

SAPO-34 molecular sieve using diglycolamine as template agent and method for preparing the same

Technical Field

The present invention belongs to the field of SAPO molecular sieve, and specifically concerns a SAPO-34 molecular sieve and method for preparing the same.

Background

The Union Carbide Corporation (UCC) researched and developed a series of novel silicoaluminophosphate molecular sieves SAPO-n in 1984 (US4440871 and US4499327), which were prepared by using organic amines as a template agent and using hydrated alumina, phosphoric acid and silica sol as an aluminum source, a silicon source and a phosphorus source, respectively. Firstly, a complex of organic amine/silicoaluminophosphate with microporous structure was obtained by a hydrothermal crystallization method, and then the template agent (organic amine) was removed by calcination to obtain the SAPO-n molecular sieves. Among this kind of molecular sieves, SAPO-34 with CHA-type framework has shown an excellent catalytic activity and selectivity in methanol to olefins (MTO) process, due to its proper pore structure, proper Brønsted acid property, higher specific surface area, preferable adsorption performance, high thermal stability, high hydrothermal stability and the like.

SAPO-34 is a molecular sieve with chabazite-type (CHA) framework containing 8-member ring ellipsoidal cage and 3-dimensional channel, which is formed by stacking of double six-rings according to ABC sequence. SAPO-34 is microporous molecular sieve with a pore size of 0.38×0.38 nm. Space group of SAPO-34 is R3m belonging to trigonal crystal system (J. Phys. Chem., 1990, 94: 2730). SAPO-34 is formed by Si, Al, P and O whose composition change at some range, generally in the order of $n(\text{Si}) < n(\text{P}) < n(\text{Al})$.

SAPO-34 molecular sieve is generally produced by a hydrothermal synthesis process which uses water as the solvent and is conducted in a sealed autoclave. The silicon source may be chosen from silica sol, active silica and orthosilicate esters. The aluminum source may be chosen from active alumina, pseudo boehmite and alkoxy aluminum. Preferable silicon source and aluminum source are silica sol and pseudo boehmite. Phosphorus source is generally 85% phosphoric acid. The template agent commonly used comprises tetraethyl ammonium hydroxide (TEAOH), morpholine (MOR), piperidine, isopropylamine ($i\text{-PrNH}_2$), triethylamine (TEA), diethylamine (DEA), dipropylamine, and the like, or a mixture thereof. The structural-directing agent partly affects the microstructure, elemental composition, morphology of synthesized molecular sieve, thus producing an impact on the catalytic performance of synthesized molecular sieve.

In the present invention, diglycolamine firstly is used as structure-directing agent for the hydrothermal synthesis of pure SAPO-34 molecular sieve. The synthetic SAPO-34 molecular sieve has shown an excellent catalytic performance in catalytic reaction and a good gas absorption separation performance.

Disclosure

An object of the present invention is to provide a SAPO-34 molecular sieve, whose chemical composition in the anhydrous state is expressed as: $m\text{DGA} \cdot (\text{Si}_x\text{Al}_y\text{P}_z)\text{O}_2$; wherein DGA is diglycolamine, distributing in the cages and pores of said molecular sieve; m is the molar number of diglycolamine per one mole of $(\text{Si}_x\text{Al}_y\text{P}_z)\text{O}_2$, and m is from 0.03 to 0.25; x, y, z respectively represents

the molar number of Si, Al, P, and x is from 0.01 to 0.30, and y is from 0.40 to 0.60, and z is from 0.25 to 0.49, and $x + y + z = 1$. Preferably, x is from 0.07 to 0.26, and y is from 0.42 to 0.52, and z is from 0.28 to 0.45, and $x + y + z = 1$. The diffraction peaks are shown in Table 2, according to the X-ray diffraction analysis of said SAPO-34 molecular sieve. The X-ray diffraction analysis result of said SAPO-34 molecular sieve at least includes the diffraction peaks as the following table:

No.	2 θ	d(Å)
1	9.4445	9.36452
2	15.942	5.55943
3	17.7583	4.99471
4	22.9708	3.87175
5	29.428	3.03525

Another object of the present invention is to provide a method for preparing SAPO-34 molecular sieve. Another object of the present invention is to provide a SAPO-34 molecular sieve prepared using the above method and catalysts prepared from the same for acid-catalyzed reaction or oxygenates to olefins reaction.

