

Adsorption characteristics of Cd(II) from aqueous solution onto activated palygorskite

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Abstract

A series of activated palygorskites were prepared by acid treatment and heat treatment, and the activated samples were applied as adsorbents for the removal of Cd(II) from aqueous solutions. The effects of various experimental parameters were investigated using a batch adsorption technique. Results showed that the adsorption capacity of the acid-treated palygorskite for Cd(II) increased with the increase of the concentration of initial Cd(II) solution, contact time and pH of initial suspension. It was found that the adsorption capacity of activated palygorskite increased with increasing the HCl concentration and calcination temperature, and the maximum adsorption capacity of acid-treated and heat-treated palygorskites for Cd(II) was obtained with 12 mol/L HCl and at about 300 °C. The adsorption isotherms of activated palygorskites for Cd(II) could be described by both Langmuir and Freundlich equations, and the Freundlich model is better to represent the adsorption process. The final pH values of the solution in all adsorption experiment were also measured. In addition, the interactions at the clay–water interface and the Cd(II) adsorption mechanisms onto the activated palygorskites were discussed.

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1. Introduction

Cadmium is released into natural water from metal plating, mining, pigments and alloy industries. It can spread into the environment through soils and water streams, and bring a chief threat to human health [1]. The removal of Cd(II) contaminants from industrial wastewaters is currently of great importance in recent years. A number of technologies for the removal of heavy metals from aqueous solutions have been developed over the years. These technologies include chemical precipitation, ion exchange, membrane filtration, carbon adsorption and coprecipitation/adsorption [2]. However, these techniques have inherent limitations in application (such as complicated treatment process, high cost and energy requirement) or have a danger of secondary pollution. It is worthy to note that the main disadvantage of the adsorption methods is the high price of the adsorbents, which increases the cost of wastewater treatment.

Clay minerals have great potential as inexpensive and efficient sorbents owing to their large quantities, chemical and mechanical stability, high surface area and structural properties. There is an upsurge of interest in recent years to utilize clay minerals to remedy heavy metal cadmium contaminated environment in environmental studies [3–8]. Many clay minerals, such as montmorillonite [3,4], kaolinite [4], vermiculite [5,6] and illite [7], etc., were chosen as adsorbents to study the adsorption for cadmium. Palygorskite clay is a kind of silicate clay with palygorskite as the main component. Natural palygorskite particles adsorb many exchangeable cations owing to isomorphic substitution during its formation process. Its porous structure and adsorbed cations provide it with large specific surface area and middling cation exchange capacity [9], which is of benefit to the adsorption of heavy metals from solution. Several work related to adsorption of heavy metal cations onto palygorskite has been studied [10–12]. However, little information concerning the effect of treated palygorskite prepared by heat- and acid-treated methods on the adsorption of Cd(II) can be seen.

Usually, palygorskite samples with different physicochemical properties can be obtained through heat treatment and acid

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treatment. For example, heat treatment can affect the specific surface area of palygorskite, and then has some influence on adsorption capacity of palygorskite. Many Si–OH groups on the surface of palygorskite can be obtained by acid treatment, which can influence adsorption mechanism of heavy metal on palygorskite. Based on the above considerations, it is necessary to investigate the effect of treatment methods on the Cd(II) adsorption capacity of palygorskite in mineral–solution system.

The main objectives of this study are: (1) to investigate the effects of the parameters, such as initial concentration of Cd(II), contact time, adsorbent dosage and pH of suspension, on Cd(II) adsorption by acid-treated palygorskite; (2) to measure the Cd(II) adsorption capacities of heat- and acid-treated palygorskites; (3) to understand the interactions between the adsorbent and Cd(II) solution through variation of pH of final solution in all adsorption tests.

2. Materials and methods

2.1. Chemicals and reagents

The palygorskite clay (supplied by Linze Colloidal Co., Gansu, China) was milled into a size of 200-mesh. Chemical composition of the sample was determined with a Magix PW 2403 XRF Spectrometer (PANalytical Co.) and the result was given in Table 1. The cation exchange capacity (CEC) of the samples was determined by the ammonium acetate method [13]. The specific surface area (SSA) of the samples was measured by the glycol dimethyl ether (C₄H₁₀O₂) method [14]. A stock solution of Cd(II), prepared by dissolving Cd(CH₃COO)₂·2H₂O in distilled water, was taken as the adsorptive solution. Other agents used were all of analytical grade and all solutions were prepared with distilled water.

