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# Adsorption of phenolic compounds from aqueous solution using salicylic acid type adsorbent

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ABSTRACT

In this study, 5-aminosalicylic acid (5-ASA) was successfully grafted onto the poly(glycidyl methacrylate) (PGMA) macromolecular chains of PGMA/$SiO_2$ to obtain adsorbent ASA-PGMA/$SiO_2$. The adsorption properties of ASA-PGMA/$SiO_2$ for phenolic compounds were studied through batch and column methods. The experimental results showed that ASA-PGMA/$SiO_2$ possesses strong adsorption ability for phenolic compounds, and its adsorption capacity for phenol, 4-chlorophenol, and *p*-nitrophenol reaches 1.0, 1.1, and 1.32 mmol $g^{-1}$, respectively. In addition, pH has a great influence on the adsorption capacity. The adsorption isotherm data obeyed the Langmuir model well than Freundlich model. The desorption of phenolic compounds from the ASA-PGMA/$SiO_2$ adsorbent was most effectively achieved in a 0.1 mol $L^{-1}$ sodium hydroxide solution. Consecutive adsorption–desorption experiments showed that the ASA-PGMA/$SiO_2$ adsorbent could be reused almost without any loss in the adsorption capacity.



## 1. Introduction

Phenol and its derivatives are multipurpose raw materials in chemical industry and widely used or generated in many industries such as petroleum, chemicals, petrochemical, coal gasification and carbonization, pharmaceutical, wood, plastic, paper, textile, rubber, photographic, dye, disinfectant and pesticide industries [1,2]. However, they are also main pollutants in surface waters or groundwater. Phenol-contained wastewater can cause protein degradation, tissue erosion and paralysis of the central nervous system and can damage the kidney, liver and pancreas even at very low concentrations due to its high toxicity, poor biodegradability and accumulation in the environment. The Environmental Protection Agency (EPA) has listed phenol and its derivatives on the priority pollutants list. Therefore, it is necessary to remove phenolic pollutants from wastewaters before discharge into water bodies.

Various methods and technologies, such as biodegradation [3–5], photocatalytic degradation [6–8], chemical coagulation [9], chemical oxidation [10,11], solvent extraction [12,13], membrane separation [14,15], and adsorption with porous inorganic materials [16–20] and synthetic polymeric adsorbents [21–24], have been studied and employed to treat the phenol-contained wastewater. Among these methods and technologies, adsorption is still the most attractive and widely used. However, the porous inorganic materials have some disadvantages, such as lower adsorption capacity, higher operation costs, and lower regenerability and so on. Therefore, functional polymers microspheres or grafted polymers have been increasingly used as adsorbents for efficient treatment of phenol-contained wastewater because of the relatively lower cost, and effective in removing phenolic compounds from wastewaters even at low concentrations.

Among the polymerizable monomers, glycidyl methacrylate (GMA) is a commercial industrial material. Poly(glycidyl methacrylate) (PGMA) has good mechanical strength, sustained acid and base resistance, ease of porosity formation, and high reactivity of the epoxy group. Thus, numerous chelating resins have been successfully prepared via an epoxy group reaction of PGMA with amines except 5-aminosalicylic acid (5-ASA) [25–31]. As regards the chemical structure, 5-ASA possesses one carboxyl, one hydroxyl, and one amine group that can form hydrogen bond interaction with hydroxyl of phenol. Furthermore, 5-ASA can be easily introduced to the side chain of a polymer owing to the reactive amine hydrogen that responds to the epoxy groups.

In this study, the chemical structure of the adsorbent was well designed. First, GMA was grafted onto the silica gel surface to obtain the PGMA/$SiO_2$ composite material. Then, the adsorbent ASA-PGMA/$SiO_2$ was obtained through ring-opening reactions between the amine of 5-ASA and the epoxide rings of PGMA. This novel adsorbent ASA-PGMA/$SiO_2$ possesses not only higher functionality than silica gel, but also higher chemical and mechanical property than PGMA microsphere. The adsorption ability and adsorption kinetic to phenolic compounds were investigated using batch and column methods.

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## 2. Experimental

### 2.1. Materials and instruments

Silica was purchased from the Ocean Chemical Company, Ltd. (120–160 mesh, about 125 μm in diameter, pore size: 6 nm, pore volume: 1.0 mL $g^{-1}$, surface area: 350 $m^2$ $g^{-1}$, Qingdao, China). Glycidyl methacrylate (GMA) was purchased from Ruijinte Chemical Ltd. (Tianjin, China, AR grade and purified by distillation under vacuum. 3-methacryloylpropyl trimethoxysilane (MPS) was purchased from Nanking Chuangshi Chemical Aux Ltd. (Jiangsu, China, AR grade). Azoisobutyronitrile (AIBN) was purchased from Shanghai Chemical Reagent Plant (Shanghai, China, AR grade). AIBN was recrystallized before use. 5-aminosalicylic acid (5-ASA) and other reagents were purchased from Beijing Chemical Plant (Beijing, China, AR grade). Phenol and other chemicals were purchased from the Beijing Chemical Plant (Beijing, China, AR grade).

