



An efficient synthesis of benzoxazoles using silica-supported tin exchanged silicotungstic acid catalyst

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ABSTRACT

An efficient method for the preparation of benzoxazoles by reacting aminophenols with orthoesters in the presence of silica-supported tin exchanged silicotungstic acid catalyst under mild conditions with high yield and selectivity is demonstrated. The catalysts were characterized by FT-IR and pyridine adsorbed FT-IR. The catalyst exhibited consistent activity upon recycling and is highly active compared to other catalysts. The role of Lewis acidity of the catalysts and plausible reaction mechanism is presented.

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1. Introduction

Benzoxazole and substituted benzoxazoles are important compounds due to their biological activity and diverse medicinal uses such as gram-positive antibacterial agents, antibiotics, antiparasitic, anti-inflammatory, elastase inhibitors, anti-stress, ulcer and anti-cancer agents [1–3]. Benzobisoxazoles are also used as building blocks for novel organic semiconductors because conjugated small molecules and polymers are well suited for use in organic semi conducting applications [4]. Common synthetic routes to benzoxazole involves the coupling of aldehydes and carboxylic acids or their derivatives with 2-aminophenol in the presence of strong acids at high temperatures and high reaction time [5–10].

Unacceptability of the conventional liquid acid catalysts gives a major impetus to search for cleaner process. Such cleaner technologies are possible by making use of environmentally friendly catalysts like solid acids. In recent years, the use of heterogeneous solid acids received more interest for use as catalysts in different organic reactions [11]. Heterogeneous solid acid catalysts are more preferable over conventional acids as these are easily recoverable from reaction mixture by simple filtration and reused. Among different solid acid catalysts heteropolyacids (HPA) attained much attention due to their unique properties such as well-defined structure, Brønsted acidity, and possibility to modify their acid–base

properties. These catalysts have the ability to accept and release electrons and possess high proton mobility [12,13]. These are mainly used as acid and oxidation catalysts.

The major disadvantages of HPAs as catalysts lie in their low thermal stability, less surface area (1–10 m²/g) and solubility in polar media. HPAs can be made eco-friendly insoluble acid catalysts with high thermal stability and high surface area by exchanging its proton with metal ion and also supporting them on suitable supports. The support provides an opportunity to spread HPAs over a large surface area, which generally increases catalytic activity.

In the present communication, we report silica-supported tin exchanged silicotungstic acid (SnSTA) as a solid acid catalyst for the synthesis of benzoxazoles from reaction of 2-aminophenol with orthoesters under mild reaction conditions. The role of metal salts of heteropoly tungstate in generating Lewis acidity and plausible reaction mechanism is elucidated.

2. Experimental

2.1. Preparation of catalysts

A series of tin exchanged silicotungstic acid supported on silica (SnSTA/SiO₂) catalysts were prepared by wet impregnation method. Required quantities of silicotungstic acid (STA) and stannous chloride were dissolved in minimum amount of water. Calculated amount of silica was added to the above solution and aged for about 1 h. The excess water was evaporated on a water bath. The amount of tin was taken to replace two protons of STA

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($\text{H}_4\text{SiW}_{12}\text{O}_{40}$). The content of tin exchanged STA was varied from 5 to 25 wt% on silica. The dried catalysts were kept for further drying in a hot air oven at 120°C for 12 h and finally calcined at 300°C for 2 h.

2.2. Characterization of catalysts

The FT-IR spectra were recorded on a Bio-Rad Excalibur series spectrometer using the KBr disc method.

The nature of the acid sites (Brønsted and Lewis) of the catalysts samples were determined by in situ Fourier Transform Infrared (FT-IR) spectroscopy with chemisorbed pyridine. The Brønsted and Lewis acidities were estimated by identifying peak areas corresponding to the acid sites.