2.2. Acid-activation and heat-activation of palygorskite

Activated palygorskite samples were obtained according to the following procedure: (1) acid-activation series: 10.0 g palygorskite micro-powder was immersed in 100 mL HCl solution with various concentrations (2, 4, 6, 8 and 12 M) at 20 °C for 2 h under mechanical stirring at 1250 rpm, and then washed with distilled water for many times until pH of 6.0 was achieved.

Table 1
Chemical composition of palygorskite sample

Component	wt.%
SiO ₂	57.06
MgO	8.63
Al ₂ O ₃	16.59
Fe ₂ O ₃	6.11
CaO	4.55
TiO ₂	0.71
MnO	0.08
K ₂ O	3.51
Na ₂ O	1.35
P ₂ O ₅	0.22
SO ₃	0.42

The resulting sample was dried at 105 °C to constant weight and ground into a size of 200-mesh. (2) Heat-activation series: 10.0 g palygorskite micro-powder was calcined at 100, 200, 300, 400 500 and 600 °C for 4 h, respectively, and then cooled to room temperature in a desiccator.

2.3. Adsorption procedure

Adsorption measurements were determined by batch experiment of known amounts of the sample with 20 mL of aqueous Cd(II) solutions. The mixtures were shaken in a thermostatic shaker bath (THZ-98A mechanical shaker) at 120 rpm at 30 °C for a given time, and then the suspensions were centrifuged at 5000 rpm for 20 min. The pH value of suspension was adjusted with dilute HCl or NaOH solution (Mettler Toledo 320 pH meter). The experiments were carried out by varying concentration of initial Cd(II) solution, contact time, adsorbent dosage and pH of initial suspension. Adsorption mechanisms were studied according to the predefined procedure with Cd(II) concentrations ranging from 25 to 500 mg/L. The initial, and the final concentration of Cd(II) in the acetate solution were measured with an atomic absorption spectrophotometer (Perkin-Elmer SIMAA 6000). The adsorption capacity of Cd(II) was calculated through the following equation:

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

where q_e is the adsorption capacity of Cd(II) on adsorbent (mg/g), C_0 the initial concentration of Cd(II) (mg/L), C_e the equilibrium Cd(II) concentration in solution (mg/L), m the mass of adsorbent used (g) and V is the volume of Cd(II) solution (L). All assays were carried out in triplicate and only mean values were presented.

The goodness of fitting of the Langmuir and Freundlich models was verified using the approaches of Alves and Lavorenti [15] by the following equation:

$$\text{S.E.} = \left[\sum (q_e - q_e^*)^2 / (n - 2) \right]^{1/2} \quad (2)$$

where S.E. represents standard error, q is the measured metal adsorbed, q^* the predicted metal adsorbed by models, and n is the number of experimental points.

3. Results and discussion

3.1. Adsorption capacities of acid-treated palygorskites for Cd(II)

3.1.1. Effect of HCl concentration

Acid treatment of palygorskite can disaggregation palygorskite particles, eliminate mineral impurities and increase its surface area [16]. As seen from Table 2, SSA and q_e of palygorskite increases with increasing HCl concentration and a maximum SSA and q_e was obtained when the HCl concentration was increased to 12 mol/L. Similar to sepiolite, palygorskite is a fibrous clay mineral, and heavy metal can be trapped by chemisorption and/or cation exchange reactions [17]. In the case

Table 2

Adsorption capacities for Cd(II), pH of final solutions, CEC and SSA of natural and acid-treated palygorskites

	HCl concentration (mol/L)					
	0	2	4	6	8	12
q_e (mg/g)	37.31	47.71	48.32	49.54	51.37	52.99
pH	7.50	7.54	7.56	7.57	7.65	7.71
CEC (mequiv./100 g)	30.0	14.4	13.7	13.6	11.7	9.9
SSA (m ² /g)	48.7	192.9	221.2	224.3	234.5	267.5

Concentration of initial solution 500 mg/L, adsorbent dosage 0.15 g, pH of initial suspension 8.50, contact time 3 h.

of the fibrous clay minerals, adsorption takes place on the oxygen of the tetrahedral sheets, the water molecules at the edges of the octahedral sheet and Si–OH groups along the direction of the fibres [18]. According to the mechanism of acid treatment [16], the relative abundance of these groups related to fibre dimensions and crystal defects enhanced by acid treatment [9]. With the increase of HCl concentration, the cations on the surface and channel of palygorskite can be substituted by H⁺, which is then exchanged gradually with Cd(II) in the adsorption process. The variations of SSAs and CECs of palygorskite samples imply that the adsorption process and cation exchange process were enhanced and weakened in the above test conditions with the increasing HCl concentration, respectively. The two processes together dominate Cd(II) adsorption on acid-treated palygorskite.