Instruments used in this study were as follows: STA449 thermogravimetric analyzer (TGA, Netzsch Company, Germany), Perkin-Elmer1700 infrared spectrometer (Perkin-Elmer Company, American), Unic-2602 UV–vis spectrophotometer (Unic Company, American), PHS-2 acidimeter (The Second Analytical Instrument Factory of Shanghai, China), THZ-92C constant temperature shaker (Boxun Medical Treatment Equipment Factory of Shanghai, China), 438VP scanning electron microscope (LEO Company, England), and NOVA3000 surface area analyzer (Beishide Instrument-S&T. Co., Ltd.).

### 2.2. Preparation and characterization of adsorbent ASA-PGMA/$SiO_2$

To prepare the adsorbent ASA-PGMA/$SiO_2$, 10 g of silica gel particles activated with methane sulfoacid and 15 mL of coupling agent MPS were added into 200 mL of a mixed solvent of ethanol and water (V/V = 1:1). The contents were maintained for 24 h at 50 °C, resulting in the formation of the surface-modified particles MPS-$SiO_2$, on which polymerizable double bonds were attached chemically. Afterwards, 6 g of particles MPS-$SiO_2$ and 20 mL of GMA were added into 400 mL of dimethyl formamide (DMF). Graft polymerization was performed by initiating of AIBN (1.4 wt% of monomer) under $N_2$ atmosphere at 70 °C for 24 h. The product particles were extracted with acetone in a Soxhlet apparatus to remove the polymers attaching physically onto the particles and then dried under vacuum, and finally the composite material PGMA/$SiO_2$ were gained. Subsequently, 1 g of PGMA/$SiO_2$ and 6 g of 5-ASA were added into 100 ml of sodium hydroxide aqueous solution with pH of 12. The ring-opening reaction between the amine of 5-ASA and the epoxide ring of PGMA was allowed to take place at 80 °C for 24 h, and finally, the adsorbent ASA-PGMA/$SiO_2$ was obtained. The preparation processe of ASA-PGMA/$SiO_2$ is expressed in Scheme 1. The grafting degree of ASA-PGMA/$SiO_2$ was determined by the TGA method and surface area was determined by the NOVA3000 surface area analyzer. The ASA-PGMA/$SiO_2$ used in this study have a grafting degree of 0.168 g $g^{-1}$ and surface area of 342 $m^2$ $g^{-1}$.

### 2.3. Batch adsorption

#### 2.3.1. Measurement of kinetic adsorption curve

About 0.01 g of ASA-PGMA/$SiO_2$ and 25 ml of aqueous metal ion solution with an initial concentration ($C_0$) of 1 mmol $L^{-1}$ (pH of 6) were directly introduced into a conical flask. This conical flask was placed into a shaker at a presettled temperature and then shaken. At different time, the concentration ($C_t$) of phenol solution was determined by UV analysis performed on a UV–vis spectrophotometer with the wavelength at 270 nm (*p*-nitrophenol at 314 nm, 4-chlorophenol at 228 nm). The adsorption capacity (Q) was calculated according to the following equation.

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

where $Q$ (mmol $g^{-1}$) is the adsorption capacity; $V$ (L) is the volume of the solution; $m$ (g) is the weight of the absorbent ASA-PGMA/$SiO_2$.

#### 2.3.2. Measurement of adsorption isotherm

About 0.01 g of ASA-PGMA/$SiO_2$ and 25 ml aqueous solution of metal ion with different initial concentrations ($C_0$ = 0.2, 0.4, 0.6, 0.8 and 1 mmol $L^{-1}$) and the same pH of 6 were directly introduced into several conical flasks. These conical flasks were placed into a shaker at a presettled temperature and then shaken. After reaching the adsorption equilibrium (10 h), the equilibrium concentration ($C_e$) was determined by UV analysis performed on a UV–vis spectrophotometer. The equilibrium adsorption capacity ($Q_e$) was calculated according to the following equation.

$$Q_e = \frac{V(C_0 - C_e)}{m} \quad (2)$$

### 2.4. Column adsorption and elution experiment

In the column experiment, 1.2514 g of ASA-PGMA/$SiO_2$ was placed in a glass column 8 mm in diameter and with a bed volume (BV) of 2 ml. The phenol solution with concentration of 1 mmol $L^{-1}$ and pH of 6 was allowed to flow gradually through the column at a rate of five bed volumes per hour (5 BV $h^{-1}$). The effluent with one bed volume was collected, the concentration of phenol was determined, and the dynamics adsorption curve was measured. The leaking adsorption capacity and the saturated adsorption capacity were also calculated.

The elution experiment was performed using sodium hydroxide solution with a concentration of 0.01 mol $L^{-1}$ as eluting agent. The flow rate of the eluting agent was controlled at 1 BV $h^{-1}$. The eluent with one bed volume was collected, the concentration was determined, and the elution curve was plotted.

