

## Article

# Catalytic oxidation of styrene to benzaldehyde over a copper Schiff-base/SBA-15 catalyst



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### ABSTRACT

The amino-modified mesoporous material SBA-15 (NH<sub>2</sub>-SBA-15) was prepared via co-condensation of tetraethylorthosilicate with 3-aminopropyltriethoxysilane in the presence of an amphiphilic triblock copolymer as a pore-directing agent under acidic conditions. The SBA-15-supported Cu Schiff-base complex (Cu-SBA-15) was then synthesized by condensation of salicylaldehyde with NH<sub>2</sub>-SBA-15, followed by the addition of a solution of Cu(NO<sub>3</sub>)<sub>2</sub>. The supported complex was systematically characterized by elemental analysis, inductive coupled high frequency plasma atomic emission spectrometry, powder X-ray diffraction, Fourier transform infrared spectroscopy, ultraviolet-visible spectroscopy, field scanning electron microscopy, transmission electron microscopy, N<sub>2</sub> absorption-desorption, and thermo gravimetric analysis, and was used as the catalyst for the selective oxidation of styrene to benzaldehyde. The influence of the reaction parameters was assessed. The maximum conversion of styrene was 84.4% and the selectivity for benzaldehyde was 83.9%, when the reaction was conducted with a 2:1 molar ratio of H<sub>2</sub>O<sub>2</sub>:styrene in the presence of 3.8 wt% catalyst at 100 °C for 8 h. The TOF was 261.1 h<sup>-1</sup>, and the catalyst could be used three times without significant loss of activity. The uniformly sized pore channels, high specific surface area, and well-distributed active centers of the catalyst may contribute to the high activity.

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## 1. Introduction

Benzaldehyde is an important and valuable fine chemical that has been widely used in the synthesis of several substances, including perfumes, dyes, and pharmaceuticals [1]. Generally speaking, it can be obtained via several routes including benzyl alcohol oxidation, indirect electrochemical oxidation of toluene, benzoic acid hydrogenation, and benzyl chloride hydrolysis [2]. However, these methods suffer from lengthy procedures, expensive starting materials, and the generation of copious and toxic waste, which is environmentally undesirable. The most ideal preparation method is the direct oxidation of toluene with air or oxygen as the oxidant in the presence of a catalyst. Nevertheless, the lack of an efficient catalyst has curtailed the adoption of this method [3].

Recently, the synthesis of benzaldehyde by styrene oxidation has drawn much attention as the process is simple and environmentally friendly [4,5]. The key to the successful use of this transformation is the design of an active, selective, and recyclable catalyst. Various catalysts, such as metal oxides [6–10], metals [11,12], metal doped zeolites [13,14], solid acids [15,16], and metal Schiff bases or salen complexes [17,18], have been discussed. Among these, the metal Schiff-base complexes demonstrate high catalytic reactivity. However, these homogenous catalysts are usually difficult to separate from the reaction mixture, making the entire catalytic process unattractive for

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industrial application. Consequently, much attention has been focused on immobilizing the complexes on solid supports such as zeolites [19-22], ordered mesoporous silicates [23-28] or polymers [29-31] to afford heterogeneous catalysts. For example, Islam et al. [29] reported a reusable polymer-anchored Cu(II) complex for the oxidation of styrene to benzaldehyde with TBHP as oxidant. However, the conversion of styrene and the selectivity for benzaldehyde were only 53% and 52%, respectively. Yang et al. [24] prepared a series of SBA-15-supported Cu(II) and V(IV) Schiff-base complexes to study the oxidation of styrene. They found that the supported oxovanadium catalyst showed good selectivity for benzaldehyde using H<sub>2</sub>O<sub>2</sub> as the oxidant. The conversion of styrene reached 84.1% and the selectivity for benzaldehyde was up to 83.3%. However, an organic solvent was used. In addition, a post-synthesis grafting method was employed for the surface modification. In summary, although the modified solid support generally maintained the ordered structure of the parent materials, the distribution of amino groups varied, largely depending on the reactivity and concentration of the precursors used as well as

ty and recoverability [32–35]. In this paper, we report the direct synthesis of a uniform amino-modified SBA-15 (NH<sub>2</sub>-SBA-15) based on a single-step co-condensation of tetraethylorthosilicate (TEOS) with 3-aminopropyltriethoxysilane (APTES). The condensation reaction took place in the presence of an amphiphilic PEO-PPO-PEO triblock copolymer (P123) as a pore-directing agent. Treatment of the prepared NH<sub>2</sub>-SBA-15 with salicylaldehyde under condensation conditions followed by the addition of a solution of Cu(NO<sub>3</sub>)<sub>2</sub> formed the SBA-15-supported Cu(II) Schiff-base complex (Cu-SBA-15). The immobilized complex was successfully used as a catalyst for the selective oxidation of styrene to benzaldehyde in an aqueous medium.