Specific adsorption can be described by a surface complexation model which defines surface complexation formation as a reaction between functional surface groups (Si–OH) and an ion in a surrounding solution, which form a stable unit [19]. However, cation exchange is a form of outer-sphere complexation with weak electrostatic attraction between metals and charged minerals surfaces [20]. It is conceivable that more silanol groups of palygorskite particles produced by an increase in HCl concentration can easily form a more stable unit with Cd(II) ions than cation exchange, and specific adsorption involving monodentate or bidentate inner-sphere complexations onto Si–OH sites on the palygorskite particles predominates under this adsorption conditions, which should be an important reason resulting in a gradual increase in adsorption capacity of acid-treated palygorskite.

The pH value of final Cd(II) solution is indicative of the property of liquid system because it is the result of interaction between mineral and Cd(II) solution. As seen in Table 2, pH of final solution increases slightly from 7.50 to 7.71 with acid-treated palygorskite prepared with the increase of HCl concentration. Based on the above analysis, it is considered that the cation exchange and specific adsorption occurred simultaneously during the adsorption process. Cation exchange which can be represented by Eq. (3) would induce the increase in pH value of solution due to the lower hydrolyse constant of Cd(II) compared to Mⁿ⁺ on palygorskite. In contrast to the former, specific adsorption of surface sites (Si–OH) on the acid-treated palygorskite by Eqs. (4) and/or (5) can bring a decrease in final pH. The result indicates that the above two mechanisms together influence Cd(II) retention on acid-treated palygorskite and result

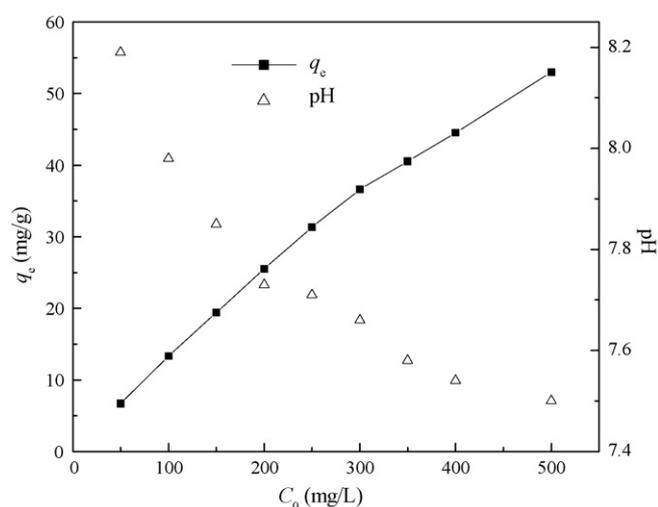
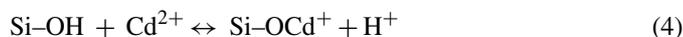
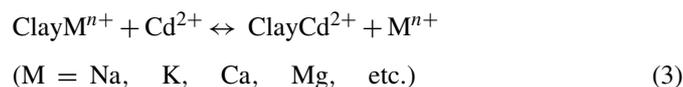


Fig. 1. Effect of concentration of Cd(II) solution on adsorption of acid-treated palygorskite for Cd(II) (adsorbent dosage 0.15 g, pH of initial suspension 8.50, contact time 3 h).

in that the pH of final solution is affected indistinctively by palygorskite treated with different HCl concentration:



Based on the above analysis, palygorskite treated with 12 mol/L HCl was selected as an adsorbent for the rest of the batch experiments.