### 2.5. Repeated use experiment

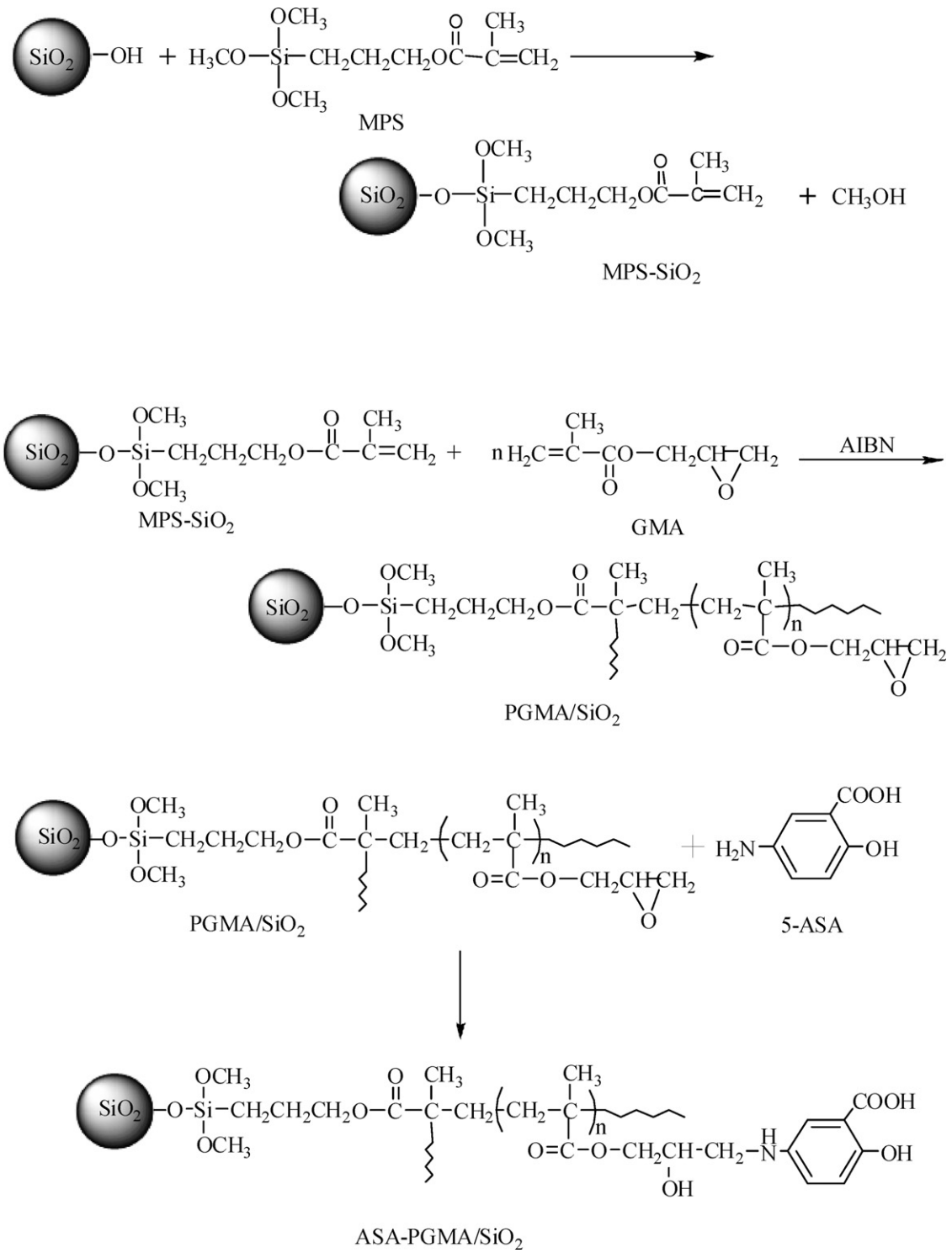
Repeated usability (i.e., regenerability) is an important factor for an effective absorbent. Desorption of the adsorbed phenol from ASA-PGMA/$SiO_2$ was also studied by batch experiment using 0.1 mol $L^{-1}$ of sodium hydroxide solution as eluent. The ASA-PGMA/$SiO_2$ adsorbed phenol was placed in the eluent and stirred continuously at room temperature (20 °C) for 5 h. The final concentration of aqueous phase was determined. Desorption ratio was calculated from the capacity and final concentration in the eluent. In order to test the reusability of ASA-PGMA/$SiO_2$, adsorption–desorption procedure was repeated 10 times using the same ASA-PGMA/$SiO_2$.

## 3. Results and discussion

### 3.1. Preparation and characterization of adsorbent ASA-PGMA/$SiO_2$

To confirm the effectiveness of PGMA grafting onto the silica gel and 5-ASA grafting onto the PGMA/$SiO_2$, the FTIR spectra of the $SiO_2$, MPS-$SiO_2$, PGMA/$SiO_2$ and ASA-PGMA/$SiO_2$ were obtained through FTIR spectrometers and shown in Fig. 1.

