Adsorption of As(V) from Aqueous Solution on Chitosan-Modified Diatomite

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Abstract: A novel chitosan (CS)-modified diatomite (Dt) was prepared by a simple mixture in the mass ratio to remove As(V) from aqueous solution in this research. The CS-modified Dt adsorbent was characterized by scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray powder diffraction (XRD) analysis. The parameters to influence the adsorption of As(V) ion were studied under such conditions as kinetics, adsorption isotherm, and pH effect. The results revealed that adsorption of As(V) was initially rapid and the equilibrium time was reached after 40 min. The optimal value of the pH was 5.0 for better adsorption. The equilibrium data were well fitted to the Langmuir isotherm compared to the Freundlich isotherm, and exhibited the highest capacity and removal efficiency of 94.3% under an initial As(V) concentration of 5 mg/L. The kinetic data were well described by the pseudo-second-order model. In addition, 0.1 M NaOH has the best desorption efficiency of As(V) adsorbed on CS-modified Dt, and the removal efficiency of As(V) was still higher than 90% when after six adsorption-desorption cycles. These results showed that the CS-modified Dt could be considered as a potential adsorbent for the removal of As(V) in aqueous solution.

Keywords: CS-modified Dt; As(V) ions; removal efficiency

1. Introduction

Water pollution is one of the most critical environmental problems at present, especially those involving heavy metal contamination which can adversely affect humans and animals [1–3]. In an aquatic environment most arsenic species are present as an inorganic oxyanion, namely arsenite (AsO₃³⁻ or As(III)) and arsenate (AsO₄³⁻ or As(V)), which are more toxic and harmful than its organic forms [4]. Under the oxidizing condition, As(III) is unstable and can be oxidized to As(V) [5]. Long-term arsenic exposure can result in serious threats to human health including cardiovascular disease, hepatosis, and even cancer [6]. Therefore, the World Health Organization have suggested the permissible limit of arsenic in drinking water as 0.01 mg/L while the permissible limit of arsenic in wastewater from industries restricted by the Ministry of Ecology and Environment of the People’s Republic of China is 0.5 mg/L before releasing to the environment. Owing to its hazard, the removal of inorganic As(V) from aqueous solution is very urgent.
Up to now, many treatment methods such as coagulation-flocculation [7], oxidation-precipitation [8], membrane filtration [9], ion exchange [10], and adsorption methods [11] have been applied to remove inorganic arsenic from water. Over the past decades, adsorption has become one of the most efficient and economical techniques among those methods [12]. Therefore, the research of low-cost adsorbents for arsenic removal from wastewater has attracted more interest.

Chitosan (CS) is a natural polymer compound, which possesses non-toxicity, biocompatibility, and biodegradation properties [13]. Due to the presence of active functional groups such as hydroxyl, amino groups, and glycosidic bond, CS displays a powerful adsorption performance toward heavy metal ions from aqueous solutions [14–18]. However, pure CS as an adsorbent has several disadvantages, including high cost and low chemical stability, which limits the further application of CS in wastewater treatment [19]. Immobilizing CS on a low-cost clay such as montmorillonite [20], bentonite [21], sand [22], perlite [23], and ceramic alumina [24] could reduce the required amount of CS without affecting the overall adsorption capacity. The CS-modified clay, therefore, has a practical use as a potential material to serve as a permeable reactive barrier in the treatment of contaminated surface water. Diatomite (Dt) is a siliceous rock made up largely from diatoms, which has a large number of natural, ordered pores and large specific surface area [25,26]. It is abundant in many areas such as China, the United States, Japan, Denmark, France, and Romania, and has a lower cost than CS. Therefore, Dt is an attractive immobilization material for CS owing to its low cost as well as its chemical and mechanical stability.