3.1.2. Effect of concentration of initial Cd(II) solution

Fig. 1 shows the effect of initial Cd(II) concentration on adsorption onto the acid-treated palygorskite. It can be seen that the q_e increases almost linearly with increasing concentration of Cd(II) solution. This result can be explained in terms of the interaction of Cd²⁺ ions and adsorbent. When adsorbent mass is constant, there is determinate amount of activated adsorption sites on adsorbent, as concentration of Cd(II) solution, i.e. the amount of Cd(II) per unit volume of solution increases, the ratio of Cd(II) ions to the available adsorption sites also increases and more Cd(II) ions in solution can be adsorbed on acid-treated palygorskite, resulting in an increase of the q_e . Similar results have been reported by other investigators [4,21,22].

In addition, pH of final solution decreases significantly as the concentration of Cd(II) increases from 50 to 200 mg/L. This result can be explained by the following fact. There is large amount of silanol groups on acid-treated palygorskite particles, the functional surface silanol groups Si–OH may act as Lewis basis in deprotonated form (Si–O[−]) to bind one or two Lewis acid metal ions Cd(II) [7,23]. Hence, when the concentration of Cd(II) increases, Cd(II) can form more monodentate or bidentate complexes with Si–O[−], and more H⁺ came into solution resulting in the decrease of pH of final solution.

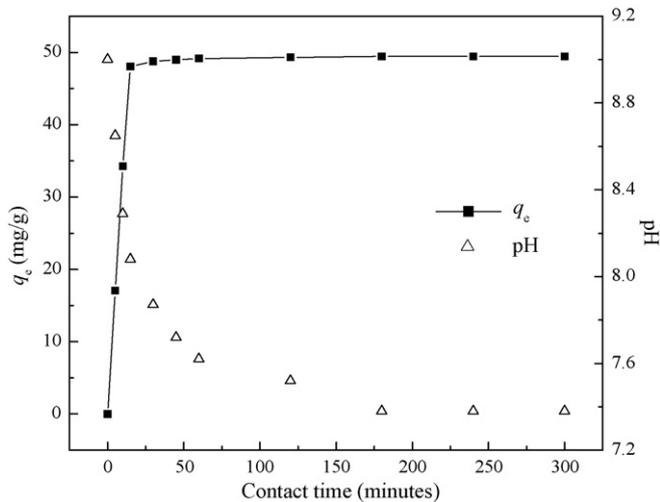


Fig. 2. Effect of shaking time on adsorption of acid-treated palygorskite for Cd(II) (concentration of initial solution 500 mg/L, adsorbent dosage 0.15 g, pH of initial suspension 8.50).

3.1.3. Effect of contact time

Contact time is an important parameter because this factor can reflect the adsorption kinetics of an adsorbent for a given initial concentration of the adsorbate. Fig. 2 shows the effect of contact time on adsorption of acid-treated palygorskite for Cd(II). It is clear that q_e increases rapidly with the increase of contact time from 0 to 25 min and then reaches equilibrium point after 1 h, followed by a constant adsorption upon further increasing shaking time. Santillan-Medrano and Jurinak [24] have demonstrated that Cd(II) adsorption on the soil was a fast process, where >95% of the adsorption took place within the first 10 min and equilibrium was attained within 1 h. Similar observation has been reported by other investigators [4].

As seen from Fig. 2, pH of final solution decreases apparently with increasing contact time from 0 to 1 h, followed by a decrease with a relatively slow rate and then reaches a constant value upon further increasing contact time. The variations of pH may be related to surface property of acid-activated palygorskite. Since it contains large numbers of adsorption sites (Si–OH) onto acid-activated palygorskite, it is most likely that complex reactions mechanisms between Cd(II) and Si–OH groups on acid-treated palygorskite particles were responsible for the decrease of pH of final solution. The above results indicate that it takes a determinate time to reach equilibrium for some interactions such as interface of palygorskite and water, surface complexation and surface ion-exchange during adsorption process.

3.1.4. Effect of adsorbent dosage

The results of adsorbent dosage effect on q_e and pH of final solution are represented in Fig. 3. The q_e decreases with increasing adsorbent dosage, which shows that the amount of Cd(II) adsorbed per unit weight of adsorbent decreases as the adsorbent mass increases. Especially, when the adsorbent added is beyond 0.15 g, the decrease in Cd(II) adsorption is not very prominent which is perhaps due to the formation of adsorbent agglomerates reducing available surface area and blocking some of the adsorption sites. Gupta et al. reported a similar find-