In the infrared spectrum of PGMA/$SiO_2$, the characteristics absorptions of epoxide rings appear at 905 $cm^{-1}$, and the characteristics absorptions of carbonyl group at 1732 $cm^{-1}$ was enhanced.




**Scheme 1.** Synthesis process of adsorbent ASA-PGMA/$SiO_2$.

These show that PGMA macromolecules have been grafted onto the silica gel surface, and PGMA/$SiO_2$ has been formed.

The characteristics absorptions of benzene ring appear at 1485 $cm^{-1}$ and 1589 $cm^{-1}$, respectively, the characteristics absorptions of bend vibration of C–N bond appear at 1408 $cm^{-1}$, the characteristics absorptions of epoxide rings at 905 $cm^{-1}$ was disappeared, and the characteristics absorptions of N–H bond at 3492 $cm^{-1}$ was enhanced. These show that 5-ASA has been reacted with PGMA of PGMA/$SiO_2$, and ASA-PGMA/$SiO_2$ has been formed.

Fig. 2 is the SEM of $SiO_2$ and ASA-PGMA/$SiO_2$. It can be seen that the surface of ASA-PGMA/$SiO_2$ is smoother than that of $SiO_2$. This implied that the macromolecular was grafted onto the silica gel surface.

### 3.2. Kinetic adsorption curve

The kinetic adsorption curve is shown in Fig. 3. The adsorption reached to equilibrium at 10 h, and the saturated adsorption

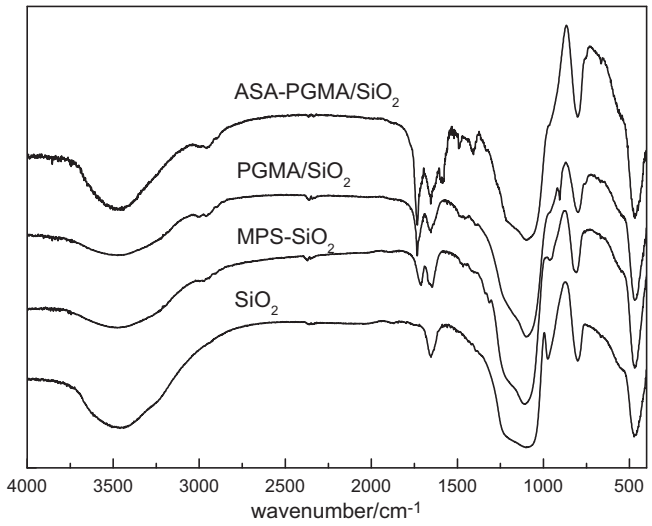



**Fig. 1.** FTIR spectra of every microgranules.

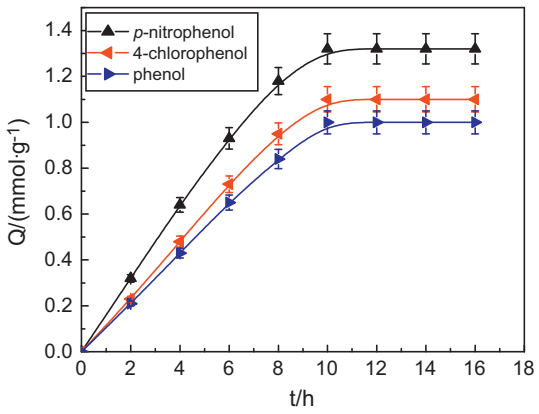



**Fig. 3.** Kinetic adsorption curve of ASA-PGMA/$SiO_2$ for phenolic compounds Temperature: 20 °C; pH = 6.

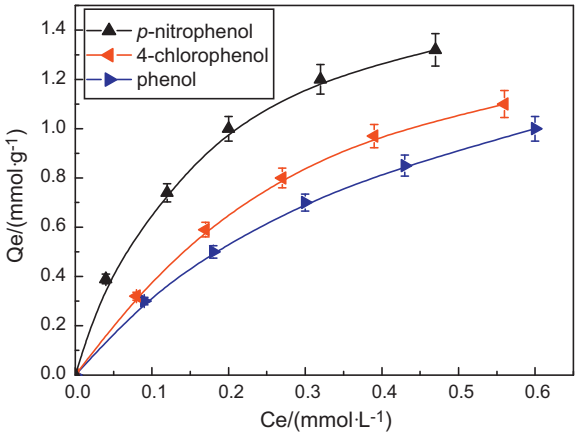



**Fig. 4.** Adsorption isotherms of ASA-PGMA/$SiO_2$ for phenolic compounds Temperature: 20 °C; Adsorption time: 10 h; pH = 6.

capacity for phenol, 4-chlorophenol and *p*-nitrophenol reached 1.0, 1.1, and 1.32 mmol $g^{-1}$, respectively. The adsorption capacity (94 mg $g^{-1}$) of ASA-PGMA/$SiO_2$ for phenol is higher than that of other adsorbents, such as zeolite (0.25 mg $g^{-1}$) [16], Hap nanopowders (0.2–10.3 mg $g^{-1}$) [19], and tirebolu bentonite (8 mg $g^{-1}$) [20]. The absorbent ASA-PGMA/$SiO_2$ clearly has very strong adsorption ability and high affinity for phenolic compounds. This can be attributed mainly to the hydrogen bond interaction between the 5-ASA on ASA-PGMA/$SiO_2$ and phenolic compound, and the interaction mechanism will be discussed below. In addition, the adsorption capacity for 4-chlorophenol and *p*-nitrophenol is higher than phenol; this is due to the –Cl and –$NO_2$ as acceptor of hydrogen bond in 4-chlorophenol and *p*-nitrophenol molecule.

