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Poly(ethyleneimine)-Loaded Silica Monolith with a Hierarchical Pore Structure for H₂S Adsorptive Removal

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Poly(ethyleneimine) (PEI) loaded hierarchical porous silica monolith has been developed as a recycle H₂S sorbent at low temperature. The sorbent was characterized by N₂ adsorption, scanning electron microscope, transmission electron microscope, Fourier transform infrared spectra, and activity tests. The effects of the amount of PEI loading, the operating temperature, and the PEI polymerization degree on H₂S removal were studied. The sorbent demonstrated a large H₂S breakthrough capacity of 1.27 mmol of H₂S/(g of sorbent) at 22 °C, which is about 60% larger than that of PEI-loaded SBA-15 or MCM-41 sorbent. The optimal PEI loading is 65 wt %, and the most ideal PEI molecular weight is 600. As the decrease of the temperature, the sorption performance of the sorbent increases greatly. There are two important factors affecting the performance of H₂S sorption: the amount of available PEI in the sorbent and the interaction between H₂S and amine functional groups of PEI. In addition, the developed sorbent can be regenerated easily at 75 °C, and it exhibits excellent regenerability and stability. These results indicate that PEI-loaded hierarchical porous silica sorbent will be promising for removing H₂S in the future.

1. Introduction

H₂S is one of the major toxic and malodorous gases from various industrial gas streams such as natural gas, coal gasification gas, and hydrogen gas.^{1–3} Governments are constantly tightening regulations to limit the emission of sulfur compounds into air, which makes it necessary to improve the desulfurization processes. For high concentration of H₂S removal, amine scrubbing^{4,5} along with the Claus process^{6,7} is the dominant technology currently used in industry. For low concentration of H₂S, the method of catalytic oxidation of H₂S over alkali-impregnated activated carbons is usually employed, due to the high activity and fast kinetic of reaction.^{8–10} In this process, H₂S can be oxidized to elemental sulfur and sulfate, which are mainly deposited into the pores of the catalysts.^{11–13} However, one of the disadvantages of this catalytic oxidation method is the difficult regeneration of the spent catalysts, since the removal of elemental sulfur and sulfate from the catalysts is very complex and uneconomical.^{14,15} Therefore, searching for a desulfurization agent with large sulfur capacity and good regeneration performance is challenging and very meaningful in industry.

Recently, a new method based on the chemical sorption was proposed for recycle H₂S removal by Song et al.^{16–18} The sorbent was prepared by loading poly(ethylenimine) (PEI) on the ordered mesoporous silica (SBA-15 or MCM-41), which exhibited high capacity and could be regenerated easily. The key point of this sorbent is that the alkaline polymer, PEI, could efficiently and reversibly react with H₂S, while the mesopores serve as the storehouse for PEI and the reactor for H₂S sorption. However, there are still some shortcomings for this sorbent, especially with respect to the supporting materials, which limit its large-scale application in industry. First, the ordered mesoporous silica is mostly in the form of powder,¹⁹ which is hardly used in fixed beds because of the huge pressure drop. Second, the pore volumes of these ordered mesopores silica are relatively small (only about 1 cm³/g),^{17,20,21} restricting the amount of PEI

loading and limiting the sorption capacities for H₂S. Lastly, these ordered mesoporous silica generally contain the cylindrical mesopores below 7 nm in size without larger textural pores, limiting their applications where mass transfer and diffusion are crucial. A hierarchical structure of multiscaled pores has obvious advantages over the ordered mesopores in terms of diffusion efficiency, accessibility to the pores by guest species, and large pore volumes.^{22–25}

In this work, PEI-loaded hierarchical porous silica has been developed as a highly efficient H₂S sorbent. The porous silica was prepared by a simple sol–gel approach from tetraethoxysilane and poly(ethylene glycol) followed by ambient drying. It can be easily formed into the shapes of monolith which can be directly used in the fixed bed without any shaping process. The hierarchical porous silica sorbent exhibited a large H₂S breakthrough sulfur capacity up to 1.27 mmol of H₂S/g and an excellent regeneration performance. These outstanding properties of the hierarchical porous silica sorbent make it more promising in industry application.

2. Experimental Section

2.1. Preparation of the H₂S Sorbent. The hierarchical porous silica (HPS) was prepared through a sol–gel method following procedures reported by Smatt et al.²² In a typical example, poly(ethylene glycol) (PEG, Sigma-Aldrich, *M_w* = 20000) was dissolved in an aqueous nitric acid solution with stirring. Then, tetraethoxysilane (TEOS, Sigma-Aldrich) was added and subsequently stirred at 25 °C until a clear solution was obtained. After that, cetyltrimethylammonium bromide (CTAB, Sigma-Aldrich) was added to the sol and stirring was continued until the surfactant was completely dissolved. The TEOS/HNO₃/H₂O/PEG/CTAB molar ratio was 1.00:0.25:14.69:0.54:0.0899. Next, the sol was left to gel at 40 °C and further aged for 48 h. The gel was then kept in 1 M NH₄OH solution for 9 h at 90 °C. After that, the gel was acidified with a 0.1 M HNO₃ solution and washed with ethanol (25 wt %). Lastly, the

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gel was dried at 60 °C for 3 days followed by calcined at 550 °C for 5 h to obtain the hierarchical porous silica.

