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Low concentration cadmium removal using weathered sand of basalt

Jae Hong Park*, Jae Kwan Lee and Dong Seok Shin

National Institute of Environmental Research, 42 Hwankyungro, Seogu, Incheon Metropolitan City, 22689, South Korea

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Abstract. The natural weathered sand of basalt (WSB) has been used for the removal of cadmium from aqueous solution. The influence of various parameters i.e., contact time, pH, weathered sand of basalt dosage, particle size of the weathered sand of basalt, temperature and initial cadmium concentration were analyzed. Cadmium adsorption kinetics was well described by the pseudo second order model. Adsorption equilibrium for cadmium was properly well fitted to Langmuir isotherm model with maximum adsorption capacity 0.50 mg/g. Compared with the other experimental results using various kinds of adsorbents at a low concentration (1.0 mg/L or so) similar to that of this study, the cadmium removal efficiency using weathered sand of basalt was higher. It has been demonstrated that weathered sand of basalt has a available alternative adsorbent for cadmium when its initial concentration is low.

Keywords: adsorption isotherms; adsorption kinetics; cadmium; weathered sand of basalt

1. Introduction

Cadmium (Cd) is known as one of the most toxic heavy metals. Therefore, Cd has been outlined in the red list of priority substance in UK (Mahmoud *et al*. 2011, UK Red List Substances 1991). Cd can be released from mine drainage, paint and ink industry, plating plants, porcelain enameling, metal finishing industry and battery industry, phosphate fertilizer, stabilizers, alloys, plastic manufacturing, etc (Mahmoud *et al*. 2011, Pahlavanzadeh *et al*. 2010, Abuzer and Hüseyin 2011, Mansour *et al*. 2011, Mobasherpour *et al*. 2011, Iqbal *et al*. 2007). It can cause a significant harmful effects to both environmental and human health due to their carcinogenicity, toxicity, non-biodegradability, subsequent biomagnifications and high mobility in the environment even at very low concentration (Barros *et al*. 2007, Preetha and Viruthagiri 2007, Lebeau *et al*. 2002). Moreover, Cd absorbed into the human body is not well excreted, so it is likely to have a negative impact on the body for a long time (Hajiaghababaei *et al*. 2011). The average daily intake for humans is estimated as 0.15 μg from air and 1 μg from water (Hajiaghababaei *et al*. 2011). The long-term and high levels exposure can cause acute or chronic damage to the nervous system (Hajiaghababaei *et al*. 2011), kidney damage (Mobasherpour *et al*. 2011), etc.

The well-known methods for removing heavy metals include chemical precipitation (Mahmoud *et al*. 2010, Saeed *et al*. 2005), adsorption (Mobasherpour *et al*. 2011, Harish *et al*. 2018, Rashed *et al*. 2018, Kalal *et al*. 2017, Mojiri *et al*. 2017, Gonsalvesh *et al*. 2017), ion exchange (Mahmoud *et al*. 2011, Buhani *et al*. 2010, Martin *et al*. 2007, Bulut and Tez 2007), vacuum evaporation (Mansour *et al*. 2011, Martin *et al*. 2007, Bulut and Tez 2007), solvent extraction (Martin *et al*. 2007, Bulut and Tez 2007), membrane technologies (Martin *et al*. 2007, Bulut and Tez 2007), reverse osmosis (Mahmoud *et al*. 2011), electrodialysis (Mobasherpour *et al*. 2011), reduction (Murugesan *et al*. 2011, Mahmoud *et al*. 2010), solvent extraction (Murugesan *et al*. 2011, Mahmoud *et al*. 2010), electrochemical techniques (Martin *et al*. 2007, Bulut and Tez 2007), ultra-filtration (Mahmoud *et al*. 2010, Mahmoud *et al*. 2011), flotation (Lü *et al*. 2010, Saeed *et al*. 2005), coagulation (Buhani *et al*. 2010), complexation (Buhani *et al*. 2010), etc.