Hence the study focused on the modification Dt by Cs for As(V) removal from the aqueous solution. The structural and chemical characterization of CS-modified Dt were studied by various techniques such as SEM, FTIR, and XRD analysis. As(V) sorption experiment was studied by optimizing various adsorption parameters like contact time, solution pH, temperature, and dosage of adsorbents in batch mode. The adsorption isotherms and kinetics of As(V) ion adsorption for the CS-modified Dt were studied, and the desorption and reusability of the CS-modified Dt for adsorption As(V) were also investigated.

2. Materials and Methods

2.1. Materials

The raw Dt (92.8% SiO₂, 4.2% Al₂O₃, 1.5% Fe₂O₃, and other metal oxides) were purchased from Jilin Kaida Diatomite Co. Ltd (China). CS (95% deacetylated) was purchased from Shanghai Aladdin Bio-chem Technology Co. Ltd (China). Sodium arsenate (Na₃AsO₄·12H₂O) was obtained from Shanghai Chemical Reagent and Supply Station (China). All other chemical reagents were analytical grade and were thus used without further purification.

2.2. Preparation of CS-Modified Dt

The CS-modified Dt was prepared according to the report by Zhao [27]. Chitosan (CS) powder (2.5 g) was dissolved in 50 mL of 4% (v/v) acetic acid solution, and then Dt (5 g) was added and stirred until the mixture was homogeneous and gel-like. The CS-modified Dt was dried in an oven at 378 K for 4 h. After drying, the final product was ground and sieved using a 100 mesh sieve and then sealed as CS-modified Dt.

2.3. Characterization

The surface morphology was observed by SEM (Hitachi S-4800, Hitachi Company, Japan). The functional groups of Dt and CS-modified Dt were characterized by FTIR (Nexus 470, Thermo Nicolet, USA). The XRD (X’Pert PRO, PANalytical B. V, Netherlands) analysis was performed with Cu Kα radiation (λ = 0.154 nm) on a Rigaku X-ray diffractometer. BET (Brunauer–Emmett–Teller) surface area and BJH (Barrett–Joyner–Halenda) pore size distribution were measured by a specific surface analyzer (Micromeritics ASAP 2020, Norcross, GA, USA). The zeta potential of adsorbent was measured by Zetasizer Nano-Zeta potential analyzer (Malvern Instruments, Malvern, UK).
X-ray photoelectron spectroscopy (XPS) measurements were taken with a VG Escalab 250Xi (Thermofischer, MA, USA) spectrometer equipped with an Al-Kα = 1486.7 eV. The concentration of arsenic in samples was measured by AFS-9130 atomic fluorescence spectrometry (AFS) (Beijing Jitian, China).

### 2.4. Batch Adsorption Experiments

Batch adsorption experiments were conducted using the CS-modified Dt as an adsorbent. To determine the optimum values for sorbent dosage, pH of solution, contact time, and temperature, a series of preliminary experiments was performed. The specific experimental operation is as follows: 0.01–0.06 g CS-modified Dt was added to 100 ml of 5 mg/L solution of As(V). The pH of the solution was adjusted from 2 to 9 by 0.01 M HCl or NaOH solution, with contact time varying from 1 to 120 min and shaking at different temperatures (298 K, 308 K, and 318 K). The adsorption amounts and the removal efficiency were calculated by the following equation:

\[
Q_t = \frac{(C_0 - C_t)V}{m}, \quad (1)
\]

\[
Q_e = \frac{C_0 - C_e}{m}, \quad (2)
\]

Remove efficiency (%) = \( \frac{C_0 - C_e}{C_0} \times 100 \), \( (3) \)

where, \( Q_t, Q_e \) (mg/g) are adsorption capacity at time \( t \) and equilibrium, \( C_0, C_t, C_e \) (mg/L) are initial, time \( t \) and equilibrium concentrations of As(V), respectively, \( V \) (L) is volume of the aqueous solution, and \( m \) (mg) is the mass of adsorbent used in experiments.