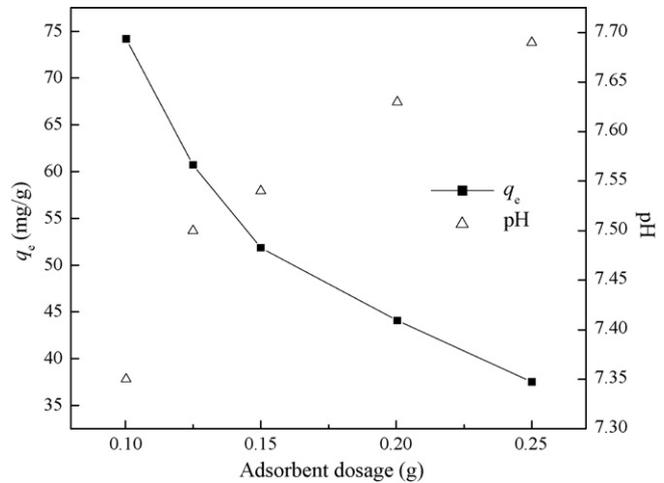


Fig. 3. Effect of amount of adsorbent on adsorption of acid-treated palygorskite for Cd(II) (concentration of initial solution 500 mg/L, pH of initial suspension 8.50, contact time 3 h).

ing for Cd(II) adsorption onto kaolinite and montmorillonite [4].

In general, pH of final solution increases gradually with the increase in adsorbent dosage. It may be attributed to evident increase of the amount of negatively charged sites. The surface of palygorskite become more negative through the acid treatment, negatively charged sites on surface of acid-treated palygorskite particles will increase with an increasing of adsorbent mass, which can induce more H^+ ions adsorb on acid-treated palygorskite surface and results in an increase in pH of the final solution.

3.1.5. Effect of initial suspension pH

The effect of the pH of initial suspension on the adsorption of Cd(II) to acid-treated palygorskite was examined in this section. It can be seen from Fig. 4 that the q_e increases at a relatively slower rate with an increase in pH of the ini-

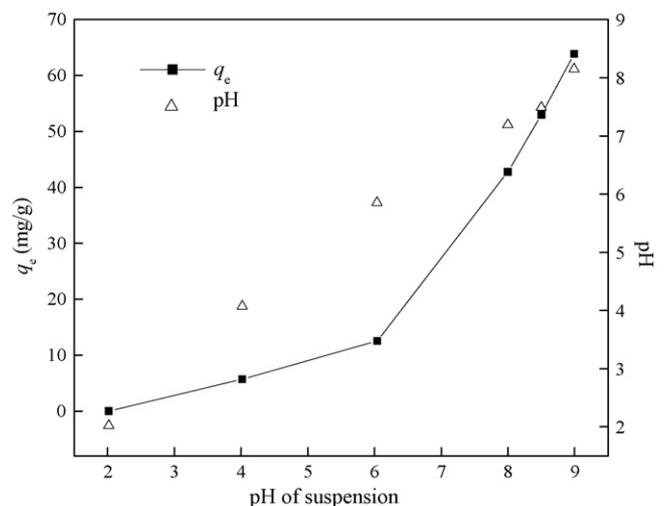


Fig. 4. Effect of pH of initial suspension on adsorption of acid-treated palygorskite for Cd(II) (concentration of initial solution 500 mg/L, adsorbent dosage 0.15 g, contact time 3 h).

tial suspension from 2 to 6, and then increases drastically as the solution becomes neutral and basic. As pH value is lower than 4.0, the silanol groups of acid-treated palygorskite are more protonated to form Si-OH_2^+ , hence, they are less available to adsorb Cd(II). Consequently, it leads to low q_e of Cd(II) on adsorbent. The fact that q_e increases with increasing pH may be attributed to the decrease of proton competition for the adsorption sites on the adsorbent surface, as well as by an enhanced electrostatic attraction between the surface and the cationic species. This increasing trend at a slower rate continues until the pH reaches to 6. Besides, it can also be interpreted in terms of isoelectric point (iep) of acid-treated palygorskite. The surface of palygorskite treated with HCl compared to that of unmodified palygorskite has gained more silanol groups, so that pH_{iep} of modified palygorskite should be obtained at higher pH compared to that of unmodified palygorskite. According to iep of palygorskite about 4.0–4.5 [25], it can be considered that iep of acid-treated palygorskite should be close to neutral. Therefore, the acid-activated palygorskite surface at the moment become negatively charged as a whole and more Cd(II) can be adsorbed on it so that the q_e of Cd(II) increases obviously.