Additional, the surface area of ASA-PGMA/$SiO_2$ (342 $m^2$ $g^{-1}$) is accordant to that of PGMA/$SiO_2$ (350 $m^2$ $g^{-1}$). This indicated again that the main adsorption force is not the higher surface area but the hydrogen bond interaction.

### 3.3. Adsorption isotherm

The adsorption isotherms of ASA-PGMA/$SiO_2$ for phenol, 4-chlorophenol and *p*-nitrophenol are shown in Fig. 4. It can be seen that the equilibrium adsorption capacity increases rapidly with the increase of the equilibrium concentrations. This also implied that ASA-PGMA/$SiO_2$ possesses very strong adsorption ability and high affinity for phenolic compounds.

Freundlich adsorption equation and its logarithms form are follows:

$$Q_e = kC_e^{1/n} \quad (3)$$

$$\mathrm{Ln}\, Q_e = \mathrm{Ln}\, k + \frac{1}{n}\mathrm{Ln}\, C_e \quad (4)$$

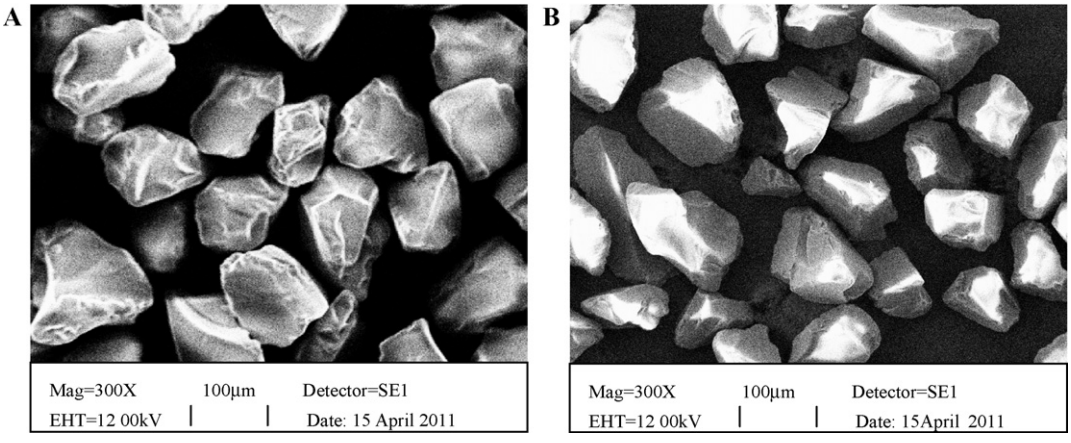



**Fig. 2.** SEM of $SiO_2$(A) and ASA-PGMA/$SiO_2$ (B).

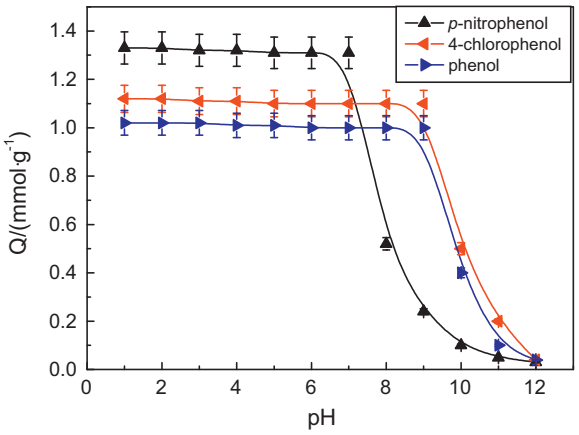



**Fig. 5.** The influence of pH on the adsorption capacity. Temperature, 20 °C; adsorption time, 10 h.

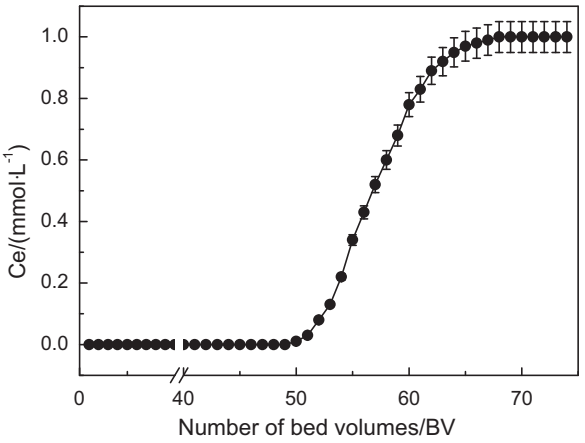



**Fig. 6.** Breakthrough curve of phenol on ASA-PGMA/$SiO_2$ column. Temperature, 20 °C; pH = 6.

Langmuir adsorption equation is as follows:

$$Q_e = Q_m \frac{bC_e}{1 + bC_e} \quad (5)$$

$$\frac{C_e}{Q_e} = \frac{C_e}{Q_m} + \frac{1}{bQ_m} \quad (6)$$

where $Q_m$ (mmol $g^{-1}$) is the saturated adsorption capacity; $b$ is the combine constant.