Another object of the present invention is to provide a material used for adsorption separation of CH_4/CO_2 .

The technical problem to be solved in the present invention is that the SAPO-34 molecular sieve is prepared in high purity under hydrothermal or solvothermal conditions, using diglycolamine as the structure-directing agent and using the phosphorus source, the silicon source and the aluminum source employed in usual molecular sieve synthesis as raw materials.

The present invention is characterized in including the preparation steps as follows:

(a) deionized water, a silicon source, an aluminum source, a phosphorus source and DGA are mixed according to a certain ratio, and an initial gel mixture with following molar ratio is obtained:

$\text{SiO}_2/\text{Al}_2\text{O}_3$ is from 0.05 to 2.5;

$\text{P}_2\text{O}_5/\text{Al}_2\text{O}_3$ is from 0.5 to 1.5;

$\text{H}_2\text{O}/\text{Al}_2\text{O}_3$ is from 5 to 200;

$\text{DGA}/\text{Al}_2\text{O}_3$ is from 2.5 to 30, DGA is diglycolamine;

(b) the initial gel mixture obtained in said step (a) is transferred into an autoclave, then sealed and heated to crystallization temperature range from 150°C to 220°C, crystallized for crystallization time range from 5h to 72h under the autogenous pressure;

(c) after finishing the crystallization, the solid product is separated, washed to neutral using deionized water and dried to obtain said SAPO-34 molecular sieve.

In said step (a), the silicon source is one or more selected from silica sol, active silica, orthosilicate esters and metakaolin; the aluminum source is one or more selected from aluminum salts, activated alumina, aluminum alkoxide and metakaolin; the phosphorus source is one or more selected from phosphoric acid, diammonium hydrogen phosphate, ammonium dihydrogen phosphate, organophosphorous compounds and phosphorus oxides.

In said step (b), the crystallization is carried out statically or dynamically.

In the initial gel mixture obtained in said step (a), the molar ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$ is preferable from 0.15 to 2.0.

In the initial gel mixture obtained in said step (a), the molar ratio of $\text{P}_2\text{O}_5/\text{Al}_2\text{O}_3$ is preferable from 0.8

to 1.5.

In the initial gel mixture obtained in said step (a), the molar ratio of $\text{H}_2\text{O}/\text{Al}_2\text{O}_3$ is preferable from 10 to 150.

In the initial gel mixture obtained in said step (a), the molar ratio of $\text{DGA}/\text{Al}_2\text{O}_3$ is preferable from 5.5 to 16.

The present invention also refers to a catalyst for acid-catalyzed reaction, which is obtained by calcining at least one of said SAPO-34 molecular sieves or at least one of the SAPO-34 molecular sieves prepared by said methods, at a temperature from 400 to 700 °C in air.

The present invention also refers to a catalyst for oxygenates to olefins reaction, which is obtained by calcining at least one of said SAPO-34 molecular sieves or at least one of the SAPO-34 molecular sieves prepared by said methods, at a temperature from 400 to 700 °C in air.

The present invention also refers to a material used for adsorption separation of CH_4/CO_2 , which is obtained by calcining at least one of said SAPO-34 molecular sieves or at least one of the SAPO-34 molecular sieves prepared by said methods, at a temperature from 400 to 700 °C in air.

The present invention can bring the advantages including:

- (1) obtaining a SAPO-34 molecular sieve using diglycolamine as the template agent.
- (2) the SAPO-34 molecular prepared by said method in present invention having excellent catalytic performance in the reaction of converting methanol or dimethyl ether to light olefins.
- (3) the SAPO-34 molecular prepared by said method in present invention having excellent adsorption separation selectivity of CH_4 and CO_2 .