2.3. General reaction procedure

A mixture of aminophenol (1 mmol), triethylorthoformate (3 mmol) and catalyst (50 mg) in acetonitrile (4 ml) were taken in 25 ml two-necked round bottom flask. The reaction mixture was allowed to stir at 60°C on oil bath. The progress of the reaction was monitored by using TLC. After ensuring the completion of reaction the catalyst was separated by filtration. The products were identified by GC-MS (SHIMADZU-2010) analysis by separating the products on a DB-5 column.

3. Results and discussion

3.1. Characterization

3.1.1. Fourier transform-infrared spectroscopy (FT-IR)

FT-IR spectra of tin exchanged silicotungstic acid supported on silica are shown in Fig. 1. The catalyst showed four characteristic bands in the region $1100\text{--}800\text{ cm}^{-1}$.

IR bands were observed at 977 , 921 , 876 , and 786 cm^{-1} , which are assigned to the stretching vibrations of $\text{W}=\text{O}$, $\text{Si}-\text{O}$, $\text{W}-\text{O}_c-\text{W}$, $\text{W}-\text{O}_e-\text{W}$, respectively of Keggin ion [14]. The FT-IR patterns suggest the existence intact tin exchanged STA Keggin structure on silica. The results support that it is possible to prepare supported metal exchanged heteropoly tungstate in single step.

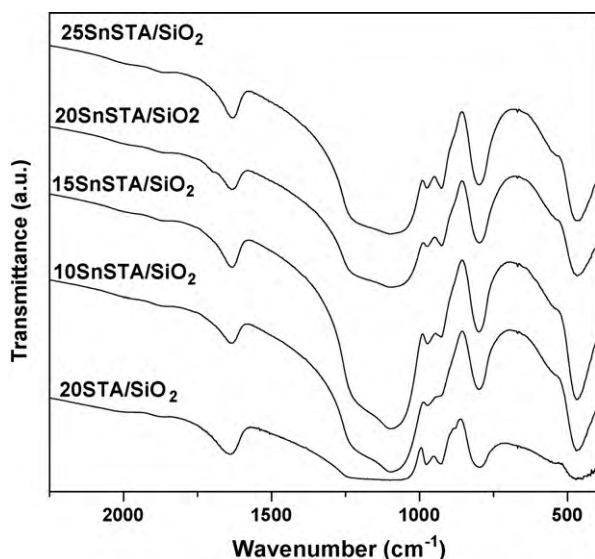
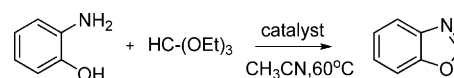


Fig. 1. FT-IR Spectra of silica-supported tin exchanged silicotungstic acid catalysts.



Scheme 1. Synthesis of benzoxazole from aminophenol and orthoesters.

Table 1

Effect of SnSTA content on silica for the synthesis of benzoxazole.

Catalyst	Conversion (%)	Selectivity (%)	
		Benzoxazole	Ether
5SnSTA/SiO ₂	58	100	–
10SnSTA/SiO ₂	70.6	100	–
15SnSTA/SiO ₂	76.8	100	–
20SnSTA/SiO ₂	85.4	100	–
25SnSTA/SiO ₂	87.2	95.4	4.6
20STA/SiO ₂	50.6	100	–
SnCl ₂	58	100	–

Reaction conditions: 2-aminophenol (1 mmol), triethylorthoformate (3 mmol), CH₃CN (solvent): 4 ml, catalyst weight: 50 mg, reaction temperature 60°C .

3.2. Synthesis of benzoxazole

Silica-supported tin exchanged STA catalysts were evaluated for the synthesis of benzoxazole. The reaction of 2-aminophenol with triethylorthoformate over these catalysts was carried (Scheme 1) and the results are shown in Table 1. The STA supported on silica catalyst (without tin) was also prepared and studied for comparison. The conversion of 2-aminophenol increased with increase in the content of SnSTA on silica and attained maximum at a loading of 20 wt%. The 20 wt% SnSTA/SiO₂ catalyst showed about 85% conversion of 2-aminophenol with 100% selectivity towards benzoxazole. The parent catalyst 20 wt% STA/SiO₂ showed only 50.6% conversion. The salts of tin also tested for this reaction and SnCl₂ showed about conversion of 58%. The presence of both tin and heteropoly anion leads to enhanced activity. The exchange of Sn resulted in substantial increase in the conversion of 2-aminophenol. The reaction profiles of these catalysts suggest that these are highly selective in getting the desired product with maximum conversion.