The hierarchical porous silica sorbent was prepared by a wet impregnation method.^{17,18} In a typical preparation, the desired amount of PEI ($M_w = 600$, from Aldrich) was dissolved in 3 g of methanol at 40 °C under stirring for 20 min, and then 0.2 g of the porous silica with the size of 0.4–0.8 mm was added to the above solution and further stirred for 8 h to obtain the sorbent. The as-prepared sorbent was denoted as HPS- x PEI, where x represents the weight percentage of PEI in the sorbent (PEI + HPS). Before sorption test, all the sorbents were pretreated at 100 °C under a nitrogen (99.999%) flow at 100 mL/min for 12 h. Except for the special denotation, the PEI used in this work was the branch polymer with a average molecular weight of 600. Also, we have used PEI with different molecular weights (423, 10K, and 750K) to investigate PEI polymerization degree on the sorption property.

2.2. Dynamic Tests of the Sorbent for H₂S Removal.

Dynamic tests were carried out to evaluate the capacity of hierarchical porous silica sorbent for H₂S removal.²⁶ The sorbent was packed in a glass tube with the diameter of 4 mm and the height of 20 mm. A simulated mixture (99% of N₂ and 1% O₂) containing 0.1% (1000 ppm) of H₂S was passed through the column of the sorbent with a flow rate of 150 mL/min. When the outlet H₂S concentration from the bottom reached to the initial concentration; i.e., the sorbent was saturated by H₂S, the gas line was switched to nitrogen (99.999%) at a flow rate of 100 mL/min, and the temperature was increased to 75 °C for regeneration. The H₂S emission was monitored by a Shuangyang LC-2 H₂S continuous monitor system (electrochemical detector) interfaced with a computer data acquisition program. The test was stopped at the point that the elution concentration was approximately equal to the inlet concentration, and never change with time any more. In this test, the breakthrough concentration of H₂S was defined as 50 ppm. The breakthrough and saturation sulfur capacities of the sorbents were calculated by integration of the areas above the breakthrough curves, and from the H₂S concentration in the inlet gas, flow rate, breakthrough and saturation times, and mass of the sorbent. Breakthrough and saturation capacities are referred to as Q_B and Q_S , respectively.

2.3. Characterization. The N₂ adsorption–desorption isotherms were measured using a Micromeritics ASAP 2020 M analyzer. The BET surface areas (S_{BET}) were analyzed by Brunauer–Emmett–Teller method. Micropore volumes (V_{mic}), micropore surface areas (S_{mic}) were obtained by T -plot method. The average mesopore sizes (D_m) were obtained by Barrett–Johner–Halendar (BJH) desorption model. The total pore volumes (V_t) and pore size distributions were calculated from the analysis of the desorption branch of the isotherms using the BJH method. Low-pressure mercury porosimetry was carried out with an AutoPore IV 9500 V1.03 apparatus.

The morphology of the samples was observed under scanning electron microscopy (SEM, FEI Q-300), digital camera (Sony, DCS-w35), and transmission electron microscopy (TEM, JEOL 2100F). Fourier transform infrared (FT-IR) spectra of the samples were collected by a Nicolet 5S × C FT-IR system. Each sample was first finely ground and then diluted with KBr. The FT-IR spectra were recorded by accumulating 400 scans at a spectra resolution of 4 cm⁻¹.

3. Results and Discussion

3.1. Morphology of the Sorbents. Monolithic silica with the diameters of ca. 1 cm and the length of several centimeters was prepared as shown in inset of Figure 1a1. The SEM images

of the silica monoliths are shown in Figure 1a,b. The as-prepared silica monoliths have an open 3-D network composed of macropores with diameters of 0.5–3 μm (Figure 1a) and mesopores (Figure 1b) inserted into the silica framework. TEM observations further confirm the hierarchical structures. As shown in Figure 1c,d, interparticle macropores and intraparticle wormlike mesopores are observed. The former pores should be a result of controlled phase separation and gelation kinetics, whereas the latter mesopores are original from the void between the silica nanoparticle.²² The hierarchical pore structures should not only offer a large surface area (by small mesopores) but also provide easier access to the active sites and reduce the pressure drop over the materials (by the macropores).