Brief Description of the Drawings

Figure 1 is a scanning electron microscope image of the sample prepared in Example 1 (SEM).

Specific Embodiments of the invention

The elemental analysis was determined using Magix 2424 X-ray fluorescence spectrometer (XRF) produced by Philips.

The X-ray powder diffraction analysis (XRD) was determined using X'Pert PRO X-ray diffractometer produced by PANalytical, with $\text{Cu K}\alpha$ radiation ($\lambda=0.15418\text{ nm}$), operated at 40KV and 100mA.

The SEM morphology analysis was determined using KYKY-AMRAY-1000B scanning electron microscope produced by Scientific Instruments Factory of Chinese Academy of Sciences.

Carbon-13 nuclear magnetic resonance analysis (^{13}C MAS NMR) was determined using Infinity plus 400WB Solid-state nuclear magnetic resonance spectrometer produced by Varian, with a BBO MAS probe operating at a magnetic field strength of 9.4T.

CHN elemental analysis was determined using German Vario EL Cube elemental analyzer.

The present invention will be described in details by Examples, but the present invention is not limited to these Examples.

Examples 1

The amount of ingredients, the crystallization condition and the sample elemental composition are shown in Table 1. The synthesis process was as follows: 14g of pseudoboehmite (with Al_2O_3 mass percent of 72.5%) and 79.2g of deionized water were mixed homogeneously, and then 5.96g of silica

sol (with SiO₂ mass percent of 30.24%) was added and stirred to smooth, and then 23.06g of phosphoric acid (with H₃PO₄ mass percent of 85%) was added by droplets. 31.5g diglycolamine(abbreviated as DGA, with mass percent of 99%) were added into the mixture, stirring to smooth to obtain the initial gel mixture. The initial gel mixture was transferred into a stainless steel autoclave. The molar ratio of the compositions in the initial gel mixture was 3.0DGA:0.30SiO₂:1Al₂O₃:1P₂O₅:50H₂O.

The autoclave was put into a stove and temperature programmed heated to 200°C, dynamically crystallized for 48h. After finishing the crystallization, the solid product was centrifugal separated, washed and dried at 100°C in air to obtain the raw powder sample. The raw powder sample was detected with XRD and XRD data were shown in Table 2, indicating that the raw powder sample prepared had the structural characteristics as same as SAPO-34 molecular sieve.

The CHN elemental analysis of the raw powder sample obtained in Example 1 was detected, and the chemical compositions of the raw powder sample were obtained by normalization of the CHN elemental analysis results and the inorganic elemental analysis results detected by XRF.

Table 1: The list of amount of ingredients and crystallization conditions of the molecular sieves*