To describe the results of As(V) ions binding onto CS-modified Dt, Langmuir and Freundlich isotherm models were adopted. The two isotherm models are typically expressed as follows:

\[
\frac{C_e}{Q_e} = \frac{C_m}{Q_m} + \frac{1}{K_f Q_m v}, \quad (4)
\]

\[
\ln Q_e = \ln K_f + \frac{1}{n} \ln C_e, \quad (5)
\]

where \( Q_t \) (mg/g) and \( C_e \) (mg/L) express the adsorption capacity of CS-modified Dt and the equilibrium concentration of the As(V) in the solution, \( Q_m \) (mg/g) is the maximum amount of the As(V) adsorbed, \( K_f \) is Langmuir adsorption coefficient, \( K_f \) is Freundlich adsorption coefficient, and \( n \) is Freundlich empirical constant.

To further examine the controlling mechanism of adsorption of As(V) ions onto CS-modified Dt, pseudo-first-order (PFO) and pseudo-second-order (PSO) kinetic models were used to test the obtained experimental data. The equations are given below:

\[
\ln(Q_e - Q_t) = \ln Q_e - K_t t, \quad (6)
\]

\[
t/Q_t = 1/(K_2 Q_e^2) + t/Q_e, \quad (7)
\]

where \( Q_t \) (mg/g) and \( Q_e \) (mg/g) are the amount of As(V) adsorption on the CS-modified Dt at \( t \) (min) and equilibrium, respectively, \( K_t \) and \( K_2 \) are the PFO and the PSO rate constant, respectively.

### 2.5. Desorption and Regeneration Studies

Adsorbent regeneration was conducted as follows: 100 ml of 5 mg/L solution of As(V) was contacted with 0.04 g of CS-modified Dt for 40 min at 298 K and pH 5. The mixture was filtered and adsorbed As(V) analyzed. Loaded adsorbents were thoroughly washed with deionized water, filtered and transferred to bottles containing desorbing agent (0.1 M NaOH, 0.1 M NaHCO₃, 0.1 M NaCl, 0.1 M HCl, and 0.1 M CH₃COOH) and shaken for 12 h at 298 K. A solution of 0.1 M NaOH was applied for adsorbent regeneration and the regeneration of CS-modified Dt was sequentially operated six adsorption-desorption cycles. Desorption ratio was calculated from the following equation:

\[
\text{Desorption efficiency} \% = \frac{(\text{As(V)desorbed})}{(\text{As(V)adsorbed})} \times 100. \quad (8)
\]
3. Results and Discussion

3.1. FTIR Analysis

Figure 1 shows the FTIR spectra of the raw Dt and CS-modified Dt. In Figure 1a, the main spectral peaks of functional groups are detected at 3697, 3621, 3432, 1635, 1383, 1090, 796, 690, and 468 cm⁻¹. The peaks at 3697, 3621, and 3432 cm⁻¹ are corresponding to the stretching vibrations of Al-OH, Si-OH, and H-OH [28,29]. The peak at 1635 cm⁻¹ is due to the bending vibration of H-OH [30]. The peak at 1383 cm⁻¹ is likely caused by the bending vibration of C–H [31]. The peak at 1090 cm⁻¹ is attributed to the anti-symmetrical stretching vibration of Si–O–Si [32]. The peaks at 796, 690, and 468 cm⁻¹ are the result of bending vibration by Si–O [30,33]. In Figure 1b, the peaks at 3697 and 3621 cm⁻¹ are disappeared and the peak at 3432 cm⁻¹ is broadened and enhanced, resulting from overlapping between the N–H and –OH stretching vibrations [27]. Compared to the spectrum of the raw Dt, there is a significant difference, with two new peaks appearing in the spectrum of the CS-modified Dt at 2924 and 1560 cm⁻¹ attributed to –CH₂ stretching vibration and –NH₂ bending vibration of the CS [34,35]. The peaks at 1635, 1090, and 1383 cm⁻¹ were shifted to 1640, 1093 and 1401 cm⁻¹, respectively. These changes could be attributed to a hydrogen bond interaction between Dt and CS [36]. Therefore, we speculate that Dt is successfully modified with CS [37].