Figure 2 shows the morphology changes of the silica after PEI loading. Within the PEI loading of 30 wt %, only slightly differences are observed as to the original sample (Figure 1b). When the PEI loading is up to 65 wt %, almost all of the mesopores are filled or blocked by PEI, but some macropores still remain (Figure 2c). This result suggests that PEI is successfully introduced into the mesopores of the silica without blocking the interconnected macropores. However, further increasing the PEI loading to 75 wt %, almost all the pores disappeared and the surface of the silica is covered completely by PEI films.

3.2. Pore Structures of the Sorbents. 3.2.1. Hg Porosimetry. The Hg porosimetry results of the hierarchical porous silica are presented in Figure 3. The cumulative pore volume curve shows that the total pore volume is 2.6 cm³/g, which is much higher than that of the ordered mesoporous silica SBA-15 or MCM-41 (ca. 1 cm³/g).^{16,17,20} The huge pore volume should enable the hierarchical porous silica to load a larger amount of PEI with better dispersion. The pore size distribution shows two peaks centered at 15 nm and 1.5 μm corresponding to the intraparticle mesopores and interparticle macropores, respectively, in good agreement with the SEM and TEM observations.

The pore structures of the hierarchical porous silica together with its PEI-loaded samples are analyzed by N₂ adsorption. As shown in Figure 4, the hierarchical porous silica exhibits a type IV adsorption–desorption isotherm according to the classification of IUPAC,²⁷ indicating the mesoporous structures of the material. The mesopores are mainly centered at 15 nm as shown in the pore size distribution curve (Figure 4b). From Table 1, the hierarchical porous silica has a large BET surface area of 469 m²/g and a BJH pore volume (pores smaller than 300 nm) of 1.26 cm³/g. The mesopore volume of the hierarchical monolith silica is about 1.0 cm³/g (calculated from N₂ adsorption at relative pressure of 0.97), and the macropore volume is 1.6 cm³/g (calculated by total pore volume from Hg porosimetry subtract to mesopore volume).

After PEI loading, the shape of isotherms is similar but the N₂ adsorption capacity decreases with the increase of PEI loading, indicating the BET surface area and pore volume decrease. It is noted that the sorbent with 65 wt % PEI has only a BET surface area of 15 m²/g and its mesopores are fully filled by PEI. That means the mesopores with the volume of 1.0 cm³/g could store about 34 wt % PEI. And another 31 wt % PEI should be loaded in the macropores. Therefore, there are still some macropores (ca. 0.7 cm³/g) unoccupied in the sorbent. These macropores can be taken as gas-buffering reservoirs which minimize H₂S diffusion distance. The shortened diffusion distance will be beneficial for the utilization of PEI. For 75% PEI loaded samples, all the pores are filled by PEI, which is in agreement with the result of SEM analysis (Figure 2d).