Exa mpl e	Molar amount of DGA	Aluminum source and molar amount of Al ₂ O ₃ thereof	Phosphorus source and molar amount of P ₂ O ₅ thereof	Silicon source and molar amount of SiO ₂ thereof	H ₂ O	Crystall ization Temper ature	Crystall ization Time	Chemical Composition
1	0.3mol	pseudoboehmite 0.10 mol	phosphoric acid 0.10mol	silica sol 0.03mol	5.0mol	200 ⁰ C	48h	0.19DGA· (Si _{0.13} Al _{0.49} P _{0.38})O ₂
2	0.59mol	aluminium isopropoxide 0.1 mol	phosphoric acid 0.10mol	silica sol 0.005mol	1.6mol	180 ⁰ C	48h	0.12DGA· (Si _{0.01} Al _{0.50} P _{0.49})O ₂
3	0.25mol	aluminium isopropoxide 0.1 mol	phosphoric acid 0.10mol	silica sol 0.15mol	0.5mol	200 ⁰ C	24h	0.10DGA· (Si _{0.30} Al _{0.45} P _{0.25})O ₂
4	0.38mol	γ-alumina 0.1 mol	phosphoric acid 0.10mol	silica sol 0.10mol	8.3mol	200 ⁰ C	24h	0.08DGA· (Si _{0.25} Al _{0.41} P _{0.34})O ₂
5	0.5mol	aluminum sulfate 0.1mol	phosphoric acid 0.05mol	active silica 0.25mol	2.6mol	190 ⁰ C	48h	0.25DGA· (Si _{0.28} Al _{0.46} P _{0.26})O ₂
6	0.3mol	aluminium chloride 0.1 mol	phosphoric acid 0.15mol	ethyl orthosilicate 0.08mol	1.2mol	200 ⁰ C	24h	0.22DGA· (Si _{0.20} Al _{0.35} P _{0.45})O ₂
7	1.0mol	pseudoboehmite 0.1 mol	phosphoric acid 0.09mol	silica sol 0.04mol	5.1mol	200 ⁰ C	24h	0.21DGA· (Si _{0.10} Al _{0.49} P _{0.41})O ₂
8	0.8mol	aluminium isopropoxide 0.1 mol	phosphoric acid 0.15mol	silica sol 0.01mol	10mol	200 ⁰ C	24h	0.17DGA· (Si _{0.06} Al _{0.60} P _{0.34})O ₂
9	0.26mol	pseudoboehmite 0.1 mol	ammonium dihydrogen phosphate 0.10mol	silica sol 0.06mol	6.6mol	220 ⁰ C	5h	0.16DGA· (Si _{0.14} Al _{0.47} P _{0.39})O ₂
10	1.5mol	pseudoboehmite 0.1 mol	diammonium hydrogen phosphate 0.10mol	active silica 0.06mol	2.2mol	200 ⁰ C	24h	0.18DGA· (Si _{0.11} Al _{0.49} P _{0.40})O ₂

11	2.0mol	aluminum sulfate 0.1mol	diammonium hydrogen phosphate 0.15mol	silica sol 0.07mol	8.8mol	200 ⁰ C	18h	0.15DGA· (Si _{0.16} Al _{0.47} P _{0.37})O ₂
12	0.3mol	pseudoboehmite 0.1 mol	diammonium hydrogen phosphate 0.12mol	silica sol 0.12mol	6.5mol	180 ⁰ C	24h	0.12DGA· (Si _{0.25} Al _{0.40} P _{0.35})O ₂
13	0.4mol	pseudoboehmite 0.1 mol	phosphoric anhydride 0.13mol	active silica 0.03mol	12mol	210 ⁰ C	18h	0.19DGA· (Si _{0.15} Al _{0.49} P _{0.36})O ₂
14	0.39mol	pseudoboehmite 0.1 mol	phosphoric acid 0.10mol	silica sol 0.03mol	4.5mol	190 ⁰ C	12h	0.19DGA· (Si _{0.15} Al _{0.49} P _{0.36})O ₂
15	0.39mol	aluminium isopropoxide 0.1 mol	phosphoric acid 0.10mol	tetramethyl orthosilicate 0.03mol	6.5mol	150 ⁰ C	72h	0.22DGA· (Si _{0.15} Al _{0.46} P _{0.39})O ₂
16	0.30mol	pseudoboehmite 0.1 mol	trimethyl phosphine 0.10mol	silica sol 0.03mol	6.5mol	210 ⁰ C	15h	0.17DGA· (Si _{0.13} Al _{0.48} P _{0.37})O ₂
17	0.35mol	pseudoboehmite 0.1 mol	triethyl phosphine 0.10mol	silica sol 0.03mol	6.5mol	170 ⁰ C	60h	0.19DGA· (Si _{0.13} Al _{0.48} P _{0.39})O ₂
18	0.8mol	pseudoboehmite 0.1 mol	phosphoric acid 0.10mol	silica sol 0.20mol	3.0mol	200 ⁰ C	24h	0.20DGA· (Si _{0.26} Al _{0.44} P _{0.30})O ₂
19	3.00mol	pseudoboehmite 0.1 mol	phosphoric acid 0.10mol	silica sol 0.03mol	20mol	200 ⁰ C	24h	0.21DGA· (Si _{0.15} Al _{0.50} P _{0.35})O ₂