Nevertheless, most of these methods have some disadvantage such as high operational cost (Lü *et al*. 2010), disposal of sludge (Bing *et al*. 2011), and low efficiency (Murugesan *et al*. 2011). On the other hand, adsorption technology is well recognized as one of the most effective methods for the removal of heavy metals (Murugesan *et al*. 2011) due to the low cost, ease of operation, no need for large facilities (Tang *et al*. 2009, Paulino *et al*. 2011) and eco-friendly techniques (Çelekli and Bozkurt 2011). A variety of adsorbents can be used to remove heavy metals by adsorption process. But nowadays the adsorbents based on natural products and their derivatives have gained attention, e.g., olive (Martín-Lara *et al*. 2008), leaf (Sert *et al*. 2008), orange peel (Lü *et al*. 2010, Ajmal *et al*. 2000), rice husk (Srivastava *et al*. 2008), mustard husk (Meena *et al*. 2008), sawdust (Gode *et al*. 2008), natural bentonite (Karapinar and Donat 2009), ore waste (Sarı and Tuzen 2009), chestnut shell (Vázquez *et al*. 2009), clay (Jiang *et al*. 2010) and red mud (Nadaroglu *et al*. 2010), due to relative abundance and low cost.

In this view, the objective of this study was to evaluate the possibility of weathered sand of basalt (WSB) as a natural adsorbent for the removal of cadmium from aqueous solutions. In particular, although Cd may have a great effect on human body and environment even at low concentration,

*Corresponding author, Ph.D.
E-mail: jhong@korea.ac.kr

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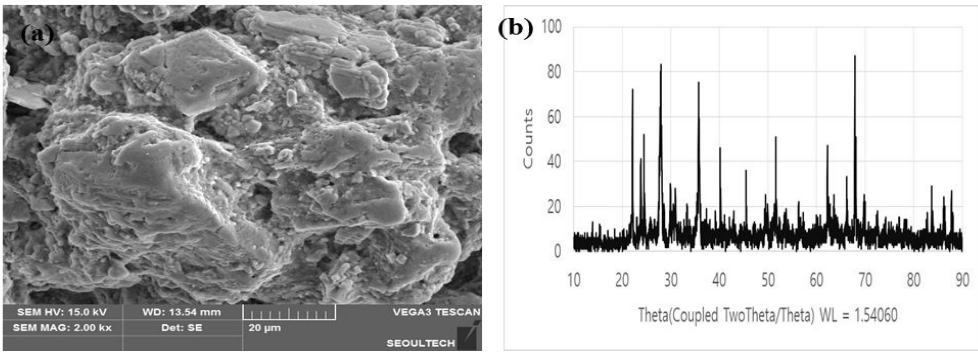

Fig. 1 **S**canning electron micrograph (a) and X-ray diffraction (b) of the WSB

the experiment was mainly conducted at high concentration in many advanced studies. Therefore, in this study, the experiment was carried out at a relatively low 1.0 mg/L. The kinetics of the process, i.e., Langmuir and Freundlich isotherms, were used to analyze the adsorption data. The effect of various experimental parameters such as adsorption time, pH, WBS dosage, WSB particle size, temperature and Cd concentration was investigated.

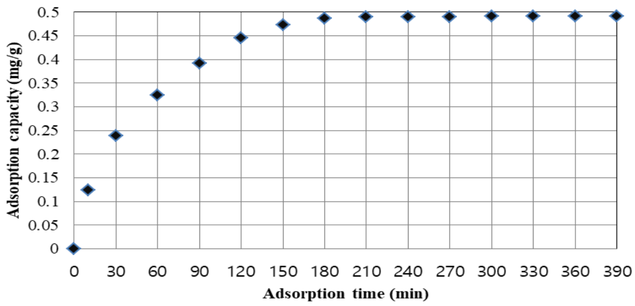

Fig. 2 Effect of contact time on Cd adsorption capacity

2. Materials and methods

2.1 Preparation of the weathered sand of basalt

WSB for the experiment was collected from Jeju island in Korea. The sand was washed 20 times with the third distilled water to remove the impurities. The washed sand was immersed in tertiary distilled water for 24 hours. After that, the sand was dried in an oven at 104°C until constant weight. The dried sand was sieved to select particle fractions of according to particle size (46~75 μm, 150~180 μm, 251~355 μm, 426~850 μm) using ASTM Standard sieve. Sieved sand was used without any kind of physical or chemical modification.

The scanning electron micrograph (SEM) and X-ray diffraction (XRD) of the WSB are given in Fig. 1. The most elements and compounds in WSB are SiO_2, Al_2O_3, CaO and FeO.