3.2. Adsorption capacities of heat-treated palygorskites for Cd(II)

The dehydration of palygorskite combined with thermal treatment can produce changes in both its structural and textural properties [26,27], which affect the SSA and adsorption capacity of palygorskite. Therefore, the effect of heat treatment on the adsorption of palygorskites for Cd(II) was investigated and the results were shown in Table 3. As seen in Table 3, q_e increases to a maximum value with the calcination temperature increases to about 300 °C, and then decreases with further increasing temperature. It also can be seen that SSA of the palygorskite increases to a maximum value with increasing the temperature to 300 °C, and then decreases with further increasing temperature. The zeolitic water and part of the coordinated water existed in palygorskite crystal are removed in turn with the increasing temperature, which increases amount of the micropores of palygorskite and results in the increase of q_e . As the calcination temperature exceeds 400 °C, the contact area between palygorskite particles and the cadmium solution decreases evidently due to the distortion of crystal structure of palygorskite, which results in the decrease of q_e notably.

Table 3
Adsorption capacities for Cd(II), pH of final solutions, pH in distilled water and SSA of natural and heat-treated palygorskites

	Calcination temperature (°C)						
	25	100	200	300	400	500	600
q_e (mg/g)	37.31	37.92	38.53	46.49	39.75	11.01	8.56
pH of final solution	7.50	7.44	7.60	7.74	7.76	7.89	7.94
pH in distilled water	8.93	9.15	9.38	9.33	9.50	10.23	10.75
SSA (m ² /g)	48.66	120.0	124.3	128.9	119.0	81.68	64.87

Concentration of initial solution 500 mg/L, adsorbent dosage 0.15 g, pH of initial suspension 8.50, contact time 3 h. pH of samples: 0.15 g of palygorskite sample, 20 mL of distilled water, the mixture were stirred for 10 min.

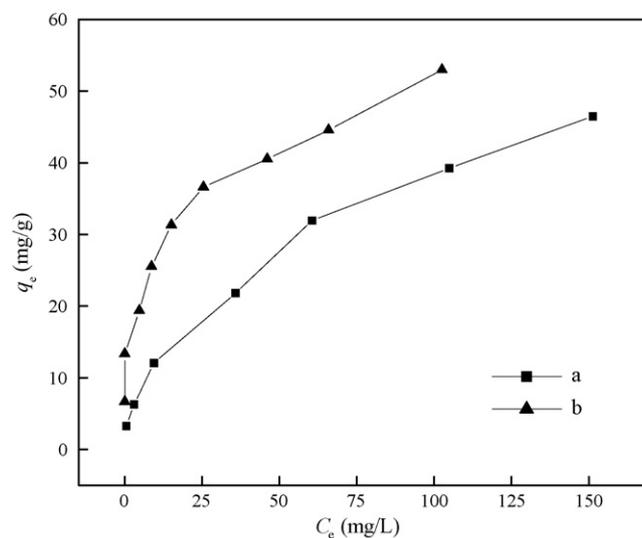


Fig. 5. Adsorption isotherms of Cd(II) on (a) 300 °C-treated and (b) 12 mol/L HCl-treated palygorskites (adsorbent dosage 0.15 g, pH of initial suspension 8.50, contact time 3 h).

The pH value of the final solution, after adsorption process completed on heat-treated palygorskites, varies in the range of 7.4–8.0 and shows a general increasing trend. This trend is similar to the pH variation of treated palygorskite in distilled water, which indicates the former result might be caused by the latter fact.

3.3. Adsorption isotherms of acid-treated and heat-treated palygorskites

The adsorption isotherms of Cd(II) onto 300 °C-treated and 12 mol/L HCl-treated palygorskites were studied with initial concentrations of Cd(II) in the range of 25 and 500 mg/L and the results were shown in Fig. 5. The Cd(II) adsorption capacity increases with increasing Cd(II) equilibrium concentration. The capacities of the 300 °C-treated and 12 mol/L HCl-treated palygorskites were approximately 39 and 52 mg/g, respectively, at the Cd(II) equilibrium concentration of 100 mg/L and pH 8.5 of the suspension. It can be clearly seen from Fig. 5 that 12 mol/L HCl-treated palygorskite has a higher adsorption capacity for Cd(II) compared to 300 °C-treated palygorskite.