The data in Fig. 3 are treated using Freundlich adsorption equation and Langmuir adsorption equation, and the related constant and linear regression coefficient is displayed in Table 1.

It can be seen that the combine constant ($b$ and $k$) of Langmuir adsorption equation and Freundlich adsorption equation is increase in the sequence of phenol, 4-chlorophenol, *p*-nitrophenol, and this order is in accord with the order of adsorption capacity. The linear regression coefficient is very close to 1. This indicated that the adsorption of ASA-PGMA/$SiO_2$ for phenolic compounds is a typical monomolecular adsorption.

### 3.4. The influence of pH value on adsorption capacity

Fig. 5 shows the adsorption performances of ASA-PGMA/$SiO_2$ for phenol, 4-chlorophenol and *p*-nitrophenol at different solution pH values.

Obviously, the pH has a great influence on the adsorption capacity of ASA-PGMA/$SiO_2$ for phenolic compounds. With increasing pH value, the adsorption capacity of ASA-PGMA/$SiO_2$ for phenol does not change obviously at first, but decreases sharply after pH 9. The same trend appeared for 4-chlorophenol and *p*-nitrophenol, but the turning point is pH 9 and 7, respectively. The turning point is relevant with its p$K_a$ value.

There are hydrogen bond interaction and $\pi$–$\pi$ stacking interaction between ASA and phenols. As pH value is lower, there are lots of hydrogen ions $H^+$ in solution, and the carboxyl groups and hydroxyl groups do not dissociate. Under the driving of $\pi$–$\pi$ stacking interaction, hydrogen bond could be formed easily. So the adsorption ability is the strongest and the adsorption capacity is the highest. The dissociation degree of the carboxyl groups and hydroxyl groups is enhanced with the increases of pH value, resulting in weakening and decrease of hydrogen bond. So the adsorption capacity decline with the increase of pH value. When of solution goes beyond the p$K_a$ of phenols, hydroxyl groups of phenol were neutralized and phenols chiefly exist as negative phenolate ions. Therefore, hydrogen bond could not be formed although the weak $\pi$–$\pi$ stacking interaction still exists. So adsorption capacity is very low.

The low adsorption capacity at high pH value indicates that the spent absorbent can be regenerated in strong basic solution.

### 3.5. Dynamic adsorption curve

Fig. 6 shows the dynamic adsorption curve of ASA-PGMA/$SiO_2$ for phenol. It can found that when solution passes through the column packed with ASA-PGMA/$SiO_2$ at a flow rate of 5 bed volumes per hour (5 BV $h^{-1}$) upstream, the leaking appears at 50 BV, the leaking adsorption capacity to be calculated is 0.78 mmol $g^{-1}$, and the saturated adsorption capacity is 0.99 mmol $g^{-1}$ that analogous to the static adsorption result.

### 3.6. Elution curve

Good desorption performance of an adsorbent is important in its potential practical applications. From the results in Fig. 4, it has been found that the ASA-PGMA/$SiO_2$ did not adsorb phenols as pH > 12, suggesting that the adsorbed phenols on the ASA-PGMA/$SiO_2$ may be desorbed in strong basic solution with a pH value of 12. Sodium hydroxide solution with a concentration of 0.01 mol $L^{-1}$ is used as the eluent, and the eluent at a rate of 1 BV $h^{-1}$ flows upstream through the column of ASA-PGMA/$SiO_2$ on which the adsorption of phenol has reached to saturation. The elution curve of ASA-PGMA/$SiO_2$ is shown in Fig. 7, and desorption ratio was calculated as follow:

$$\text{Desorption ratio} = \frac{\text{amount of phenol desorbed to the elution medium}}{\text{amount of phenol sorbed on absorbent}} \times 100\% \quad (7)$$