Table2: XRD result of the sample obtained in Example 1

No.	2θ	d(Å)	100×I/I ⁰
1	9.4445	9.36452	66.76
2	12.7935	6.91968	15.26
3	13.9312	6.35701	6.2
4	15.942	5.55943	43.18
5	17.7583	4.99471	21.85
6	18.9695	4.67843	2.26
7	20.5083	4.33075	100
8	20.9495	4.24053	4.27
9	21.9655	4.04662	16.19
10	22.2848	3.98936	8.18
11	24.9225	3.57281	70.93
12	25.7931	3.45415	22.85
13	27.5092	3.24245	6.1
14	28.1221	3.17316	4.82
15	29.428	3.03525	3.39
16	30.4672	2.93405	42.98
17	31.0098	2.88394	25.27
18	32.2329	2.77725	1.71

19	33.4612	2.67805	4.49
20	34.3373	2.61171	7.7
24	34.8199	2.57661	1.71
21	35.9729	2.49663	6.8
22	39.5319	2.27967	3.7
23	43.2766	2.0907	3.73
24	47.4623	1.91563	4.54
25	49.3238	1.84761	2.58
26	50.6098	1.80364	6.32
27	53.0197	1.7272	4.94
28	55.2438	1.66281	2.49
29	58.1695	1.58595	0.83
30	59.3794	1.5565	1.83

Examples 2 to 19

The amount of ingredients and the crystallization conditions were shown in Table 1, and the synthesis processes were the same as Example 1.

The samples were detected with XRD. XRD data of samples were similar to Table 2, which showed that each corresponding peak had the same peak position and the $\pm 10\%$ difference of peak intensity, indicating the samples prepared had the structural characteristics as same as SAPO-34 molecular sieve.

The elemental analysis results of the samples were shown in Table 1.

The raw powder samples obtained in Examples 1 to 10 were detected with ^{13}C MAS NMR analysis respectively, comparing the results with the ^{13}C MAS NMR standard spectrum of diglycolamine, only the resonance peak of diglycolamine was observed.

Example 20

The sample obtained in Example 1 was calcined at 550°C for 4 hours in air, then pressed, crushed and sieved to 20-40 mesh. 5.0g of the sample was added into a batch reactor loaded 30mL of ethanol to carry out an ethanol dehydration reaction evaluation. The reaction was carried out at 150°C under stirring. The result showed that ethanol conversion reached 92% and the selectivity for ether in products was 92%.

Example 21

The sample obtained in Example 1 was calcined at 550°C for 4 hours in air, then pressed, crushed and sieved to 20-40 mesh. 1.0g of the sample was weighted and loaded into a fixed bed reactor to carry out a methanol to olefins reaction evaluation. The sample was activated at 550°C for 1 hour in nitrogen gas and reduced to 450°C to perform a reaction. Methanol was carried by nitrogen gas with a flow rate of 40 ml/min and the Weight Hour Space Velocity of the methanol was 4.0 h^{-1} . The reaction products were analyzed by an on-line gas chromatograph (Varian3800, FID detector, capillary column was PoraPLOT Q-HT). The result was shown in Table 3.

Table 3: The reaction result of methanol to olefins on the sample

Sample	Life (min)	Selective (mass%) *							
		CH ₄	C ₂ H ₄	C ₂ H ₆	C ₃ H ₆	C ₃ H ₈	C ₄ ⁺	C ₅ ⁺	C ₂ H ₄ +C ₃ H ₆
Example 1	126	1.38	43.14	0.55	37.60	1.03	12.17	4.13	80.74

Example 22

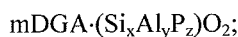
The sample obtained in Example 10 was calcined at 550°C for 4 hours in air. The adsorption isotherms of CO₂ and CH₄ were detected using Micrometrics ASAP 2020. Before being detected, the sample was degassed at 350°C for 4 hour under vacuum conditions. The adsorption isotherms were detected at the temperature of 25°C and the pressure of 101kpa.