2.2 Preparation of cadmium aqueous solutions and reagents

Cd standard solution (10 mg/L) from AccuStandard was used. The concentration of Cd (0.1, 0.5, 1.0, 2.0, 3.0 mg/L) in the aqueous solution used in this experiment was prepared by diluting STD (10 mg/L) with deionized water (conductivity: 0.055 μS/cm, purification process: UV (254 nm) photooxidation → Adsorption & Ion exchange → Ultrafilteration → Membrane filter, model : TKA GenPure UV, Germany). The pH of the solutions was adjusted using 0.1 M of HCl and 0.1 M of NaOH. All chemicals were of reagent grades.

2.3 Experimental procedures

Adsorption experiments were performed in a shaking incubator (IS-971R, JEIO TECH, Korea) at 100 rpm using a 300 mL bottle containing 200 mL Cd aqueous solutions and 0.1~10.0 g WSB.

Samples were taken at 0, 10, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, and 360 min. At the end of the each equilibrium time, they were centrifuged at 4,000 rpm for 20 min to remove WSB from suspension by centrifugation (Combi-514R, HANIL Science Industrial, Korea). The supernatant liquid was analyzed for the residual Cd using ICP-MS (Agilent Technologies 7900).

The adsorption properties of WSB were evaluated by depending on different conditions such as adsorption time, pH, dosage, particle size, temperature and initial Cd concentration. The effects of adsorption time were evaluated at time periods ranging from 0 min to 390 min and pH value ranging from 2 to 12. The effects of WSB particle size were studied in the range of 46 μm to 850 μm. The effects of Temperature were evaluated in the range of 5~60°C by incubated shaker (model: JERO TECH IS-971R, Korea).

3. Results and discussion

3.1 Influence of contact time

Contact time is one of the important operating parameters for effective use of the WSB. In order to establish the equilibrium time for maximum adsorption, samples were taken at intervals of 30 minutes for 390 minutes to measure the Cd concentration.

Fig. 1 shows the effect of adsorption time on the adsorption process, at pH 6, initial Cd 1.0 mg/L, WSB dose 2 g, WSB particle size 251~355 μm and temperature 30°C,

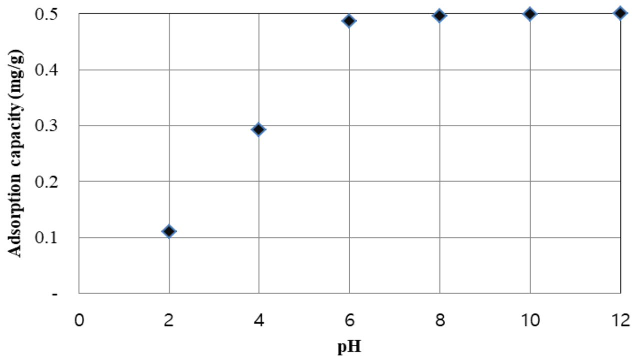

Fig. 3 Effect of pH on Cd adsorption capacity

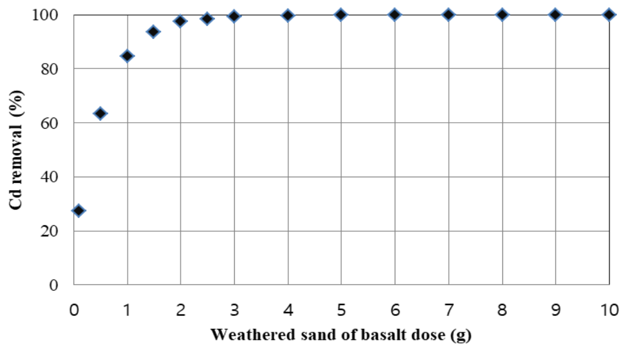

Fig. 4 Effect of weathered sand of basalt dosage on Cd adsorption capacity

respectively. As shown in Fig. 2, although the adsorption amount of Cd did not increase rapidly at the initial stage of the reaction, it can be seen that the adsorption capacity of Cd continuously increased with increasing contact time. Cd adsorption occurred continuously up to the reaction time of 180 minutes and almost equilibrium was reached thereafter. The equilibrium uptake was achieved at 180~390 min.

The removal rate of Cd was reached 99.9% from the initial concentration of 1.0 mg/L. during the contact time of 180 min, after that the adsorption capacity rate is attained. From this result, therefore, 180 min has been selected as optimum contact time in the following experiments.

3.2 Influence of pH

In order to investigate the contribution of pH, the pH of the solution was adjusted within the range of 2~12. The results are presented in Fig. 3, at initial Cd 1.0 mg/L, WSB dose 2 g, WSB particle size 251~355 μm, adsorption time 180 min and temperature 30°C, respectively.