the reaction conditions. The result was inferior catalytic activi-

## 2. Experimental

## 2.1. Catalyst preparation

## 2.1.1. Preparation of NH<sub>2</sub>-SBA-15

NH<sub>2</sub>-SBA-15 was prepared via the co-condensation method described in the literature [36]. P123 (4.0 g, Sigma-Aldrich) was dissolved in 125.0 g aqueous HCl (2 mol/L). After vigorous stirring at 40 °C for 4 h, 7.9 mL TEOS was added dropwise. The resultant solution was pre-hydrolyzed for 1 h before 0.92 mL APTES (Yaohua Chemical Industry, Shanghai, China) was added. After stirring for 20 h, the white solution was transferred into a polypropylene bottle, and aged at 90 °C for 24 h. The solid was collected by suction filtration and dried at 50 °C overnight. The residual P123 was removed by extraction with boiled ethanol (1.0 g of as-synthesized material per 200 mL of ethanol and 10 mL of concentrated HCl) for 24 h. The solid was collected by suction filtration, washed with water and ethanol, and dried at 50 °C overnight. Elemental analysis gave C 8.00%, H 3.27%, N 1.53%. The calculated N content was 1.09 mmol/g.

2.1.2. Preparation of Cu-SBA-15

NH<sub>2</sub>-SBA-15 (2.35 g) was dispersed in 80 mL methanol, and 20 mL salicylaldehyde/methanol solution (0.2 mol/L, 0.488 g salicylaldehyde) was added to form a light-yellow solution. After stirring at 30 °C for 6 h, the mixture was heated to 50 °C and 10 mL Cu(NO<sub>3</sub>)<sub>2</sub>/methanol solution (0.1 mol/L) was added dropwise to form a green solution. The reaction mixture was stirred for a further 12 h. The solid was then collected by suction filtration, washed with methanol and water, and finally dried at 80 °C overnight. The content of Cu was 0.101 mmol/g (ICP-AES).

### 2.2. Catalyst characterization

Low-angle X-ray diffraction (XRD) patterns were recorded with a Rigaku X-ray diffractometer with nickel-filtered Cu  $K_{\alpha}$ radiation at 40 kV and 30 mA. The samples were scanned in the range  $2\theta = 0.7^{\circ}-5.0^{\circ}$ . The Fourier transform infrared (FT-IR) spectra were collected on a Nicolet IS10 spectrometer (Thermo). Field emission scanning electron microscope (FESEM) images of the samples were obtained with an HITACHIS4800 FSEM and the particle sizes were measured using Adobe Photoshop software. The channel structures were observed on a JEM-2010-UHR transmission electron microscope (TEM) and ultraviolet-visible (UV-Vis) spectra were recorded on a Perkin Elmer UV-Vis spectrophotometer, Lambda 950, in the region of 200-800 nm. A BELSORP II adsorption instrument was used to determine the specific surface area, pore volume, and pore size. The specific surface area  $(A_{\text{BET}})$  was calculated by the BET method, the pore volume  $(V_{total})$  was calculated at the relative pressure of 0.99 and the pore size distributions and *D*<sub>peak</sub> were measured by the BJH method from the adsorption branch of the isotherms. Thermo gravimetric analysis (TGA) was carried out on a Netzsch STA409 instrument. CHN element analysis was carried out using a Perkin-Elmer 2400 instrument. The content of Cu was measured by inductive coupled high frequency plasma atomic emission spectrometry (ICP-AES) analysis.