Figure 2 shows the FTIR spectra of the CS-modified Dt and CS-modified Dt after adsorption. Comparing Figure 2a and Figure 2b, the peak at 3432 cm⁻¹ was shifted to 3435 cm⁻¹, the peak at 1640 cm⁻¹ was shifted to 1646 cm⁻¹, the peak at 1560 cm⁻¹ was shifted to 1602 cm⁻¹. It indicates that the adsorption of As(V) ions on the surface of CS-modified Dt are either through complexation or through the physical way which might be through weak electrostatic interaction and Van der Waals forces [38].

![Figure 1. The FTIR spectra of (a) raw diatomite and (b) chitosan (CS)-modified diatomite (Dt).](image1)

![Figure 2. The FTIR spectra of (a) CS-modified and (b) CS-modified Dt after adsorption.](image2)

3.2. SEM Images

The SEM images of the raw Dt and CS-modified Dt samples are presented in Figure 3. As can be seen in Figure 3a1, Dt morphology was clearly visible; the shape was mainly a disk structure
similar to that of a ceramic membrane. Its surface was smooth and flat, with abundant porous structures (Figure 3a2). As illustrated in Figure 3b1, the CS attached to the surface of the Dt did not change the porous structure of Dt. Moreover, surface of CS-modified Dt was rough presented in Figure 3b2. These findings indicated that Dt was successfully combined with Dt.

Figure 3. SEM images of raw Dt (a1,a2) and CS-modified Dt (b1,b2).

3.3. BET Analysis

According to the classification curve proposed by the IUPAC for adsorption isotherms, the isothermal curves of raw Dt and CS-modified Dt, illustrated in Figure 4 of (a) and (b) belonged to a type IV curve. The adsorption capacities of the two curves presented in the diagram were not equal to 0 in the extremely low-pressure range \( (P/P_0 < 0.01) \), and the increase of pressure promoted the adsorption capacity of CS-modified Dt to a greater degree than that of Dt. This outcome showed that both of them had micropore structures [39], and those of CS-modified Dt were more abundant because of modification that had occurred. As can be seen in Table 1, the average pore diameter of raw Dt and CS-modified Dt were 9.998 nm and 5.185 nm, respectively. The hysteresis of raw Dt and CS-modified Dt at a relative pressure \( (P/P_0) \) of 0.45–1 and 0.43–1, respectively, indicated that both samples had mesoporous properties [40]. The hysteretic loop of the type H3 in CS-modified Dt was more prominent, which might be due to the irregular slit pore formed on the surface of CS-modified Dt by the bulk heap formed by schistose CS [39].

As can be seen in Table 1, the BET surface area of CS-modified Dt, which was 148.251 m²/g, was 7.68 times greater than that of raw Dt (19.303 m²/g), which confirmed that the CS that adhered to the surface of Dt increased the specific surface area of CS-modified Dt. Meanwhile, the average pore diameter of CS-modified Dt was higher than that of raw Dt because of the modification. Given the large specific surface area and porous structure of CS-modified Dt, it could provide more adsorption sites and was a good adsorbent.
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Figure 4. N2 adsorption/desorption isotherms of (a) raw Dt and (b) CS-modified Dt (Insets are pore diameter distributions).

Table 1. Comparison of Brunauer–Emmett–Teller (BET) surface area and BJH (Barrett–Joyner–Halenda) average pore diameter of raw Dt and CS-modified Dt.

| Sample         | BET Surface Area (m²/g) | BJH Average Pore Diameter (nm) |
|----------------|-------------------------|-------------------------------|
| Dt             | 19.303                  | 9.998                         |
| CS-modified Dt | 148.251                 | 5.185                         |