According to Fig. 3, the adsorption of Cd seems to be significantly affected by pH. Therefore, the pH value of the solution is an important factor for Cd removal. Cd adsorption capacity remarkably increases with the rise in the solution pH up to 6. At higher pH value than 6, it reaches a constant value corresponding to maximum. However, the capacity notably decreased in the pH range of 2~6 with the decrease of pH, i.e., acid condition. These above results might be due to the following reasons. In other words, the higher the pH, the lower the zeta potential and the more sites the Cd ion binds to the negatively charged WSB surface. These results have been reported in many previous studies for removing metal ions using minerals as adsorbents. Huang *et al*. (2011) explains these results as follows, i.e., the metal ion uptake was limited in this acidic medium, this can be attributed to the presence of H^+ ions which compete with the Cd (II) ions for the adsorption sites.

The amount of Cd ions per unit of WSB at time t (q_t: mg/g) was calculated by using Eq. (1).

$$q_t = [(Co\text{-}Ct) \times V] / M \quad (1)$$

where, Co and Ct (mg/L) represent concentrations of WSB ions at initial, at *t* time in the solution, respectively. *V* is the volume of solution (L), and *M* is the mass of WSB (g).

At pH 2, the Cd absorption capacity was the lowest at 0.110 mg/g. As the pH increased to 4, 6, 8 and 10, the amount of Cd absorption capacity increased to 0.293, 0.487, 0.496, 0.499 and 0.500 mg/g, respectively. The Cd absorption capacity increased abruptly in the neutral and alkaline pH, and the maximum value was obtained at pH 10.

Cd adsorption efficiency also showed the same tendency as the Cd absorption capacity. At pH 2, 4, 6, 8, and 10, the removal efficiencies were 22.1, 58.6, 97.4, 99.9, 99.9, and 100%, respectively. Therefore, the optimal pH condition is judged to be 8 from the results of Cd adsorption capacity and removal efficiency.

Since the optimal pH condition is the pH range of the natural water, it is a great advantage that the pH adjustment is not necessary when removing Cd from WSB.

3.3 Influence of weathered sand of basalt dosage

The effect of WSB dosage on Cd adsorption capacity was investigated by different WSB doses (0.1~10 g). The results of this study are presented in Fig. 4, at initial Cd 1.0 mg/L, pH 8, WSB particle size 251~355 μm, adsorption time 180 min and temperature 30°C, respectively.

Cd removal efficiency was 28.2% at 0.1 g of WSB dose, and the removal efficiency were increased to 63.4, 85.1, 99.9%, and 99.9% at 0.5, 1.0, 2.0, and 3.0 g, respectively. Cd removal efficiency increased steadily until the WBS dosage reached 2.0 g, but no significant increase at 3.0~10.0 g. The increase in the removal efficiency may be an increase in the surface area and the availability of more active sites on the surface of WSB particles. However, when the amount of adsorbent dosage is excessively large, the adsorption effect is hindered. This phenomenon could be explained as a result of probable aggregation of the WSB particles at higher dosage, which limit the effective surface area and active adsorption sites on the WSB (Bibi *et al*. 2015). Therefore, no further rapid removal of Cd is observed at 3.0 g or higher.

From the results of Fig. 4, this optimal WSB dosage was adopted to be 2.0 g in the following experiments.

3.4 Influence of weathered sand of basalt particle size

In order to investigate the removal characteristics of Cd

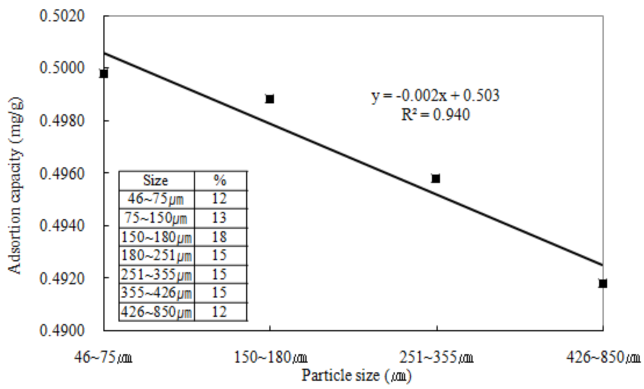

Fig. 5 Effect of weathered sand of basalt particle size on Cd adsorption capacity

according to the particle size difference, WBS was separated and the experiment was conducted for each size section. As shown in Fig. 5, the WBS particle size used in this study was found to vary from 46~850 μm. The ratio of each particle size range is in the range of 12~18%, and it is found that it occupies a similar ratio.