## 2.3. Catalytic activity test

The oxidation of styrene was conducted in a 100-mL stainless-steel high-pressure autoclave (Parr, USA). The catalyst, water,  $H_2O_2$  (30 wt%), and styrene (5.200 g) were added into the vessel and it was then heated to 100 °C with a stirring speed of 800 r/min. After the reaction was complete, the mixture was centrifuged (8000 r/min, 2 min) and the solid was washed with EtOAc. The combined organic phases were dried over anhydrous MgSO<sub>4</sub>, and analyzed on a gas-chromatograph (GC2014, Shimadzu Instruments, Japan) equipped with DB-5 capillary column (30 m × 0.25 mm × 0.25 µm). The recovered catalyst was washed with acetone, alcohol, and water, and dried at 100 °C overnight before reuse.

## 3. Results and discussion

## 3.1. Catalyst characterization

are depicted in Fig. 1(a). The pattern of NH<sub>2</sub>-SBA-15 shows an intense diffraction indexed to the (100) plane, which indicates the typical mesoporous structure of SBA-15. The other two small characteristic peaks are not clearly observed, probably because the use of the silane coupling agent negatively affected the formation of micelles and resulted in an irregularity of the pores. FT-IR spectra of SBA-15, NH<sub>2</sub>-SBA-15, Schiff-base-SBA-15, and Cu-SBA-15 are shown in Fig. 1(b). The peaks at 467, 799, 1081, and 1230 cm<sup>-1</sup> indicate the characteristic absorption of O-Si-O bonds and the peak at 946 cm<sup>-1</sup> indicates the existence of Si-OH. The strong peak around 1632 cm<sup>-1</sup> in all the samples results largely from the bending vibration of adsorbed water, and the broad band observed between 3700 and 2800 cm<sup>-1</sup> is attributed to the -OH stretching vibration of water adsorbed on the surface of the catalyst. The presence of the -NH<sub>2</sub> stretching vibration at 3250 cm<sup>-1</sup>, the bending vibration at 1510 cm<sup>-1</sup> and the N-H bending vibration at 668 cm<sup>-1</sup> confirm the incorporation of the amino groups. The absorption

at about 1510 cm<sup>-1</sup> can be observed in both Schiff-base-SBA-15 and Cu-SBA-15 but has a low intensity, indicating the occurrence of the condensation of salicylaldehyde with the amino groups on the surface of NH<sub>2</sub>-SBA-15. Generally, a weak absorption peak of C=N stretching vibration should occur around 1640–1650 cm<sup>-1</sup> for the Schiff-base-SBA-15. However, this peak is overlapped by the stretching vibration absorption of H<sub>2</sub>O. Notably, comparison of the IR spectra of Cu-SBA-15 and Schiff-base-SBA-15 indicates the presence of a new adsorption peak around 1387 cm<sup>-1</sup> in Cu-SBA-15. This new peak may result from the red shift of the C=N stretching vibration absorption due to coordination to copper ions.

The FESEM image of NH<sub>2</sub>-SBA-15 is presented in Fig. 2(a). The sample shows a typical rod-like morphology of SBA-15. As shown in Fig. 2(b), the diameters of most particles are typically in the range of 600–700 nm and the average particle size is 740 nm. The TEM images of NH<sub>2</sub>-SBA-15 and Cu-SBA-15 are shown in Fig. 2(c) and (d), respectively,



Fig. 1. (a) XRD patterns of NH<sub>2</sub>-SBA-15 and Cu-SBA-15. (b) FT-IR spectra of SBA-15, NH<sub>2</sub>-SBA-15, Schiff-base-SBA-15, and Cu-SBA-15.



Fig. 2. (a) FESEM image of NH<sub>2</sub>-SBA-15; (b) Particle size distribution of the sample; (c) TEM image of NH<sub>2</sub>-SBA-15; (d) TEM image of Cu-SBA-15.



Fig. 3. UV-Vis spectra of NH<sub>2</sub>-SBA-15and Cu-SBA-15.

and provide a direct visualization of well-ordered hexagonal arrays of 1D mesoporous channels for both types of sample. Some pore walls in the sample have collapsed, which accounts for the absence of the two low-intensity characteristic peaks in the XRD patterns.

Figure 3 shows the UV-Vis spectra of  $NH_2$ -SBA-15 and Cu-SBA-15. In contrast to the spectrum of  $NH_2$ -SBA-15, a typical metal-ligand band around 390 nm is observed for Cu-SBA-15 [24], indicating the successful anchoring of the Cu(II) Schiff-base complex to the SBA-15 matrix.