3.4. Zeta Analysis

As shown in Figure 5, the zeta potential of Dt and CS-modified Dt decreased with the increase of the pH value. At pH < 3.76, the silanol (–Si–OH) of Dt was protonated and attained a positive charge under the form of –Si–OH⁺. By contrast, when pH > 3.76, –Si–OH⁻ started to deprotonate and showed negative charge in the form of –Si–O⁻ [41]. The pH of point of zero charge (pH_{pzc}) of Dt was 3.76. The pH_{pzc} of CS-modified Dt was 6.78. As such, the amino functionalization of CS increased the pH_{pzc} of CS-modified Dt [42]. CS-modified Dt exhibited a positive potential at pH < 6.78. However, a negative potential was observed at pH > 6.78. Hence, CS-modified Dt was a modified adsorbent that had the potential to adsorb anions in acidic environment and cations in the alkaline condition [39].

Figure 5. Zeta potential curves of Dt and CS-modified Dt.

3.5. XPS Analysis

X-ray photoelectron spectroscopy (XPS) wide-scan spectra of the Dt and CS-modified Dt are respectively shown in Figure 6 (1)a and (1)b. The signals with binding energies at 399.1 and 285.5 eV, attributable to the N 1s and C 1s species respectively [43,44], appeared in the XPS wide scan spectrum of the CS-modified Dt, clearly suggesting the successful immobilization of CS on the surface of Dt [45]. As shown in Figure 6(2)a, the peak at approximately 401.3 eV corresponds to the protonated N in CS (Ncs) [46]. In addition, the binding energy (BE) of Ncs is shifted to higher
values (Figure 6(2)b, BE = 402.1 eV) after As(V) adsorption. This finding indicates that the Ncs play an indispensable role in arsenic adsorption [47].

![Figure 6. XPS spectra of (1)a Dt, (1)b CS-modified Dt, (2)a N1s energy before adsorption, and (2)b N1s energy after adsorption.](image)

3.6. XRD Analysis

Figure 7 shows the X-ray powder diffraction pattern of (a) CS, (b) raw Dt, (c) CS-modified Dt, and (d) CS-modified Dt after adsorption. Figure 7(a) suggests that CS exhibited typical semi-crystalline properties (110) at its diffraction peak at 19.92° [JCPDS File No. 35-1974] [48]. Figure 7(b) suggests that the raw Dt consists mainly of silica (SiO$_2$) [49] with a little kaolin (Al$_2$Si$_2$O$_5$(OH)$_4$·2H$_2$O) [50], cristobalite [51], and montmorillonite [52]. The diffraction broad-bands observed in range of 18–32° may be attributed to the amorphous SiO$_2$ [53]. Comparing Figure 7(b) and Figure 7(c), the crystalline characteristic peak intensity of both Dt is much reduced, the characteristic diffraction peaks of cristobalite is almost disappeared, and the characteristic diffraction peak of CS (2θ = 19.92°) appears, which indicated that CS and Dt have formed a good interface attachment effect [39]. Figure 7(d) shows that the peak position of CS remains a constant except that the intensity of characteristic diffraction peak is slightly increased, indicating that the structure of CS-modified Dt has a certain stability, and the diffraction peak of arsenic-bearing substances appears, indicating that the CS has a certain adsorption effect on arsenic.
Figure 7. XRD patterns of (a) CS, (b) raw Dt, (c) CS-modified Dt, and (d) CS-modified Dt after adsorption.

3.7. Adsorption Analysis

3.7.1. Effect of Adsorbent Dosage

The adsorbent dosage determines the removal efficiency of an adsorbent in a fixed initial concentration of adsorbent. The effect of adsorbent amount on As(V) removal was investigated by changing the dosage from 0.1 to 0.6 g/L at an initial As(V) concentration of 5 mg/L. The results are shown in Figure 8 and as exhibits, by increasing the dose of CS-modified Dt, the removal of As(V) increased from 68.0% to 89.2%. It is noticed that the As(V) removal efficiency increased rapidly as the adsorbent dosage increased from 0.1 to 0.4 g/L, which may be due to that the active sites for binding target ions on the adsorbent surface was less at a lower dose of adsorbent [54]. When the dosage of the CS-modified Dt was more than 0.4 g/L, the removal efficiency increased relatively slowly, and the adsorption surface of CS-modified Dt might gradually reach the saturation state [35]. Therefore, considering As(V) removal and economy, 0.4 g/L is the optimal value of adsorbent dosage.