Experiments were performed at each optimum condition, pH 8, WSB dose 2 g, adsorption time 180 min and temperature 30°C, respectively. Fig. 5 shows Cd adsorption capacity against various particle size, i.e., 46~75 μm, 150~180 μm, 251~355 μm and 426~850 μm.

As shown in Fig. 5, as the WSB particle size increased to 46~75 μm, 150~180 μm, 251~355 μm and 426~850 μm, the adsorption capacities of Cd tended to decrease to 0.4998, 0.4988, 0.4958, and 0.4918 mg/g, respectively. Therefore, it is considered to be effective to use as small particle sand as possible to increase the removal rate of Cd in aqueous solution. This might be explained by the fact that the smaller the particle size, the wider specific surface area which can be contacted with Cd in aqueous solution.

However, the difference Cd removal rate for each particle size was only about 0.2~1.6%, compared with 46~75 μm which showed the highest removal efficiency. Therefore, it is considered that natural WSB in Jeju island can be used as it is without selecting only the grain size with the highest Cd removal efficiency.

3.5 Influence of adsorption temperature

To investigate the influence of temperature on the adsorption of Cd by WSB, various temperatures were selected. The other operating parameters were tested at the optimum conditions derived from the previous experiment, i.e., at pH 8, WSB dose 2 g, adsorption time 180 min.

Fig. 6 shows the experimental results obtained from a series of temperature at 5~60°C. As shown in Fig. 6, adsorption capacity of Cd on WSB increased from 0.38 mg/g to 0.50 mg/g when the temperature was increased from 5°C to 30°C during the equilibrium time. On the other hand, when the temperature was increased more than 30°C, adsorption capacity of Cd was slightly increased but showed almost equilibrium value. It can be estimated that an increase in temperature involves an increase in mobility of the adsorbate and a decrease in the retarding forces acting

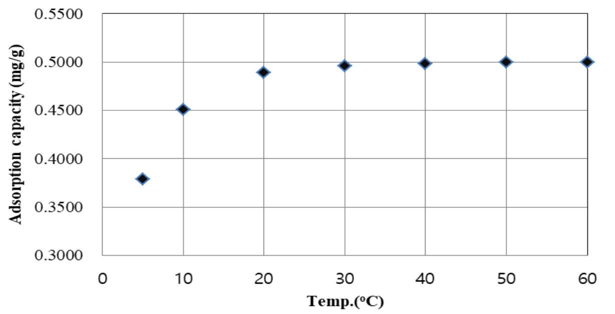

Fig. 6 Effect of adsorption temperature on Cd adsorption capacity

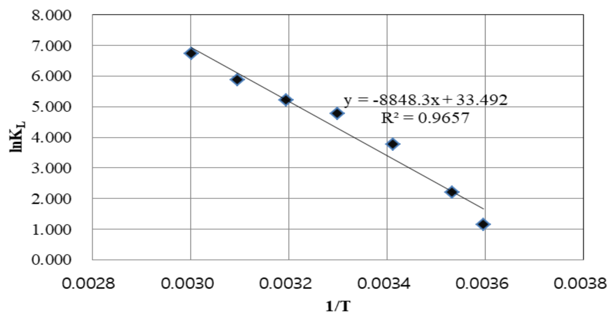

Fig. 7 Van't Hoff plot for the Cd adsorption onto WSB

on the diffusing ions (Elouear *et al*. 2008).

As can be seen in Fig. 6, Cd removal rate reaches the equilibrium stage at the 30°C, so that the maximum Cd removal rate can be obtained even if the experiment is performed at room temperature without greatly controlling the temperature.

On the whole, it can be seen that the Cd removal efficiency is high when the temperature is relatively high. Therefore, this result indicated that the temperature is associated with changes in thermodynamic parameters and the adsorption of Cd by WSB is an endothermic process. This could be a result of increase in the mobility of Cd^{2+} with increasing temperature.