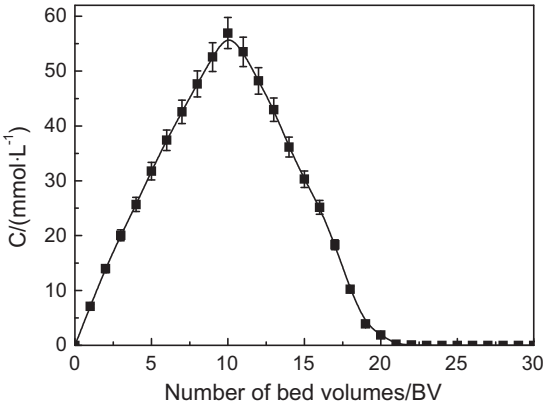



**Fig. 7.** Elution curve of ASA-PGMA/$SiO_2$. Temperature, 20 °C.

**Table 1**
The related constant and linear regression coefficient of Langmuir–Freundlich fitting.

| Fitting model | Parameter | Uncertainty | Adsorbate | | |
|---|---|---|---|---|---|
| | | | Phenol | 4-Chlorophenol | *p*-Nitrophenol |
| Langmuir | $b$ | ±0.5% | 2.76 | 3.40 | 7.23 |
| | $R^2$ | | 0.9924 | 0.9973 | 0.9986 |
| Freundlich | $k$ | ±0.5% | 2.08 | 1.70 | 1.51 |
| | $n$ | ±0.5% | 1.59 | 1.66 | 2.00 |
| | $R^2$ | | 0.9811 | 0.9799 | 0.9768 |

It can be seen that the shape of desorption curve is cuspate and without tailing, and it shows fine elution result. The calculation results show that within 18 and 22 bed volumes, phenol is eluted from ASA-PGMA/$SiO_2$ column with a desorption ratio of 95.29% and 97.93%, respectively. The fact reveals fully that ASA-PGMA/$SiO_2$ has outstanding elution property, and this novel adsorbent ASA-PGMA/$SiO_2$ has excellent reusing property.

### 3.7. Reusability

In order to show the reusability of ASA-PGMA/$SiO_2$, adsorption-desorption cycle was repeated 10 times by using the same material.

Adsorption–desorption cycle of ASA-PGMA/$SiO_2$ is shown in Fig. 8. The results clearly showed that the ASA-PGMA/$SiO_2$ could be used repeatedly without significantly loosing its adsorption amount.

### 3.8. Real sample analysis

To demonstrate its potentially application value, the adsorbent ASA-PGMA/$SiO_2$ was used to dispose there kinds of wastewater by batch method, such as wastewater containing phenol (10.5 mmol $L^{-1}$) and formaldehyde (11.2 mmol $L^{-1}$) from bakelite plant, wastewater containing 4-chlorophenol (5.22 mmol $L^{-1}$) and phosazetim (3.14 mmol $L^{-1}$) from pesticide plant, and wastewater containing *p*-nitrophenol (2.84 mmol $L^{-1}$) and phenacetinum (1.06 mmol $L^{-1}$) from pharmaceutical factory.

In the batch study, 200 mL of wastewater was disposed using the adsorbent ASA-PGMA/$SiO_2$. The removal rate ($R$) was calculated according to the following equation and shown in Figs. 9–11.

$$R = \frac{C_0 - C_e}{C_0} \quad (8)$$

For 200 mL of wastewater containing phenol and formaldehyde, the removal rate of ASA-PGMA/$SiO_2$ for phenol could reach 98.0%