For each isotherm, Langmuir and Freundlich adsorption models were applied to analysis. The Langmuir model is valid for monolayer sorption onto a surface with a finite number of iden-

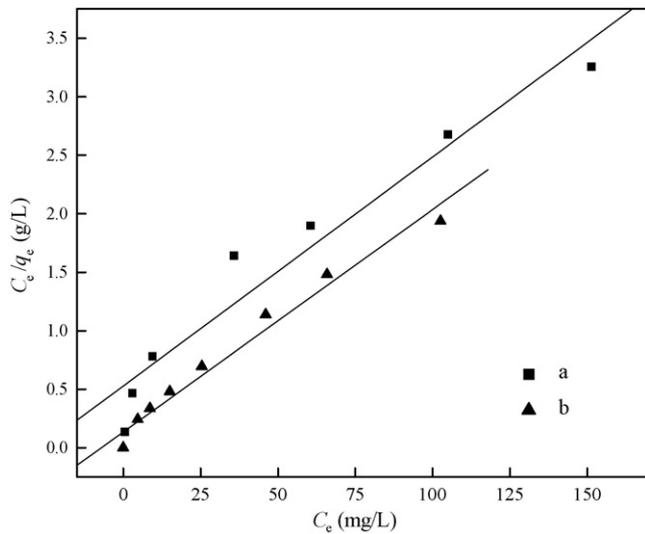


Fig. 6. Langmuir plots of C_e/q_e against C_e for the adsorption of Cd(II) on (a) 300 °C-treated and (b) 12 mol/L HCl-treated palygorskites (adsorbent dosage 0.15 g, pH of initial suspension 8.50, contact time 3 h).

tical sites [28]. The well-known expression of the Langmuir model is given by Eq. (6):

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

where C_e is the equilibrium concentration of cadmium solution (mg/L), q_e the equilibrium capacity of cadmium on the adsorbent (mg/g), q_m the monolayer adsorption capacity of the adsorbent (mg/g), and b is the Langmuir adsorption constant (L/mg) and related to the free energy of adsorption.

The empirical Freundlich equation based on sorption onto a heterogeneous surface is given as [29]:

$$q_e = K_f C_e^{1/n} \quad (7)$$

where K_f and n are the Freundlich constants for the system, which are indicators of adsorption capacity and intensity, respectively.

In Langmuir model equation, q_m and b could be calculated from the slopes and intercepts of the straight lines of plots of (C_e/q_e) versus C_e (Fig. 6). While the values of Freundlich model constants, i.e. K_f and n could be calculated from the plots of $\log C_e$ against $\log q_e$ (Fig. 7). The isotherm constants and the correlation coefficients (r^2) are presented in Table 4. As seen from Table 4, the values of the correlation coefficients indicate that the adsorption data fit both Langmuir and Freundlich isotherm models. However, since the value of r^2 in the Freundlich isotherm

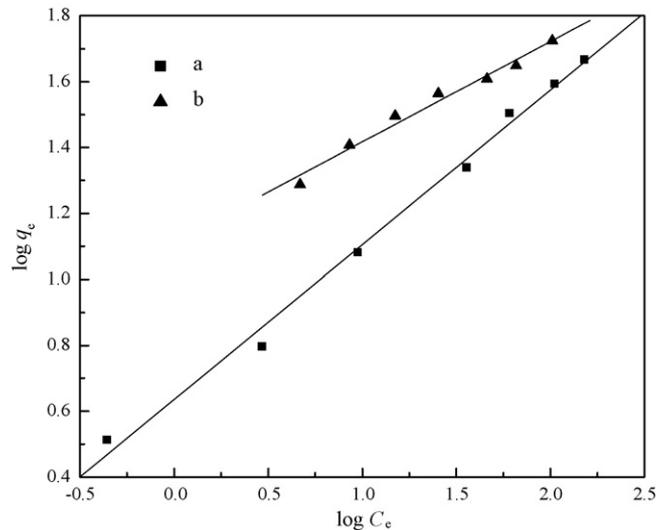


Fig. 7. Freundlich plots of $\log q_e$ against $\log C_e$ for the adsorption of Cd(II) on (a) 300 °C-treated and (b) 12 mol/L HCl-treated palygorskites (adsorbent dosage 0.15 g, pH of initial suspension 8.50, contact time 3 h).

model is higher than that of the Langmuir model for both treated palygorskites, the Freundlich model appears to fit the data better.