The amounts of WSB adsorbed at equilibrium were utilized to evaluate the thermodynamical parameters at different temperatures. Thermodynamic parameters, entropy change (ΔS^o), Gibbs free energy change (ΔG^o) and enthalpy change (ΔH^o) were determined using the following Van't Hoff plot (Palanisamy and Sivakumar 2009).

$$\ln K_L = \frac{\Delta S^o}{R} - \frac{\Delta H^o}{R} \times \frac{1}{T} \tag{2}$$

$$\Delta G° = \Delta H° - T\Delta S° \tag{3}$$

where K_L is the equilibrium constant, T is the solution temperature in Kelvin and, R is the universal gas constant. The value of $\Delta S°$ and $\Delta H°$ are calculated from the slopes and intercepts of the linear plot of K_L versus $1/T$.

The Van't Hoff plot for the adsorption process is shown in Fig. 7 and Table 1. The K_L values were founded to be 3, 9, 43, 118, 184, 356 and 832 L/mol, respectively. The increase in K_L values with increase in temperature shows an increase in feasibility of adsorption at high temperatures.

Table 1 Thermodynamical parameters for the adsorption of Cd on WSB

Temperature (K)	$\Delta H°$ (kJ/mol)	$\Delta S°$ (kJ/mol K)	$\Delta G°$ (kJ/mol)
278			-3.843
283			-5.253
293			-8.020
303	73.566	0.2785	-10.804
313			-13.589
323			-16.373
333			-19.158

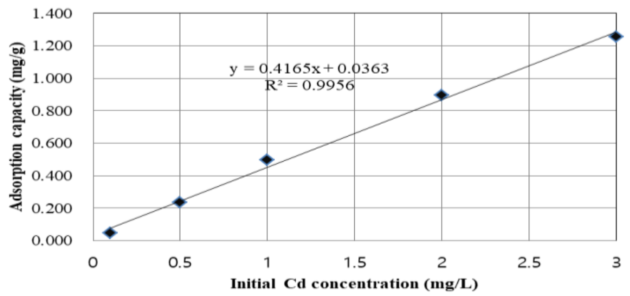

Fig. 8 Effect of initial Cd concentration on Cd adsorption capacity

The negative values of $\Delta G°$ indicate that the Cd adsorption on WSB is a favorable and spontaneous process in nature. The positive value of enthalpy ($\Delta H°$) indicates that the adsorption process is endothermic in nature. The positive value of $\Delta S°$ suggests the increased randomness at the solid-solution interface during the adsorption of Cd on WSB as many literature results about various adsorbents and adsorbates have shown (Bascetin *et al*. 2003, Gupta *et al*. 2005).

3.6 Influence of initial Cd concentration

The effect of initial concentration on the adsorption of Cd using WSB was carried out at different initial Cd concentrations ranging from 0.1 to 3.0 mg/L, at pH 8, WSB 2 g, WSB particle size 251~355 μm, adsorption time 180 min and temperature 30°C, respectively.

As shown in Fig. 8, the initial Cd concentration was found to significantly affect the adsorption capacity. When the initial Cd concentration increased from 0.1 to 3.0 mg/L, the adsorption capacity of WSB increased from 0.01 to 1.34 mg/g. It can be seen that the Cd adsorption capacity increases almost linearly with increasing initial Cd concentration.

In some range of Cd concentration, these results corroborated the early research results for naphthalene by An *et al.* (2005). As the Cd concentration increases, the possibility of contact with WSB increases, which is more favorable for the adsorption process. These results can be explained that the initial concentration provides necessary driving force to overcome the resistance to the mass transfer between the aqueous and solid phase (Hameed *et al*. 2008).

3.7 Adsorption kinetics

Several kinetic models are available to explain the mechanism of solute adsorption and design an effluent treatment process. In order to examine adsorption kinetics of Cd on WSB, pseudo-first-order kinetic and pseudo-second-order kinetic models were considered to experimental data.

The pseudo-first-order kinetic model can be applied for the adsorption of solid/liquid systems. The integrated linear form is given by

$$log(q_e-q_t) = log q_e-(k_1t/2.303) \quad (4)$$

where q_t is the adsorption capacity at time t (mg/g) and k_1 (min^{-1}) is the rate constant. The value of k_1 and q_e can be determined from the slop and intercept of the log(q_e-q_t) versus t. Fig. 9 shows a plot log(q_e-q_t) versus t and the results are listed in Table 2.