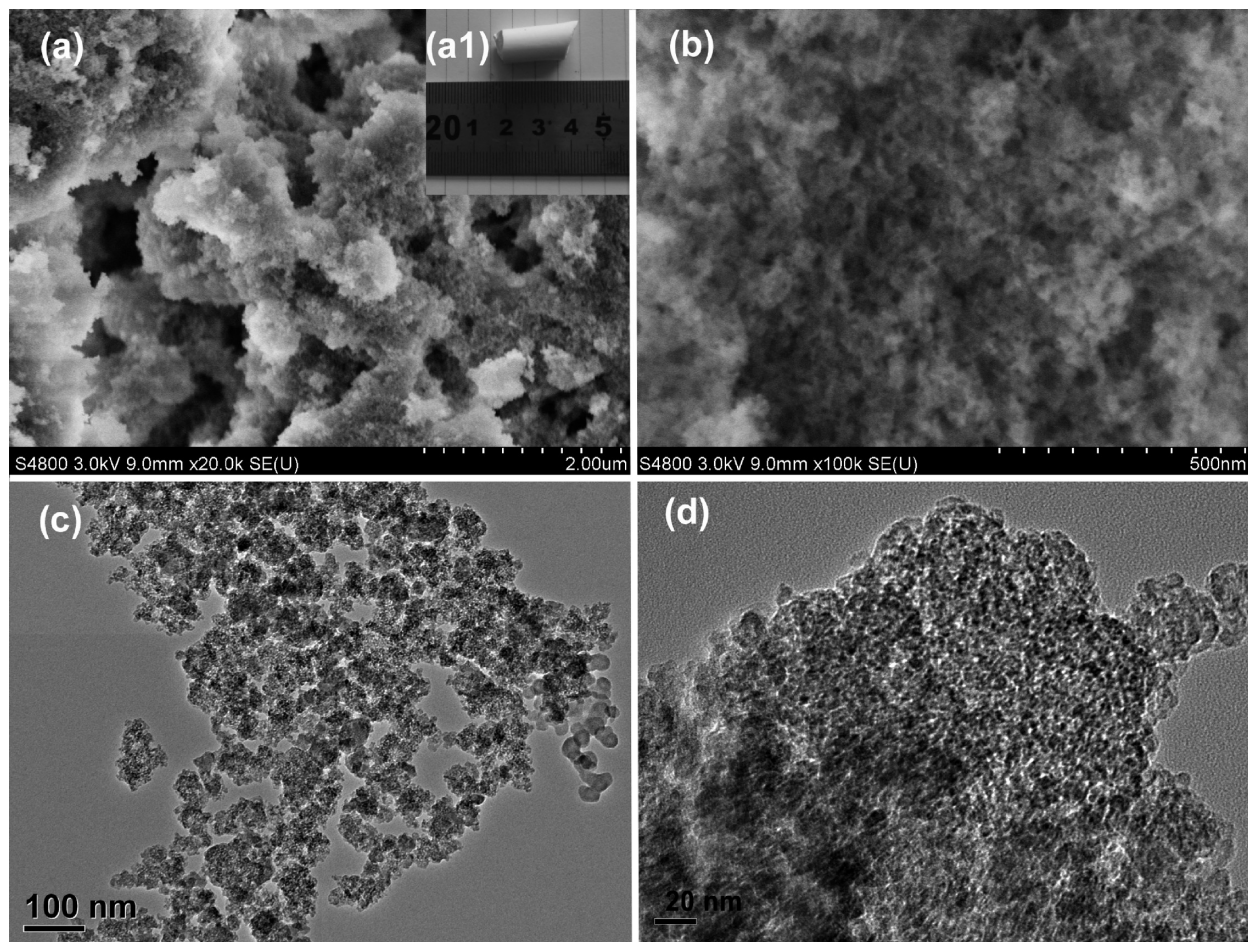


Figure 1. SEM (a, b) and TEM (c, d) images of the hierarchical porous silica.

3.2.2. FT-IR Analyses of the Sorbents. The FT-IR spectra of hierarchical porous silica sorbents with different PEI loadings are shown in Figure 5. The sharp absorption bands at 1640 cm^{-1} , and the broad band at around 3500 cm^{-1} presenting in the IR spectra of the hierarchical porous silica are assigned to the stretching vibrations of single Si—OH and hydrogen-bonded Si—OH groups, respectively.^{28,29} With the increase of the PEI loading, the intensity of single Si—OH bond decreases gradually and almost disappears at the PEI loading of 30 wt %. This result indicates that the loaded PEI could shield the stretching vibration of the Si—OH groups due to the possible the chemical interaction between them. Such interaction could work as an anchor to the PEI molecules on the surface of silica, resulting in an increase of thermal stability of the sorbent. The bands at 2922 and 2834 cm^{-1} are assigned to the CH_2 asymmetric and symmetric stretching modes of the PEI chain in the hierarchical porous silica.³⁰ In the spectrum of the sorbent, the bands at 1570 and 1470 cm^{-1} were attributed to asymmetric and symmetric bending of the primary amines ($-\text{NH}_2$), respectively, while that emerging at 1646 cm^{-1} was assigned to the bending of secondary amines ($-\text{N(R)H}$) in PEI.³¹ With the increase of PEI loading, the peaks for primary and secondary amines increase. For the sorbent after H_2S sorption, the bands at 1567 and 1483 cm^{-1} are slightly shifted from the bands for primary amines (1570 and 1470 cm^{-1}). This should be attributed to the chemical interaction between PEI and H_2S .¹⁶ Similar result was also observed in CO_2 sorption over PEI-loaded SBA-15.²⁹

3.3. Performance of the Hierarchical Porous Silica Sorbents for H_2S Removal. **3.3.1. Effect of PEI Loading.** The breakthrough curves of H_2S over the hierarchical porous silica

sorbents with different PEI loadings are shown in Figure 6. H_2S sorption capacities calculated from breakthrough curves are collected in Table 2. The original silica exhibits negligible breakthrough and saturation sulfur capacities (0 and 0.04 mmol of $\text{H}_2\text{S}/(\text{g}$ of sorbent)), due to the weak physisorption of H_2S over this material. After the impregnation of PEI, the H_2S adsorption capacity increased greatly. Both the breakthrough and saturation capacities increase with the increase of PEI loading and achieve maxima at the PEI loading of 65 wt %. The largest breakthrough capacity of the sorbents developed in this work is 1.27 mmol of $\text{H}_2\text{S}/(\text{g}$ of sorbent), which is about 60% higher than that of PEI impregnated SBA-15 ($0.79\text{ mmol}/(\text{g}$ of sorbent)) or MCM-41 ($0.81\text{ mmol}/(\text{g}$ of sorbent)).¹⁷ The excellent performance should be attributed to the large pore volume and the hierarchical pore structures of the support material, in which the former is available for increasing the PEI loading (65 wt %) in good dispersion, and the latter could provide easier access to the sorption sites and reduce the distance of internal diffusion. Excessive loading of PEI (75 wt %) could block all porosity of the hierarchical porous silica, resulting in the great degradation of adsorptive property of the sorbent. This should be due to the long diffusion distance of H_2S from the external surface of PEI into the internal PEI, making most of PEI unused.