Table 4: The adsorption separation result of CO₂/CH₄ on the sample

Sample	Adsorption Capacity (mmol/g)		CO ₂ /CH ₄
	CO ₂	CH ₄	
Example 10	3.82	0.20	19.1

Claims

1. A SAPO-34 molecular sieve whose chemical composition in the anhydrous state is expressed as:



wherein,

DGA is diglycolamine; m is the molar number of diglycolamine per one mole of $(\text{Si}_x\text{Al}_y\text{P}_z)\text{O}_2$, and m is from 0.03 to 0.25;

x, y, z respectively represents the molar number of Si, Al, P, and x is from 0.01 to 0.30, and y is from 0.40 to 0.60, and z is from 0.25 to 0.49, and $x + y + z = 1$.

2. A SAPO-34 molecular sieve according to claim 1, wherein the X-ray diffraction spectrogram of said SAPO-34 molecular sieve includes the diffraction peaks at following peak positions:

No.	2 θ
1	9.4445
2	15.942
3	17.7583
4	22.9708
5	29.428

3. A method for preparing said SAPO-34 molecular sieve according to claim 1, including the steps as follows:

(a) deionized water, a silicon source, an aluminum source, a phosphorus source and DGA are mixed according to a certain ratio, and an initial gel mixture with following molar ratio is obtained:

$\text{SiO}_2/\text{Al}_2\text{O}_3$ is from 0.05 to 1.5;

$\text{P}_2\text{O}_5/\text{Al}_2\text{O}_3$ is from 0.5 to 1.5;

$\text{H}_2\text{O}/\text{Al}_2\text{O}_3$ is from 5 to 200;

$\text{DGA}/\text{Al}_2\text{O}_3$ is from 2.5 to 30, DGA is diglycolamine;

(b) the initial gel mixture obtained in said step (a) is transferred into an autoclave, then sealed and heated to crystallization temperature range from 150°C to 220°C, crystallized for crystallization time range from 5h to 72h under the autogenous pressure;

(c) after finishing the crystallization, the solid product is separated, washed to neutral using deionized water and dried to obtain said SAPO-34 molecular sieve.

4. A method according to claim 3, wherein in the initial gel mixture obtained in said step (a), the silicon source is one or more selected from silica sol, active silica, orthosilicate esters and metakaolin; the aluminum source is one or more selected from aluminum salts, activated alumina, aluminum alkoxide and metakaolin; the phosphorus source is one or more selected from phosphoric acid, diammonium hydrogen phosphate, ammonium dihydrogen phosphate, organophosphorous compounds and phosphorus oxides.

5. A method according to claim 3, wherein in said step (b), the crystallization is carried out statically or dynamically.

6. A method according to claim 3, wherein in the initial gel mixture obtained in said step (a), the molar

ratio of organic amine DGA to Al_2O_3 SDA/ Al_2O_3 is from 5.5 to 16.

7. A catalyst for acid-catalyzed reaction, which is obtained by calcining at least one of said SAPO-34 molecular sieves according to claims from 1 or 2 or at least one of the SAPO-34 molecular sieve prepared by said methods according to claims from 3 to 6, at a temperature from 400 to 700 °C in air.

8. A catalyst for oxygenates to olefins reaction, which is obtained by calcining at least one of said SAPO-34 molecular sieves according to claims from 1 or 2 or at least one of the SAPO-34 molecular sieve prepared by said methods according to claims from 3 to 6, at a temperature from 400 to 700 °C in air.

9. A material used for adsorption separation of CH_4/CO_2 , which is obtained by calcining at least one of said SAPO-34 molecular sieves according to claims from 1 or 2 or at least one of the SAPO-34 molecular sieve prepared by said methods according to claims from 3 to 6, at a temperature from 400 to 700 °C in air.