Experimental data were also tested by the pseudo-second-order kinetic model. This model is based on the

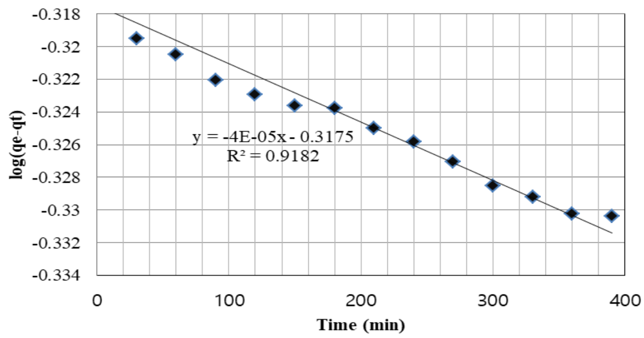

Fig. 9 Pseudo-first-order kinetic plot for the adsorption of Cd onto WSB (pH 8, initial Cd concentration 1.0 mg/L, WSB dose 2 g, adsorption time 180 min, WSB particle size 251~355 μm and temperature 30°C)

Table 2 A comparison of the pseudo-first-order and pseudo-second-order rate constants (pH 8.0, initial Cd concentration 1.0 mg/L, WSB dose 2 g, adsorption time 180 min, WSB particle size 251~355 μm and temperature 30°C)

Pseudo-first-order kinetic		Pseudo-second-order kinetic	
$k_1\times10^{-5}$ (min^{-1})	9.2	$k_2\times10^{-2}$ (g/mg min)	6.0
q_e (mg/g)	0.482	q_e (mg/g)	0.541
R^2	0.9180	R^2	0.9970

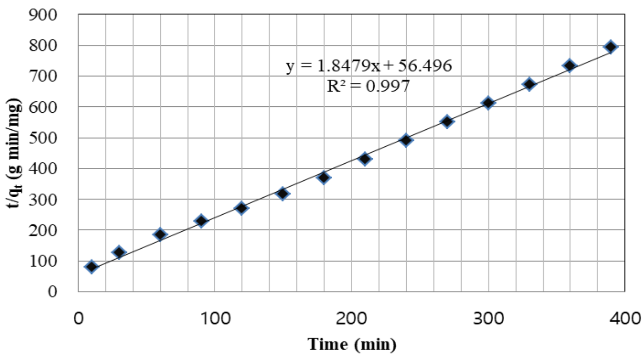

Fig. 10 Pseudo-second-order kinetic plot for the adsorption of Cd onto WSB (pH 8, initial Cd concentration 1.0 mg/L, WSB dose 2 g, adsorption time 180 min, WSB particle size 251~355 μm and temperature 30°C)

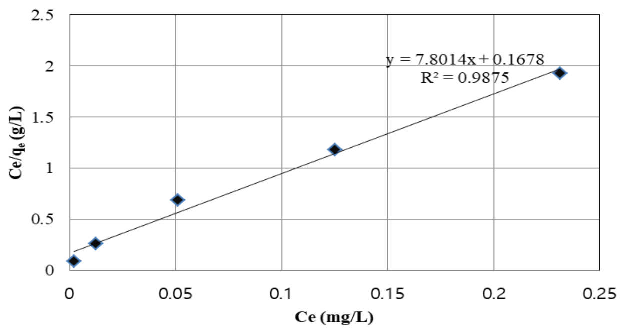

Fig. 11 The Langmuir sorption isotherm (pH 8, WSB dose 2 g, adsorption time 180 min, WSB particle size 251~355 μm and temperature 30°C)

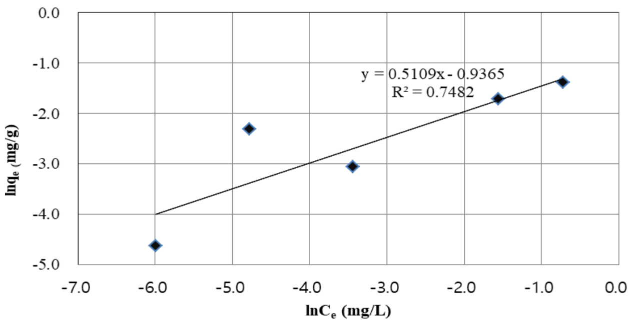

Fig. 12 The Freundlich sorption isotherm (pH 8, WSB dose 2 g, adsorption time 180 min, WSB particle size 251~355 μm and temperature 30°C)

Table 3 Adsorption isotherm constants for adsorption of Cd

Langmuir isotherm		Freundlich isotherm	
q_m (mg/g)	0.1282	K_F	0.3920
K_L (L/mg)	46.7085	n	1.9608
R^2	0.9870	R^2	0.7480

assumption that the adsorption follows second order chemisorption (Barka *et al*. 2010). The integrated linear form is given by

$$t/q_t = 1/(k_2 q_e^2) + 1/q_e t \qquad (5)$$

where k_2 is the pseudo-second-order rate constant (g/mg min). k_2 and q_e can be calculated from the intercept and slope of the plot of t/q_t against t. If the adsorption follows the second order, the plot of t/q_t and t should show a linear relationship. Fig. 10 shows a plot t/q_t versus t and the rate constant and correlation coefficient are also summarized in Table 2.