The chemical sorption of H_2S should be attributed to the interaction between H_2S and amine groups in PEI molecules (23.3 mmol of $\text{NH}_x/(\text{g}$ of PEI)). To further understand the adsorptive interaction, the breakthrough and saturation capacities per molar amine group (mmol of $\text{H}_2\text{S}/(\text{mol}$ of $\text{NH}_x)$) in the sorbents were calculated and shown in Figure 7. At the low

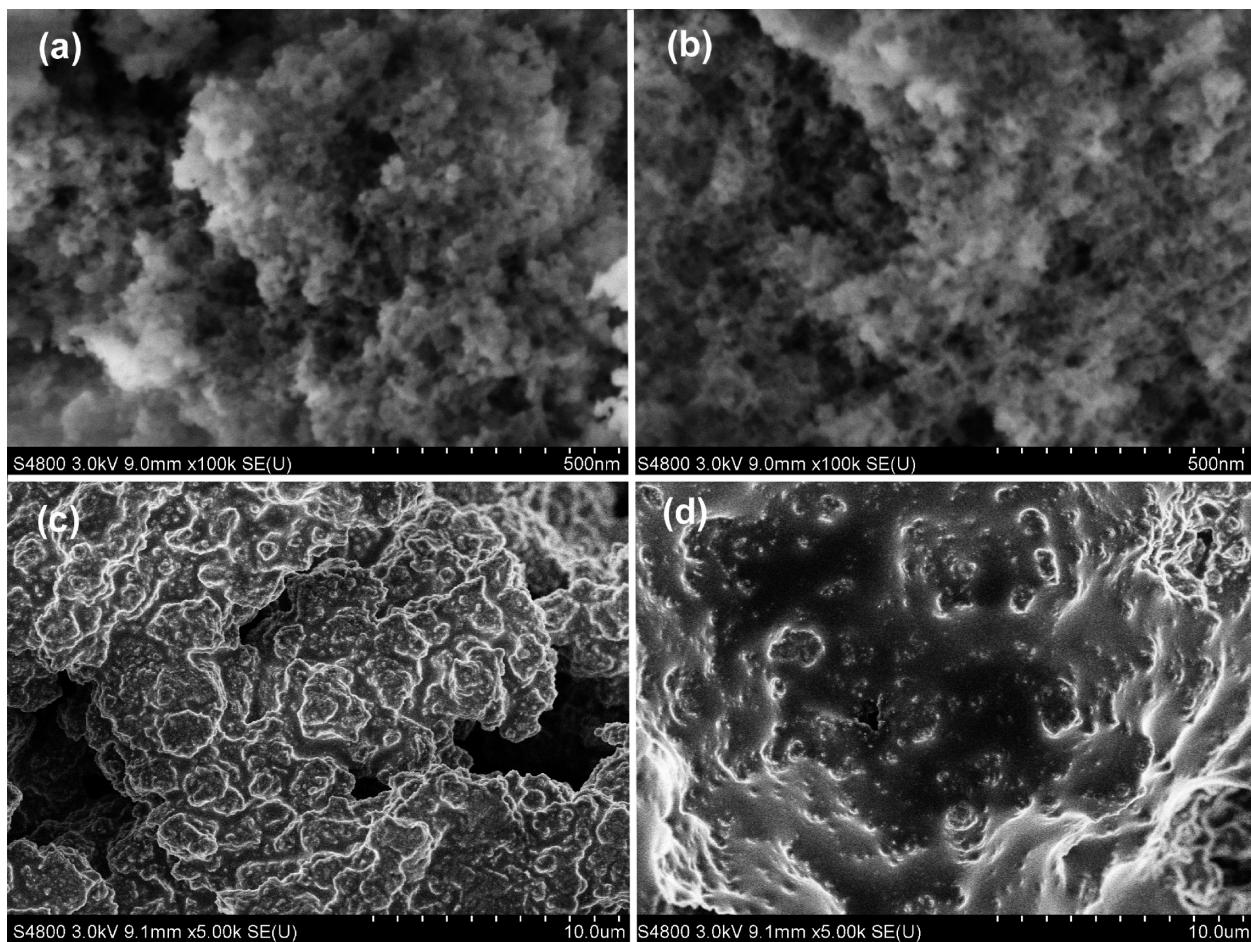


Figure 2. SEM images of the hierarchical porous silica sorbents with different PEI loadings: a, HPS-15%PEI; b, HPS-30%PEI; c, HPS-65%PEI; d, HPS-75%PEI.