As shown in Fig. 4, the N<sub>2</sub> adsorption-desorption isotherm for NH<sub>2</sub>-SBA-15 is type IV with an H1-type hysteresis loop, typical for mesoporous materials with cylindrical porous channels. The Cu-SBA-15 sample maintains the characteristics of type IV yet with an H2 hysteresis loop, probably because of a partial blocking of the pores. The size distribution curves show similar peaks at 5.41 nm while the peak for Cu-SBA-15 has a lower intensity and is broader. The textural properties of NH<sub>2</sub>-SBA-15 and Cu-SBA-15 are summarized in Table 1. The *A*<sub>BET</sub> and pore volumes of Cu-SBA-15 are slightly lower than those of NH<sub>2</sub>-SBA-15. We consider that these results reflect the introduction of the Schiff-base-coordinated copper complex on the material, leading to the blockage of some pores.

The TGA results for  $NH_2$ -SBA-15 and Cu-SBA-15 are illustrated in Fig. 5. For both  $NH_2$ -SBA-15 and Cu-SBA-15, the weight loss below 100 °C is mainly attributed to the loss of adsorbed water. The subsequent weight loss from 200–350 °C

#### Table 1

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Textural properties of NH<sub>2</sub>-SBA-15 and Cu-SBA-15.
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Sample	$A_{\text{BET}}/(m^2/g)$	$V_{\rm total}/(\rm cm^3/g)$	$D_{\rm peak}/\rm nm$	
NH <sub>2</sub> -SBA-15	443	0.54	5.41	
Cu-SBA-15	423	0.34	5.41	



Fig. 5. TG curves of NH<sub>2</sub>-SBA-15 and Cu-SBA-15.

is due to the decomposition of the amino groups and the Schiff bases. The weight loss of Cu-SBA-15 occurs at lower temperatures, relative to NH<sub>2</sub>-SBA-15, because of the higher molecular mass of the Schiff-bases compared with that of the amino groups. Finally, the decomposition of the aminopropyl groups caused the weight loss at temperatures above 350 °C.

## 3.2. Optimization of reaction conditions

## 3.2.1. Effect of the reaction time

Figure 6(a) shows the effect of reaction time on styrene oxidation at 100 °C using 0.300 g Cu-SBA-15 as the catalyst and 1.5 equiv.  $H_2O_2$  (10 wt% aqueous) as the oxidant. The styrene conversion increased with reaction duration while the selectivity for benzaldehyde declined slowly. The conversion reached 55.4% and the selectivity was 80% after 8 h. The conversion of styrene further increased after 9 h, but styrene then underwent polymerization, resulting in a considerable decrease in selectivity. This behavior is because the  $H_2O_2$  was completely consumed after 9 h, and the residual styrene underwent polymerization under these conditions.



Fig. 4. N2 adsorption-desorption isotherms (a) and corresponding mesopore size distribution curves (b) of NH2-SBA-15 and Cu-SBA-15.

## 3.2.2. Effect of the reaction temperature

Figure 6(b) shows the effect of reaction temperature on styrene oxidation using 0.300 g Cu-SBA-15 as the catalyst and 1.5 equiv.  $H_2O_2$  (10 wt% aqueous) as the oxidant for 8 h. It is clear that the conversion of styrene rapidly decreased with a decrease in the reaction temperature. When the reaction was performed at 80 °C, the conversion of styrene was only 6.8%. However, the selectivity was much higher at a lower reaction temperature because the rate of benzaldehyde oxidation to benzoic acid is also lower. When the reaction was conducted at 100 °C for 8 h, the conversion of styrene reached 55.4% and the selectivity for benzaldehyde was up to 79.3%.

## 3.2.3. Effect of the amount of $H_2O_2$

The effect of the amount of  $H_2O_2$  used was investigated by conducting the reactions at 100 °C for 8 h.  $H_2O_2$  (10 wt% aqueous) was used in the presence of 0.300 g Cu-SBA-15 and 17.167 g  $H_2O$ . As shown in Fig. 6(c), the conversion of styrene gradually increases with an increase in the amount of  $H_2O_2$ used. When 2 equiv.  $H_2O_2$  was used, the conversion of styrene was 70.6% and the selectivity for benzaldehyde was 79.6%. When 2.5 equiv.  $H_2O_2$  was used, the conversion increased to 84.5%, but the selectivity dropped sharply to 65.4%. A further increase in the amount of  $H_2O_2$  employed resulted in no increase in styrene conversion, and a much lower selectivity. This can be ascribed to the remaining  $H_2O_2$  promoting the further oxidation of benzaldehyde to benzoic acid. Overall, the use of 2 equiv.  $H_2O_2$  for the catalytic oxidation of styrene is suitable. of H<sub>2</sub>O added in the reaction determines the H<sub>2</sub>O<sub>2</sub> concentration. We investigated the effect of H<sub>2</sub>O by conducting the reactions at 100 °C for 8 h with various amounts of H<sub>2</sub>O in the presence of 0.300 g Cu-SBA-15 and 2 equiv. H<sub>2</sub>O<sub>2</sub>. The results are shown in Fig. 6(d). It is obvious that the conversion of styrene is the highest with no extra H<sub>2</sub>O added. The addition of H<sub>2</sub>O slowed the oxidation process and led to a low conversion.