The variation in the activity with change in STA content is related to the high dispersion of active component on silica. There is not much variation in conversion beyond 20-wt% of SnSTA on silica. This suggests that bulk nature of STA was attained at high loadings. As the 20-wt% SnSTA supported on silica showed better activity for this reaction, the reaction profile was studied over this catalyst and the results are shown in Fig. 2. The conversion of aminophenol is increased with increase in reaction time and attained complete

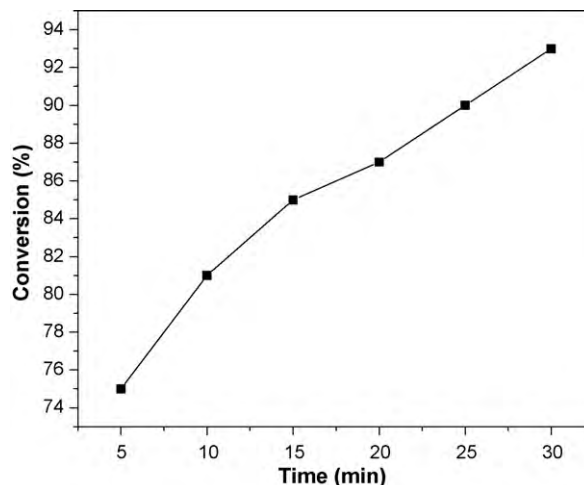


Fig. 2. Reaction profile for the synthesis of benzoxazole over SnSTA/SiO₂.

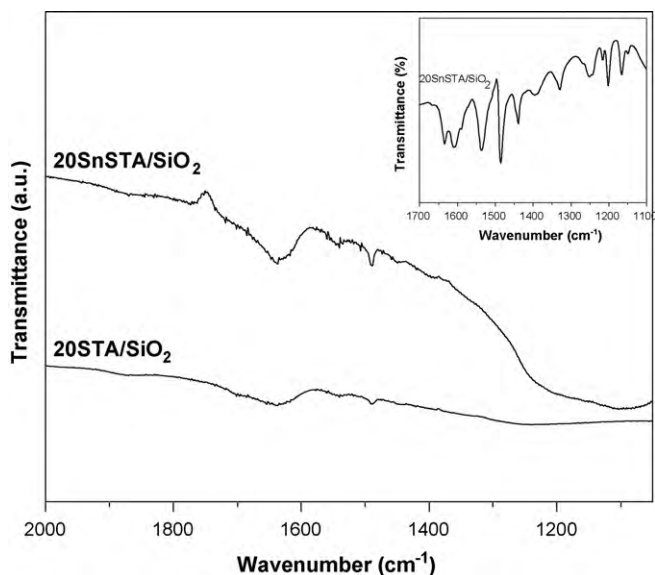


Fig. 3. Pyridine adsorption FT-IR Spectra of SnSTA/SiO₂ catalyst.

conversion with in 30 min. The catalyst showed high conversion even within 5 min of reaction time. The reported acid catalysts such as rare earth metal triflates, mineral acids took 1–5 h for reasonable conversion for similar reactions [4,10]. The high activity of the present catalyst is due to the presence of both Lewis and Brønsted acid sites as noticed from pyridine adsorbed FT-IR spectra shown in Fig. 3. The IR bands related to both Lewis and Brønsted acid peaks are clearly seen in the inset of Fig. 3. The present protocol requires strong acidity and the catalyst possess strong acidity resulting due to the presence of Sn. The presence of Sn results in generation of Lewis acidity [15]. The plausible reaction mechanism for the synthesis of benzoxazole from aminophenol with triethylorthoformate is shown in Scheme 2. The Lewis acidic sites of the Sn exchanged STA catalyst might be participating in the reaction by accepting the lone pair of electron from amine group of aminophenol. The high activity of the tin exchanged STA compared to the STA (Table 1), suggests the participation of Lewis acidic sites also for this reaction. The conversion obtained with tin salts further supports the role of tin in enhancing the overall activity of tin exchanged STA catalysts.