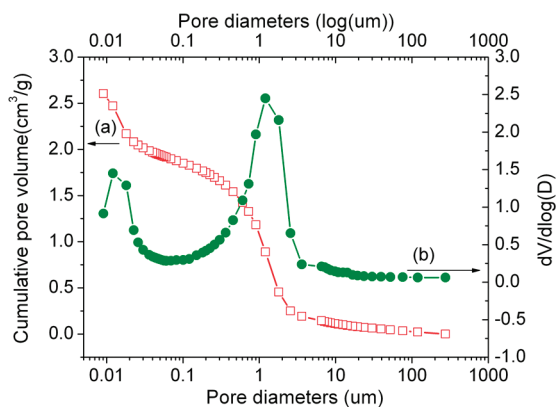


Figure 3. Cumulative pore volume (a) and pore size distribution (b) of the hierarchical porous silica determined by Hg porosimetry.

PEI loadings, the amine groups have a very low utilization. In that case, a very limited amount of PEI is dispersed on the surface of the porous silica. However, a considerable amount of amine groups should be consumed by an interaction with silanol functional groups on the silica interface. This interface effect should reduce the effective number of the amine groups, resulting in a low H_2S sorption capacity. Increasing the PEI loading could dilute the interface effect, and consequently, the utilization of amine groups increases greatly with the PEI loading. The maximum utilization of amine group is 0.12 mol of $\text{H}_2\text{S}/(\text{mol of NH}_x)$ at the PEI loading of 65 wt %.

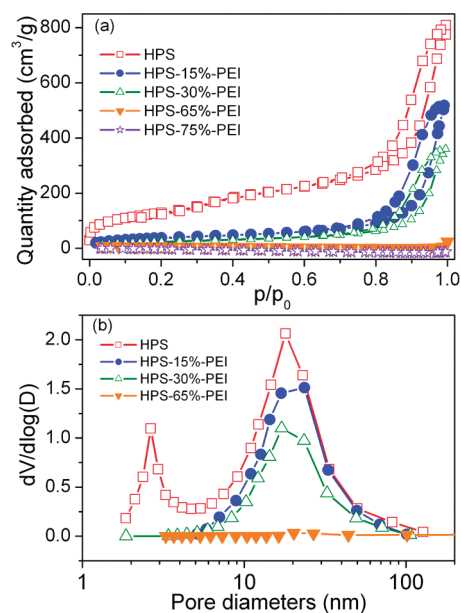


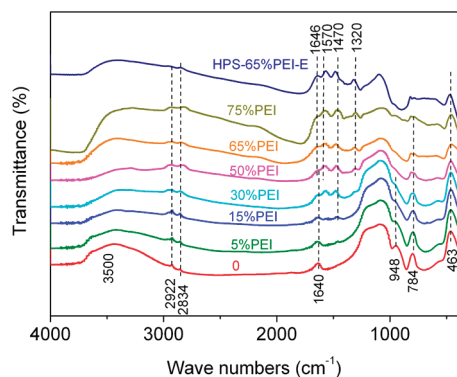
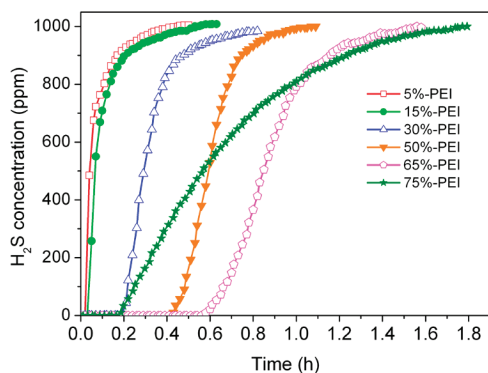
Figure 4. N_2 adsorption-desorption isotherms (a) and pore size distributions (b) of the hierarchical porous silica sorbents with different PEI loadings.

However, the maximum utilization of amine groups in this sorbent is far smaller than the theoretical value (0.5 mol of $\text{H}_2\text{S}/(\text{mol of NH}_x)$).¹⁸ There are two possible reasons for this phenomenon: First, the chemical interaction between weak alkali PEI ($-\text{NH}_x$) and acid H_2S is intrinsically low. Second, after 65

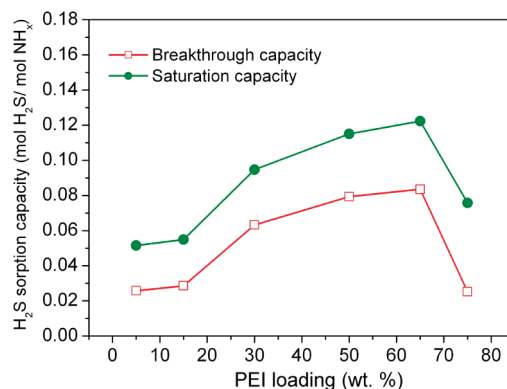
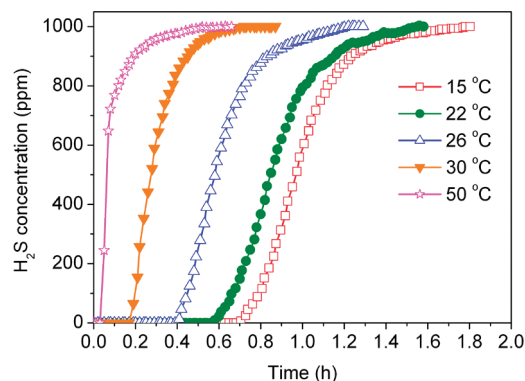
Table 1. Pore Structure Parameters of the Hierarchical Porous Silica Sorbents