As shown in Table 2, pseudo-second-order kinetic model shows correlation coefficients of 0.9970 i.e., nearly equal to 1, therefore, the theoretical adsorption capacity was consistent with the experimental adsorption capacity for the pseudo-second-order kinetic model. In contrast, pseudo-first-order kinetic model shows lower value. From these results, it can be concluded that pseudo-second-order kinetic model has a better correlation of adsorption of cadmium by WSB than pseudo-first-order kinetic model.

3.8 Adsorption isotherms

Various adsorption isotherm models have been reported, but in this study Langmuir and Freundlich models, which are most commonly used model, are used to analyze the equilibrium adsorption of Cd onto WSB.

As shown in Figs. 11 and 12, the Langmuir isotherm model presented poor linearity. The constants of the Langmuir and Freundlich isotherms and correlation coefficients calculated from the data are summarized in Table 3. The correlation coefficients of the Langmuir and Freundlich model were calculated to be 0.9870 and 0.7480, respectively. Therefore, the Langmuir isotherm model is suitable for describing adsorption equilibrium of Cd by WSB. The Langmuir adsorption capacity of weathered sand of basalt for the uptake of Cd was found to be 0.1282 mg/g.

3.9 Other studies to remove low concentration of Cd

Table 4 summarizes the maximum Cd removal capacities of various adsorbents tested at Cd concentrations that are the same or similar to the Cd concentrations tested in this study, i.e., 1 mg/L. A direct comparison of WSB with other adsorbents for Cd removal may be difficult because of the different experimental conditions. However, judging from the initial concentration and the maximum Cd removal efficiency, it can be concluded that the WSB may be sufficiently available as a potential adsorbent for Cd removal.

4. Conclusions

The adsorption experimentals for the removal of Cd from aqueous solutions have been carried out using WSB. The adsorption process was a function of the contact time, pH, WSB dosage, particle size of the WSB, agitation speed,

Table 4 Adsorption of Cd by various adsorbents in low concentration

Adsorbent	Dosage	Initial conc.	Equilibrium time	Max. removal	References
Rice Husk	6 g/L	1.6 mg/L		60%	Munaf and Zein (1997)
Shrimp Shell	115 g/L	0.45 mg/L	10 min	92%	Yudhasasmita and Nugroho (2015)
Vermiculite	2 g/L	1 mg/L	4h	96%	Mathialagan and Viraraghavan (2003)
Giridih Coal	1 g/L	1 mg/L	24h	85%	Bhattacharya and Venkobachar (1984)
Coconut Shell	1 g/L	1 mg/L	24h	75%	Bhattacharya and Venkobachar (1984)
Peat	5 g/L	1 mg/L	2h	95%	Viraraghavan and Rao (1993)
Flyash	20 g/L	1 mg/L	3h	93%	Viraraghavan and Rao (1991)
Reed Leaves	20 g/L	1 mg/L	4h	92%	Sayrafi *et al*. (1966)
WSB	10 g/L	1 mg/L	3h	>99.9	This study

temperature and initial Cd concentration.

The adsorption equilibrium was achieved at 180 min. The optimal conditions for adsorption of Cd on each parameter were pH 8, WSB dose 2 g, adsorption time 180 min, WSB particle size 251~355 μm and temperature 30°C, respectively.

It revealed the maximum Cd adsorption capacity 0.50 mg/g and the maximum Cd removal efficiency adsorption capacity was over 99.9%.

Adsorption kinetic studies indicated that the pseudo-second-order kinetic model fits better than the pseudo-first-order kinetic model.

The adsorption isotherm data fits well for the Langmuir isotherm model with good correlation coefficient than Freundlich model.

Compared with the removal of low concentration Cd adsorption experiments using various adsorbents, it was found that WSB can be used as an available alternative adsorbent for Cd removal. Above all, the application of WSB for the Cd removal would be useful and effective since it can be easily acquired and used without any kind of modification.

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