## 3.2.5. Effect of catalyst loading

Figure 6(e) shows the influence of catalyst loading. The conversion of styrene and the selectivity for benzaldehyde were 84.4% and 83.9%, respectively, when the reaction was conducted at 100 °C for 8 h with 2 equiv.  $H_2O_2$  and 0.200 g Cu-SBA-15. An increase in the amount of catalyst used has little effect on the reaction. However, when the amount of the catalyst was reduced to 0.150 or 0.100 g, the reaction mixture became viscous after 8 h, probably because of the formation of styrene oligomers. A high loading of the catalyst is required to accelerate the rate of the oxidation process and prevent styrene polymerization.

Based on the above results, we obtained the optimum conditions as follows: the reaction should be carried out at 100 °C for 8 h using 2.0 equiv  $H_2O_2$  (30 wt% aqueous) and 3.8 wt% Cu-SBA-15 catalyst. The conversion of styrene obtained was up to 84.4%, and the selectivity for benzaldehyde was 83.9%. The TOF of the catalyst was 261.1 h<sup>-1</sup>. Benzoic acid was the only by-product and the formation of styrene oxide was not observed. At the optimum conditions, we found that this heterogeneous catalyst gave competitive results compared with other reported catalysts in terms of conversion and selectivity and, in addition, a high TOF was obtained (Table 2). When

## 3.2.4. Effect of the amount of $H_2O$

Since there is no co-solvent used in the reaction, the amount



**Fig. 6.** Effect of reaction time (a), temperature (b), amount of  $H_2O_2$  (c), weight of  $H_2O$  (d), and the amount of catalyst (e) on the oxidation of styrene to benzaldehyde. Other reaction conditions: (a) 100 °C,  $n(\text{styrene}):n(H_2O_2) = 1:1.5$ , 10 wt%  $H_2O_2$ , 0.3 g catalyst, 800 r/min; (b) 8 h,  $n(\text{styrene}):n(H_2O_2) = 1:1.5$ , 10 wt%  $H_2O_2$ , 0.3 g catalyst, 800 r/min; (b) 8 h,  $n(\text{styrene}):n(H_2O_2) = 1:1.5$ , 10 wt%  $H_2O_2$ , 0.3 g catalyst, 800 r/min; (c) 100 °C, 8 h, 10 wt%  $H_2O_2$ , 0.3 g catalyst, 800 r/min; (d) 100 °C, 8 h,  $n(\text{styrene}):n(H_2O_2) = 1:2$ , 0.3 g catalyst, 800 r/min; (e) 100 °C, 8 h,  $n(\text{styrene}):n(H_2O_2) = 1:2, 30$  wt%  $H_2O_2$ , 800 r/min.

 Table 2

 Activity of the supported metal complex catalysts.

Catabast	Conversion	Selectivity (%)		TOF (h. 1)	Oridant	Columnt	Defremes
Catalyst	(%)	Benzaldehyde	Styreneoxide	- 10F (n-1)	Oxidant	Solvent	Refrence
Cu-SBA-15	84.4	83.9	0	261.1	$H_2O_2$	H <sub>2</sub> O	this work
VO-Salen-SBA	84.1	83.3	11.9	67.4	$H_2O_2$	CH <sub>3</sub> CN	25
Cu-Salen-SBA	96.9	45.2	13.5	134.6	$H_2O_2$	CH <sub>3</sub> CN	25
Co-[H <sub>4</sub> ]Salen-SBA	78.5	43.6	54.1	196.0	Air	CH <sub>3</sub> CN	28
SBA-Fe(acac:salen)	45.0	99.0	0	0.24	$H_2O_2$	CH₃CN	26
SBA-VO(acac)	84.0	96.0	0	9.5	$H_2O_2$	CH <sub>3</sub> CN	27
PS-NH <sub>2</sub> -Cu-Sal	53.0	52.0	48.0	12.6	TBHP	CH <sub>3</sub> CN	29
Polymer supported cobalt complex	100	89.0	11.0	50.0	$H_2O_2$	$H_2O$	30