samples	S_{BET} (m^2/g)	V_{BJH} (cm^3/g)	V_{mic} (cm^3/g)	D_{m} (nm)
HPS	469	1.26	0.01	18.55
HPS–15%PEI	137	0.82	0	17.85
HPS–30%PEI	90	0.55	0	17.65
HPS–65%PEI	15	0.01	0	17.63
HPS–75%PEI	0			

wt % PEI loading, the mesopores of the sorbent are almost filled and the specific surface area is very small (only about $15 \text{ m}^2/\text{g}$). So the PEI films in the pores are very thick, which results in the difficult diffusion of H_2S to the internal PEI and decreasing the NH_x capturing efficiency. For 50 wt % PEI loaded SBA-15 and MCM-48, the sorption capacity per mol of NH_x group (0.2 mol of $\text{H}_2\text{S}/(\text{mol of } \text{NH}_x)$) are slightly higher than

**Figure 5.** FT-IR spectra of the hierarchical porous silica sorbents with different PEI loadings.**Figure 6.** Breakthrough curves of H_2S over the hierarchical porous silica sorbents with different PEI loadings (sorption temperature is 22°C).**Table 2. H_2S Sorption Capacities of the Hierarchical Porous Silica Sorbents**

PEI loading (wt %)	temperature ($^\circ\text{C}$)	Q_{B}		Q_{S}	
		(mg/g)	(mmol/g)	(mg/g)	(mmol/g)
0	22	0	0	0	0.04
5	22	1.0	0.03	2.0	0.06
15	22	3.4	0.10	6.5	0.19
30	22	15	0.44	23	0.66
50	22	31	0.92	45	1.33
65	22	43	1.27	63	1.85
75	22	15	0.44	45	1.32
65	15	46	1.35	61	2.00
65	26	29	0.85	42	1.23
65	30	13	0.38	22	0.65
65	50	3.0	0.09	7	0.21
65 (M_{w} , 423)	22	27	0.79	50	1.47
65 (M_{w} , 15K)	22	18	0.53	38	1.12
65 (M_{w} , 750K)	22	14	0.41	24	0.71

**Figure 7.** Effect of PEI loadings on the breakthrough and saturation capacities per molar amine groups in the sorbents.**Figure 8.** Breakthrough curves of H_2S over the hierarchical porous silica sorbents (HPS–65%PEI) at different sorption temperatures.

the hierarchical monolith silica sorbent.^{17,18} This is because their surface area is higher ($60\text{--}80 \text{ m}^2/\text{g}$) and the average PEI films are thinner, which is benefit for H_2S diffusion and H_2S capture by NH_x .

Although the hierarchical monolith silica sorbent only has a relative smaller utilization of amine groups, it can obtain a larger amount of PEI loading because of the larger total pore volume, which make the hierarchical monolith silica sorbent exhibit 60% higher breakthrough sulfur capacity than that of SBA-15 or MCM-48 sorbents and more promising in industry application.

3.3.2. Effect of Sorption Temperature. The effect of temperature on the H_2S removal performance of the hierarchical porous silica sorbents has been investigated, as shown in Figure 8. The corresponding H_2S sorption capacities are also listed in Table 2. Clearly, the breakthrough and saturation sulfur capacities decreased significantly with the increase of sorption temperature.

The sorption process of H_2S on the sorbent should include several steps: H_2S diffusion from the gas flow to the surface of PEI through the open macropores (external diffusion); the diffusion of H_2S from the surface into the bulk of PEI films (internal diffusion) and the dynamic balance between chemical sorption and desorption of H_2S with the PEI molecules. Generally, lower temperature favors sorption and higher temperature favors desorption and diffusion. Our results clearly demonstrated that the lower temperature favors the increase in the H_2S equilibrium sorption capacity, which indicates that the sorption of H_2S over PEI-loaded porous silica was predominately determined by the thermodynamic factor rather than the kinetic diffusion. The weak thermodynamic stability of bonds between the amine groups and H_2S molecules should be the major reason.

