameters of CH<sub>4</sub> adsorption by (hydrophobic) biochar amended soils with different additions

Materials	Addition amount	Langmuir			Freundlich		
		k <sub>L</sub> (k/Pa)	q <sub>e</sub> (mol/kg)	R <sup>2</sup>	k <sub>F</sub>	1/n	R <sup>2</sup>
S	-	-0.60×10 <sup>-2</sup>	-0.03	0.877	0.96×10 <sup>-5</sup>	1.81	0.986
	-	-0.10×10 <sup>-2</sup>	-1.74	0.999	1.50×10 <sup>-3</sup>	1.07	0.999
	5	0.24×10 <sup>-2</sup>	0.27	0.998	0.95×10 <sup>-3</sup>	0.87	0.999
BS	10	0.20×10 <sup>-2</sup>	-0.22	0.987	0.32×10 <sup>-3</sup>	1.12	0.993
	15	1.14×10 <sup>-2</sup>	0.13	0.988	3.70×10 <sup>-3</sup>	0.64	0.999
	20	6.00×10 <sup>-2</sup>	0.15	0.973	2.79×10 <sup>-2</sup>	0.34	0.994
HBS	-	0.63×10 <sup>-2</sup>	0.60	0.999	0.72×10 <sup>-2</sup>	0.76	0.994
	5	1.09×10 <sup>-2</sup>	0.13	0.988	3.67×10 <sup>-3</sup>	0.64	0.999
	10	-5.26	-13.09	0.995	0.70×10 <sup>-3</sup>	1.00	0.995
	15	5.51×10 <sup>-2</sup>	0.11	0.984	1.96×10 <sup>-2</sup>	0.35	0.989
	20	3.92×10 <sup>-2</sup>	0.13	0.982	1.62×10 <sup>-2</sup>	0.41	0.997

## CONCLUSIONS

In this work, the effects of different CH<sub>4</sub> concentrations and different (hydrophobic) biochar contents on the CH<sub>4</sub> sorption behavior of (hydrophobic) biochar-amended soils were investigated, and the experimental results were fitted using adsorption isotherms and kinetics. The results indicate that the CH<sub>4</sub> adsorption onto (hydrophobic) biochar-amended soils follows pseudo-second-order kinetics and Freundlich isothermal sorption model, which is justified by kinetic and isothermal data. The addition of hydrophobic biochar significantly improved the CH<sub>4</sub> adsorption capacity of soil, and the adsorption amount increased with the increase of CH<sub>4</sub> concentration and hydrophobic biochar addition.

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