In the case of Langmuir isotherms, the maximum adsorption capacities (q_m) of 300 °C-treated and 12 mol/L HCl-treated palygorskites for Cd(II) are similar (51.07 and 52.58 mg/g, respectively). However, the value of b for 12 mol/L HCl-treated palygorskite is larger than that for 300 °C-treated palygorskite. Since b is related to the bonding energy coefficient [30], this result indicates that the 12 mol/L HCl-treated palygorskite has higher affinity for Cd(II) than the 300 °C-treated palygorskite. Besides, adsorption of different species can also be determined according to the value of b [31]. Higher b value has been related to specifically adsorbed metal at high energy surfaces with low dissociation constants; while lower b value appears to be related to adsorption at low energy surfaces with high dissociation constants [32,33]. So, higher b value of the 12 mol/L HCl-treated palygorskite may indicate that the retention of Cd(II) on the HCl-treated palygorskite occurred mainly on specific adsorption positions, i.e. functional surface groups (Si–OH), while the cation exchange should be the main adsorption mechanism for 300 °C-treated palygorskite. As a result, although the maximum adsorption capacities of the two adsorbents are similar, the Cd(II) are trapped more strongly on the HCl-treated palygorskite.

Values of the essential characteristics of Langmuir isotherm can be expressed by a dimensionless constant called equilibrium

Table 4
Langmuir and Freundlich constants and correlation coefficients associated with adsorption isotherms of Cd(II) onto 300 °C-treated and 12 mol/L HCl-treated palygorskites

Adsorbents	Langmuir equation					Freundlich equation			
	q_m (mg/g)	b (L/mg)	R_L	r^2	S.E.	K_f	n	r^2	S.E.
300 °C-treated palygorskite	51.07	0.037	0.051	0.9719	4.112	4.32	2.13	0.9968	1.380
12 mol/L HCl-treated palygorskite	52.58	0.14	0.014	0.9872	3.330	12.95	3.28	0.9903	1.645

parameter [34]:

$$R_L = \frac{1}{1 + bC_0} \quad (8)$$

where C_0 is the highest initial metal concentration. For cadmium, the R_L values were between 0 and 1.0, indicating that adsorption of Cd(II) onto the two treated palygorskites are both favorable.

The Freundlich coefficient, K_f , can be defined as an adsorption or distribution coefficient which describes the amount of Cd(II) adsorbed onto the adsorbent for the unit equilibrium concentration. As seen from Table 4, K_f value of the 12 mol/L HCl-treated palygorskite is much higher than that of the 300 °C-treated palygorskite, indicating that the former has a higher adsorption capacity or affinity for Cd(II). The n values between 1 and 10 indicate beneficial adsorption [35]. For the adsorption of Cd(II) onto the 300 °C-treated and 12 mol/L HCl-treated palygorskites, both n values were within the favorable limit beneficial adsorption. This result is similar to the above discussion on R_L value. However, Cd(II) adsorption onto 12 mol/L HCl-treated palygorskite shows a higher capacity (K_f) compared to 300 °C-treated palygorskite, which might be related to the difference in linearity of Langmuir and Freundlich adsorption isotherms.

4. Conclusions

The following conclusions have been drawn from this study:

- (1) For the acid-treated palygorskites, adsorption capacities for Cd(II) increase with increasing HCl concentration of acid treating solution and a maximum was obtained at 12 mol/L of HCl concentration.
- (2) In a batch of adsorption studies, the adsorption capacity of HCl-treated palygorskite for Cd(II) increases with increasing initial Cd(II) concentration, contact time and pH, but the decrease of adsorbent dosage.
- (3) The study of the adsorption of heat-treated palygorskite for Cd(II) reveals that adsorption capacity increases to a maximum as the treating temperature increased to 300 °C and the variation of adsorption capacity of heat-treated palygorskites with treating temperature is consistent with that of the specific surface area.
- (4) The adsorption isotherms of 300 °C-treated and 12 mol/L HCl-treated palygorskites indicated that the Freundlich model is better than to ascribe the adsorption process. The two models coefficients implied that the adsorption of Cd(II) onto the two treated palygorskites are both favorable. Moreover, the HCl-treated palygorskite has higher affinity for Cd(II) due to a large amount of silanol groups on the surface of acid-treated palygorskite.

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