The influence of reaction temperature on the synthesis of benzoxazole over 20 wt% SnSTA/SiO₂ catalysts was evaluated and the results are shown in Fig. 4. The conversion of 2-aminophenol increased with increase in reaction temperature with near 100% selectivity to benzoxazole. The catalysts showed reasonable conversion of about 35% conversion even at 30 °C with in 15 min. These results suggest that the catalyst activity is comparable with that of homogeneous acid catalysts, which are generally more active.

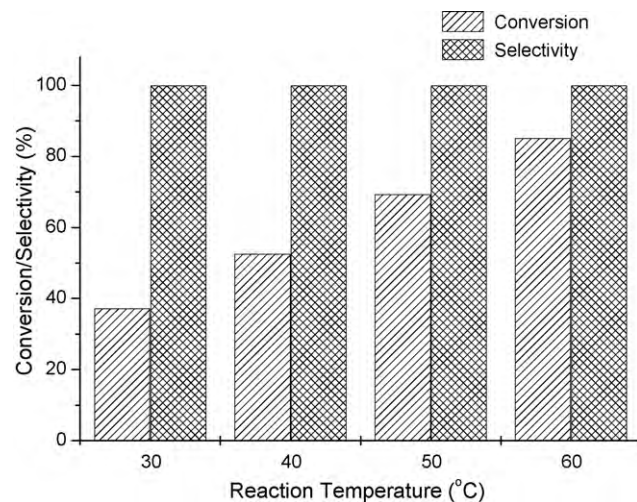


Fig. 4. Influence of reaction temperature for the preparation of benzoxazole over SnSTA/SiO₂ catalyst.

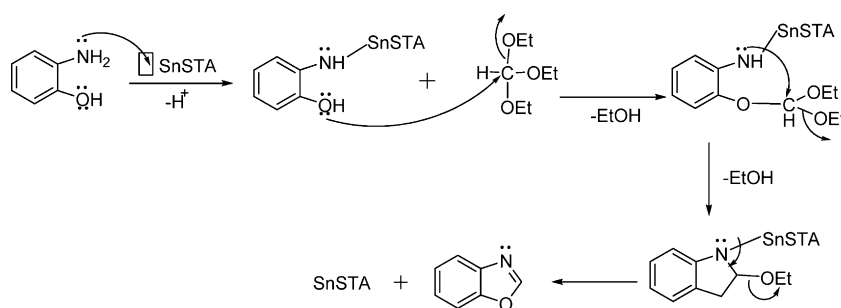
The scope of the reaction for the present catalyst was explored and the results are presented in Table 2. The catalyst is highly active for the synthesis of substituted benzoxazole within 15 min of reaction time with near 100% selectivity towards the desired products. The chloro or nitro group containing aminophenols were reacted with ethyl or methyl orthoesters with quantitative yields in short time. It is noteworthy to mention that the catalyst gives a selective product when different substrates are used for the synthesis of substituted benzoxazole. The metal exchanged heteropoly acids are working as metal salts of triflic acids.

3.3. Recyclability of the catalysts

After completion of the reaction, the catalyst was separated by simple filtration and washed 2–3 times with acetonitrile. Later the catalyst was dried in air oven at 120 °C for 1 h and reused. The recovery of the catalyst is quantitative and is varied with in 95–90%. The results obtained by recycling of the catalyst are shown in Table 3. The conversion of the aminophenol after four cycles was almost constant and no loss of catalytic activity upon reuse. The recycling result suggests heterogeneity of the catalyst.