Figure 8. Effect of adsorbent dosage on the As(V) removal.

3.7.2. Effect of pH

The pH plays an important role on adsorbing metal ions, since it determines the degree of ionization and the surface charge of the adsorbent as well as the species of the adsorbate [55]. The effect of pH was investigated over a broad pH range of 2–9 with the dosage of adsorbent at 0.4 g/L and As(V) initial concentration 5 mg/L at room temperature (298 K). The results were shown in Figure 9. In the pH range of 2–3, the removal efficiency increases sharply as the pH increasing. The removal efficiency increases slightly at pH 3–5, decreases slightly at pH 5–7, and then decreases sharply at pH 7–9. The different removal behavior of As(V) on adsorbent can be explained by the distribution forms of As(V) at various pH values in Figure 10. As can be seen, As(V) exists mainly as neutral H₃AsO₄ species at pH 2, only physical adsorption driving forces between H₃AsO₄ and the sorbent were present, resulting in less adsorption. In the range of pH 3–7, the predominant species is H₂AsO₄⁻. The amount of H₂AsO₄⁻ reaches the maximum at pH 5, which leads to the strongest electrostatic interaction between H₂AsO₄⁻ and protonated-amino groups on the surface of CS-modified Dt [56], so that the removal efficiency reaches 83.2%. At pH 7–9, the main species are H₂AsO₄⁻ and HAsO₄²⁻, hence, the removal efficiency of As(V) decrease can be contributed partly to the competition between OH⁻ and negative charged As(V) anions (H₂AsO₄⁻, HAsO₄²⁻) [57]. The H₂AsO₄⁻ and HAsO₄²⁻ are difficult to be adsorbed on the surface of amino-deprotonated CS-modified Dt at higher pH values [40]. Therefore, the optimum pH for As(V) removal is 5.
3.7.3. Effect of Contact Time.

The effect of contact time on the removal efficiency of As(V) was investigated by varying the contact times from 2 to 120 min under the following conditions: 5 mg/L initial As(V) concentration, 0.4 g/L sorbent dosage, and temperature set at 298 K. As clearly seen from Figure 11, the removal efficiency of As(V) was rapid within the first 10 min, due to more availability adsorption sites and smaller mass transfer resistance on the adsorbent surface, and slowly increased with time until it reached saturation. The adsorption reached equilibrium in about 40 min. The observed removal efficiency was 94.3% at 40 min. The differences in the adsorption values after 40 min were very small. So, this duration was selected as the optimum contact time.

3.7.4. Adsorption Isotherm

In this work, the adsorption isotherms were obtained for the sorption of As(V) ions onto the CS-modified Dt by altering the initial concentration of the solution in the range of 2–10 mg/L under the optimized batch conditions. The linear fit of isotherms of Langmuir and Freundlich can be seen from Figure 12 and Table 2, the adsorption of As(V) by CS-modified Dt is better fitted by Langmuir
model as correlation coefficients \((R^2 > 0.99)\) were higher compared to Freundlich throughout the temperature ranges. Apparently, the adsorption occurred on the CS-modified Dt surface by monomolecular layer sorption \([58]\). Furthermore, the values of \(Q_m\) decreased with temperature increase which is in line with theoretical adsorption capacities of CS-modified Dt which ranged from 11.95 mg/g at 298 K to 9.83 mg/g at 318 K, which indicate the exothermic route of As(V) sorption onto CS-modified Dt \([54]\).

![Figure 12](image)

**Figure 12.** Adsorption isotherms for As(V) adsorption by CS-modified Dt (sorbent dosage: 0.4 g/L; contact Table 40. min; pH 5).