acetonitrile was used as a solvent under these conditions, the conversion of styrene reached up to 96.7%, while the selectivity for benzaldehyde was only 58.3% because of the formation of several by-products including benzoic acid (16.7%), phenylacetaldehyde (15.8%) and phenylethylene glycol (9.2%).

## 3.3. Catalyst recycling

Recyclability is one of the most important benefits of supported catalysts and makes them attractive for commercial applications. We therefore investigated the recovery and recyclability of the supported catalyst used. The results are summarized in Table 3 and show that the Cu-SAB-15 catalyst could be successfully used three times without significant loss of the activity. The main product and by-product were benzaldehyde and benzoic acid, respectively, and no styrene oxide was detected in any of the cases. The slight decrease in selectivity for the recovered catalyst is probably due to residual organics on the catalyst impeding the desorption of benzaldehyde from the catalytic centers, leading to over-oxidation to benzoic acid.

## 3.4. Mechanism of styrene oxidation

Styrene can generally be oxidized to benzaldehyde via two distinct pathways using a copper(II) Schiff-base complex as a catalyst (Scheme 1) [27]. The first path involves a radical mechanism. One molecule of  $H_2O_2$  adsorbed on the catalyst first decomposes to two hydroxyl radicals. These radicals then add to the C=C bond of styrene to form phenylethylene glycol, which then undergoes oxidative cleavage to form benzaldehyde and formaldehyde. Benzaldehyde is readily oxidized to benzoic acid. Alternatively, styrene first reacts with the active  $H_2O_2$  molecule to form styrene oxide, which may further transform

## Table 3

Experimental results on the recycling of Cu-SBA-15.

Cuelo	Styrene	Selectivity <sup>b</sup> (%)			
Cycle	Conversion <sup>a</sup> (%)	Benzaldehyde	Benzoic Acid	Styrene oxide	
1	84.4	83.9	16.1	0	
2	86.9	81.6	18.4	0	
3	85.7	81.2	18.8	0	
0.		1 . 1			

<sup>a</sup> Styrene conversion calculated via GC analysis.

<sup>b</sup> Product selectivity calculated via GC analysis.



Scheme 1. Plausible reaction mechanism of styrene oxidation.

to a hydroxyl-hydroxylperoxistyrene intermediate upon nucleophilic attack by another molecule of  $H_2O_2$ . Carbon bond cleavage of this unstable intermediate then produces benzaldehyde and formaldehyde. Since the intermediate styrene oxide was not detected during the course of the reaction, we concluded that the catalytic oxidation of styrene with Cu-SBA-15 follows the first pathway. In addition, as can be seen from the reaction mechanism, 2 equiv.  $H_2O_2$  is required for styrene oxidation to benzaldehyde. This is in good agreement with our experimental results, which showed that the conversion was generally low when less than 2 equiv. of  $H_2O_2$  was used, while a high conversion of styrene was observed, with decreased selectivity if more  $H_2O_2$  was employed.

## 4. Conclusions

We prepared NH<sub>2</sub>-SBA-15 using a one-pot co-condensation method, and anchored the copper(II) Schiff-base complex to afford a solid catalyst, Cu-SBA-15, for the selective oxidation of styrene to benzaldehyde. The highest conversion of styrene reached 84.4%, the selectivity for benzaldehyde was up to 83.9%, and the TOF of the catalyst was 261.1 h<sup>-1</sup>. The catalyst could be used three times without significant loss of activity. The distribution of amino groups on the material prepared by the one-pot co-condensation method may be better than is the case with a post-synthesis grafting method. Therefore, the active species could be well distributed on the surface of the prepared Cu-SBA-15 catalyst, leading to a higher catalytic activity.



A Cu-SBA-15 catalyst was prepared by immobilizing a copper Schiff-base complex onto an amino-modified mesoporous material SBA-15, synthesized via a one-pot co-condensation method. The catalyst was used for the oxidation of styrene to benzaldehyde in an aqueous medium.

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