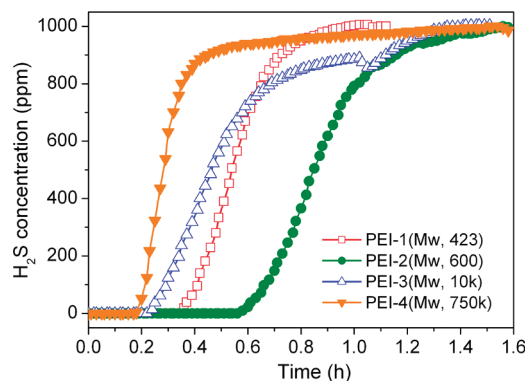


Figure 9. Breakthrough curves of H_2S over the hierarchical porous silica sorbents loading 65 wt % PEI with different average molecular weight.

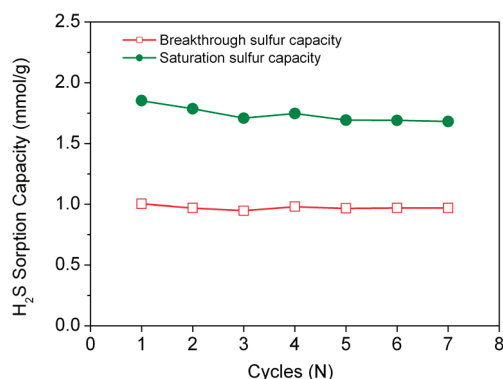


Figure 10. Regeneration performance of the hierarchical porous silica sorbents (HPS-65%PEI).

3.3.3. Effects of PEI Average Molecular Weight. Four kinds of PEI with different polymerization degrees were supported on the hierarchical porous silica to remove H_2S . The sorption results of these sorbents are shown in Figure 9 and Table 2. It is clear that the sorbent with a PEI M_w of 600 has the best sorption property among these samples. The PEI with higher polymerization degree should have very large steric hindrance and low fluidity, restraining the internal diffusion of H_2S and lowering the amine utilization. On the other hand, PEI with the $M_w = 423$ is the mixture of linear monomers and branch polymers. Some monomers may be consumed or volatilized during the impregnation and drying, resulting in the decrease of efficient amine groups. Except for these external factors, the internal factors, such as the weak interaction between the monomers and H_2S or the weak thermodynamic stability of monomers may also contribute to the low sorption property.

3.3.4. Regeneration Performance. The regeneration of the spent sorbent can be easily performed at $75\text{ }^\circ\text{C}$ using N_2 as a purge gas. Figure 10 gives the regeneration performance of this sorbent as a function of the number of the sorption–desorption cycles. During seven repeated sorption–desorption cycles, no significant change in H_2S sorption capacity was observed. This result confirmed that the PEI-loaded hierarchical porous silica sorbent can be recovered completely. Except the high sorption capacity, the excellent regeneration performance is also a crucial advantage of this hierarchical porous silica sorbent for practical application.

For the hierarchical porous silica sorbents, the sorption of H_2S is at room temperature ($20\text{--}30\text{ }^\circ\text{C}$) and desorption is at $75\text{ }^\circ\text{C}$. The sorption process is no energy consumption, and the desorption step is the only process for energy consumption. The energy is most consumed on the heating process from room temperature to $75\text{ }^\circ\text{C}$. Since the heat capacity of the solid

material is small, the energy consumption is very small. For liquid amine method, the sorption is at low temperature ($20\text{--}40\text{ }^\circ\text{C}$),^{32,33} but the desorption is at $105\text{--}120\text{ }^\circ\text{C}$ and the heat capacity of amine and water is much higher than hierarchical silica sorbent.^{34,35} So the desorption energy consumption for regeneration is much higher than hierarchical silica sorbent. Also, the sorption–desorption process needs the circle of liquid amine, which also consume much energy. Thus, the energy consumption of liquid amine method should be higher than the hierarchical silica sorbent. At the same H_2S partial pressure (0.1 kPa), the balance sorption capacity of 65 wt % PEI loaded hierarchical silica ($63\text{ g of H}_2\text{S}/(\text{g of sorbent})$) is much higher than liquid amine absorbent (about $5\text{ mg of H}_2\text{S}/(\text{g of absorbent})$).⁴ Due to the high sorption capacity and low-energy consumption, the hierarchical silica sorbent will be more promising in industry application.

4. Conclusions

The present work has shown that PEI-loaded porous silica sorbents could effectively remove H_2S from gas streams at ambient conditions. It is found that decrease of the temperature favors enhancing the sorption capacity of the supported PEI sorbents. The amount of PEI loading on the porous silica has a strong influence on the sorption performance of the sorbents. A loading of 65 wt % PEI gives the largest breakthrough capacity of $1.27\text{ mmol of H}_2\text{S}/(\text{g of sorbent})$ at $22\text{ }^\circ\text{C}$. In addition, the developed sorbents can be regenerated easily at mild conditions (temperature range of $75\text{--}100\text{ }^\circ\text{C}$) and have the excellent regenerability and stability. Considering the excellent sorption performance, regenerability and stability, the PEI-loaded porous silica sorbent may be one of the promising sorbents for removing H_2S from the gas streams more environmentally benignly and more energy efficiently.

Acknowledgment

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