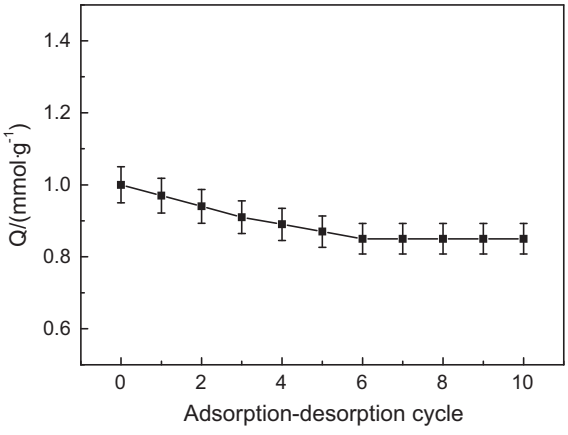



**Fig. 8.** Adsorption–desorption cycle of ASA-PGMA/$SiO_2$.

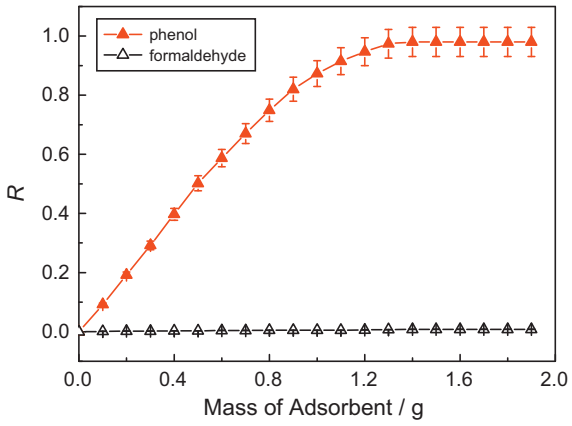



**Fig. 9.** The removal rate curve for phenol and formaldehyde.

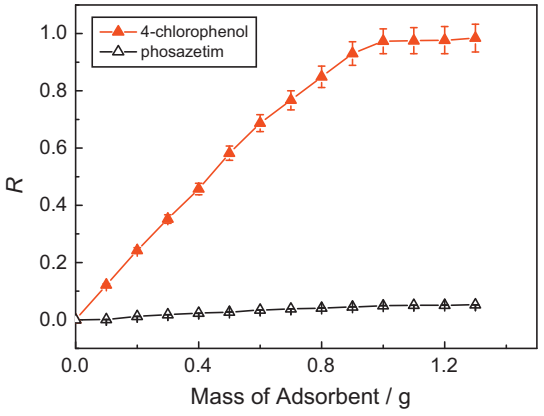



**Fig. 10.** The removal rate curve for 4-chlorophenol and phosazetim.

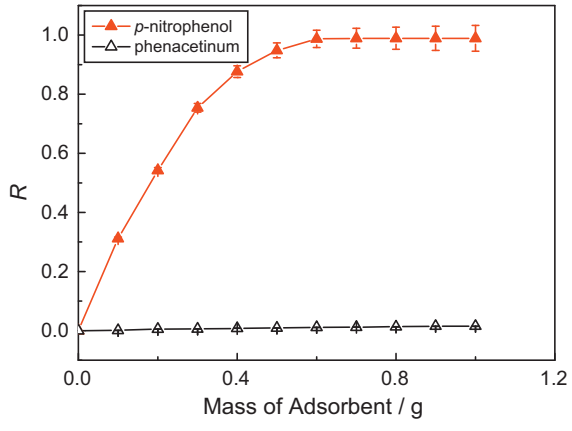



**Fig. 11.** The removal rate curve for *p*-nitrophenol and phenacetinum.

**Table 2**
Distribution coefficient and selectivity coefficient data of ASA-PGMA/$SiO_2$.

| $K_d$/(L g$^{-1}$) | | $k$ | $K_d$/(L g$^{-1}$) | | $k$ | $K_d$/(L g$^{-1}$) | | $k$ |
|---|---|---|---|---|---|---|---|---|
| Phenol | Formaldehyde | | 4-Chlorophenol | Phosazetim | | *p*-Nitrophenol | phenacetinum | |
| 1.24 | 0.06 | 20.67 | 3.84 | 0.26 | 14.77 | 4.62 | 0.11 | 42.00 |

when 1.4 g of ASA-PGMA/$SiO_2$ was used, while the removal rate for formaldehyde is very low ($R < 0.9\%$).

For 200 mL of wastewater containing 4-chlorophenol and phosazetim, the removal rate of ASA-PGMA/$SiO_2$ for 4-chlorophenol could reach 97.3% when 1.0 g of ASA-PGMA/$SiO_2$ was used, while the removal rate for phosazetim is very low ($R < 5\%$).

For 200 mL of wastewater containing *p*-nitrophenol and phenacetinum, the removal rate of ASA-PGMA/$SiO_2$ for *p*-nitrophenol could reach 98.7% when 0.6 g of ASA-PGMA/$SiO_2$ was used, while the removal rate for phenacetinum is very low ($R < 2\%$).

This result clearly shows that ASA-PGMA/$SiO_2$ could adsorb selectively phenol, 4-chlorophenol and *p*-nitrophenol from wastewater, and possesses potential application value.

The adsorption capacity towards phenol, 4-chlorophenol and *p*-nitrophenol is very high, but the adsorption capacity towards another competitor species is very low. This indicated that the ASA-PGMA/$SiO_2$ has excellent selectivity.

In order to show further the selectivity of ASA-PGMA/$SiO_2$ for every target molecular, distribution coefficients ($K_d$) were calculated by Eq. (9) [32].

$$K_d = \frac{Q_e}{C_e} \tag{9}$$

The selectivity coefficient ($k$) of ASA-PGMA/$SiO_2$ for every target molecular ($A$) with respect to the competitor species ($B$) can be obtained according to Eq. (10),

$$k = \frac{K_d(A)}{K_d(B)} \tag{10}$$

Table 2 summarizes the data of the distribution coefficients $K_d$ and selectivity coefficients $k$.

It could be seen that the distribution coefficient towards target molecular is larger than that towards competitor species, and the selectivity coefficient ($k$) is very large. This indicated again that ASA-PGMA/$SiO_2$ has excellent selectivity.

## 4. Conclusions

In this study, macromolecule poly(glycidyl methacrylate) was grafted onto micron-sized silica gel to prepare the PGMA/$SiO_2$. And then the novel adsorbent ASA-PGMA/$SiO_2$ was successfully obtained through ring-opening reactions between amine of 5-ASA and epoxide rings of poly(glycidyl methacrylate). ASA-PGMA/$SiO_2$ has very strong adsorption ability for phenols. The adsorption ability of ASA-PGMA/$SiO_2$ for phenols is largely dependent on pH value of solution. This study shows that ASA-PGMA/$SiO_2$ could dispose wastewater containing phenols. Additional, ASA-PGMA/$SiO_2$ has excellent reusability and high selectivity.

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