**Table 2.** Parameters of the Langmuir and Freundlich equation.

| T(K) | Langmuir | Freundlich |
|------|----------|------------|
|      | \(Q_m\)  | \(K_L\)    | \(R^2\)    | \(1/n\) | \(K_F\) | \(R^2\)    |
| 298  | 11.95    | 21.88      | 0.9999     | 0.17    | 10.03   | 0.8426     |
| 308  | 10.98    | 25.92      | 0.9999     | 0.15    | 9.27    | 0.7970     |
| 318  | 9.83     | 22.37      | 0.9999     | 0.14    | 8.33    | 0.7467     |

3.7.5. Adsorption Kinetics

The linear fit of kinetics of PFO and PSO can be seen from Figure 13 and Table 3, the PSO \((R^2 > 0.99)\) has a better fit than that of PFO model for the adsorption of As(V). Therefore, the adsorption data were well obeyed PSO kinetic model, which indicated that the adsorption rate mainly depended on chemisorption with exchange of ions on the arsenate and the protonated-amino \([59]\).

The adsorption mechanism is expressed as follows:

\[
\begin{align*}
(Dt@CS) - NH_2 + H_2O & \rightleftharpoons (Dt@CS) - NH_3^+ OH^- , \\
(Dt@CS) - NH_3^+ OH^- + Na^+H_nAsO_4^{(3-n)^-} & \rightleftharpoons (Dt@CS) - NH_3^+H_n AsO_4^{(3-n)^-} + Na^+OH^- \quad (n = 1, 2, 3).
\end{align*}
\]

![Figure 13](image)

**Figure 13.** Adsorption kinetic for As(V) adsorption by CS-modified Dt (sorbent dosage: 0.4 g/L; initial As(V) ions concentration: 5 mg/L; pH 5).
3.8. Desorption and Regeneration Analysis

Desorption of the adsorbed As(V) anions from the CS-modified Dt was also studied in a batch experimental system. Various factors are probably involved in determining efficiencies of As(V) desorption, such as the extent of hydration of the metal ions and sorbent microstructure. However, an important factor appears to be binding strength. Figure 14 (a) illustrates As(V) desorption with NaOH, NaHCO₃, HCl, NaCl, and CH₃COOH. According to results, 0.1 M NaOH showed the best desorption efficiency among all the solvents. In an alkaline solution the surface charge of CS-modified Dt possibly changed thereby causing detachment of the arsenic ions from the adsorbent. To show the reusability of the CS-modified Dt, adsorption-desorption cycle was repeated 6 times by using the same CS-modified Dt. As shown in Figure 14 (b), the removal efficiency still remained as 90.98% after six cycles. The result indicated that the prepared CS-modified Dt could be effectively used for wastewater treatment containing As(V) ions at least for 6 times.

![Figure 14](image)

**Figure 14.** (a) Effect of type of desorption solvent on the desorption rate. (b) The reusability of CS-modified Dt for removal of As(V) ions.

4. Conclusions

Chitosan (CS) is a great potential adsorbent for wastewater treatment. In this study, a novel CS-modified Dt sorbent was prepared and characterized by using SEM, FTIR, and XRD techniques, and the CS-modified Dt successfully applied as a novel biocomposite sorbent for the removal of As(V) ions from aqueous solution using the batch method. The maximum removal rate of the As(V) ions reached 94.3% with the optimum adsorbent dosage of 0.4 g/L, pH 5, and 40 min contact time at 298 K. It was found that the adsorption experiment data of CS-modified Dt fit well to the P–S–O kinetic model and Langmuir isotherm model, and the adsorption process of the As(V) ions onto the CS-modified Dt was based on monolayer chemical adsorption. Furthermore, the desorption efficiency reached 98.76% with 0.1 M NaOH as the desorbent. Most importantly, the data obtained in this study show that the removal efficiency of As(V) shows no significant decrease after six adsorption-desorption cycles. In summary, CS-modified Dt will be an environmental and cost-effective adsorbent applied in the fields of As(V) ions adsorption with strong removal efficiency and excellent stability.

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