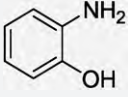
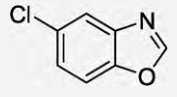
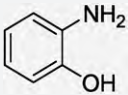
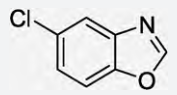
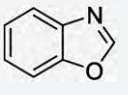
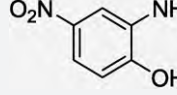
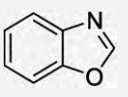
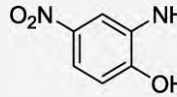
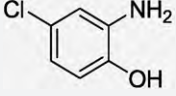
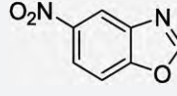
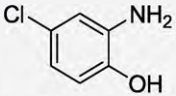
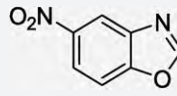
3.4. Comparison of different catalysts with SnSTA/SiO₂

The present catalyst SnSTA/SiO₂ was compared with the reported catalysts for the synthesis of benzoxazole. The comparative results are shown in Table 4. When compared to other catalysts, present catalyst showed high conversion with 100% selectivity to benzoxazole at 60 °C temperature within 15 min. Where as the other reported acid catalysts took about 15–240 min at high



Scheme 2. Plausible reaction mechanism for the synthesis of benzoxazole over tin exchange silicotungstic acid.

Table 2
Synthesis of substituted benzoxazole over SnSTA/SiO₂ catalyst.

Aminophenol	Orthoester	Product	Time (min)	Conversion (%)	Selectivity (%)
	HC-(OEt) ₃		15	85.4	100
	HC-(OMe) ₃		15	83.2	100
	HC-(OEt) ₃		15	86.5	100
	HC-(OMe) ₃		15	86.1	100
	HC-(OEt) ₃		15	83.6	100
	HC-(OMe) ₃		15	83.4	100

Reaction conditions: aminophenol (1 mmol), orthoester (3 mmol), catalyst weight: 50 mg, CH₃CN (solvent): 4 ml, reaction temperature 60 °C.

Table 3
Recycling results of SnSTA/SiO₂ catalyst.

S. no.	No. of recycles	Conversion (%)	Selectivity (%)	Catalyst recovery (%)
1	0	85.4	100	–
2	1	83.6	100	95
3	2	81.7	100	93
4	3	79.4	100	90

Table 4
Comparison of different catalyst with SnSTA/SiO₂.

S. no.	Substrate 1	Substrate 2	Catalyst	Reaction time	Temperature (°C)	Yield (%)	References
1	o-Hydroxyamino pyridine	Orthoester	p-TsOH	–	100 °C	60	[10]
2	Aminophenol	Carboxylic acid	PS-PPh ₃ /CCl ₃ CN	15 min	Microwave, 150 °C	97	[9]
3	Aminophenol	Aldehyde	Activated carbon	4 h	120 °C	78	[8]
4	Aminophenol	Triethylorthoester	ZrOCl ₂ ·8H ₂ O	10 min	85 °C	89	[5]
5	Diamino benzenediol	Orthoester	H ₂ SO ₄	1 h	130 °C	64	[4]
6	Aminophenol	Triethylorthoester	SnSTA/SiO ₂	15 min	60 °C	85	Present study

temperature to get reasonable conversion. Moreover, most of the reported catalysts are homogenous in nature and used in stoichiometric quantities.

4. Conclusions

Silica-supported tin exchanged STA catalysts were prepared with intact Keggin structure. SnSTA/SiO₂ catalyst is demonstrated as an efficient solid acid catalyst for the synthesis of benzoxazoles under mild reaction conditions with in short reaction time. The catalyst is active even at ambient temperatures with high activity and selectivity. The exchange of tin with the protons of STA results in generating the Lewis acidity and there by results in substantial increase in catalytic activity for the synthesis of benzoxazole. The involvement of Lewis acid sites for this reaction was explained by plausible reaction mechanism. The catalyst is reusable with consistent activity

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