J. Chem. Sci. Vol. 127, No. 7, July 2015, pp. 1315–1320.
DOI 10.1007/s12039-015-0895-x

Synthesis of naphthoxazinone derivatives using silica-bonded *S*-sulfonic acid as catalyst under solvent-free conditions

KHODABAKHSH NIKNAM* and PARISA ABOLPOUR
Department of Chemistry, Faculty of Sciences, Persian Gulf University, Bushehr 75169 Iran
e-mail: niknam@pgu.ac.ir; khniknam@gmail.com

MS received 19 September 2014; revised 17 April 2015; accepted 17 April 2015

Abstract. Silica-bonded *S*-sulfonic acid is employed as a recyclable catalyst for the synthesis of naphthoxazinone derivatives from the reaction of β-naphthol, aromatic aldehydes and urea at 150°C under solvent-free conditions. The heterogeneous catalyst was recycled for five runs after the reaction of β-naphthol, benzaldehyde and urea without losing its catalytic activity.

Keywords. Silica-bonded propyl-*S*-sulfonic acid; naphthoxazinones; aromatic aldehydes; heterogeneous catalysts; solid acids.

1. Introduction

The important advantages of solid acids and bases such as operational simplicity, environmental compatibility, non-toxicity, reusability, low cost, and ease of isolation recommend them as suitable catalytic systems in organic synthesis.[1–4] In fact, simplified recovery and reusability are critical advantages of heterogeneous catalytic systems, which could lead to novel environmentally benign chemical procedures for academia and industry.[1–5] Metal colloids, mineral clays and supported reagents on silica gel, alumina and other solid supports are various types of heterogeneous and reusable catalytic systems, which have been designed and used in organic synthesis. Among them, silica-supported catalysts have attracted more attention because they are inexpensive, easy to prepare, and insoluble in most of organic solvents, which make them being recycled from various reactions

Along the line of our studies in preparation and application of solid acid and base catalysts in chemical transformations,[6–24] herein, we report the catalytic activity of some of these catalysts such as, silica-bonded propyl *S*-sulfonic acid (**1**), silica-bonded *N*-propyl sulfamic acid (**2**), silica-bonded tin chloride (**3**), silica-bonded titanium chloride (**4**), silica-bonded n-propyl-imidazolium hydrogen sulfate (**5**), and silica-bonded n-propyl-methylimidazolium hydrogen sulfate (**6**)] as heterogeneous solid acid for the synthesis of naphthaoxazines (scheme 1).

Aromatic-condensed oxazinone derivatives are an important class of heterocyclic compounds, since many of these heterocyclic systems exhibit biological activities.[25] Among them, naphthalene-condensed 1,3-oxazin-3-ones have been reported to act as antibacterial agents.[25,26] This class of compounds has also been used as precursors in the preparation of phosphinic ligands for asymmetric catalysis.[27] Due to the pharmacological importance, several protocols have been developed over a period of time. The conventional method includes condensation of phenols, formaldehyde and amines through Mannich reaction.[28] Additionally they have been synthesized by the reaction of amino alkylnaphthols with phosgene[29] and reaction with carbonyl di-imidazole.[30] However, these methods have some drawbacks like prolonged reaction time, lack of easy availability/preparation of starting materials, and hazardous reaction conditions.

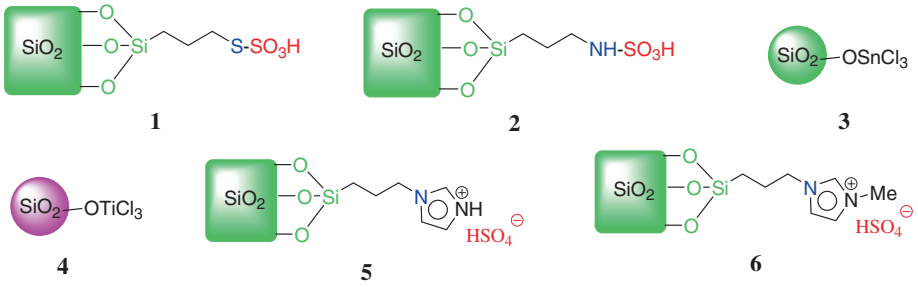
Recently, the preparation of naphthoxazinone derivatives has been achieved in the presence of various catalysts such as *p*-TSA,[31] [bmim]Br,[32] TMSCl/NaI,[33] $HClO_4/SiO_2$,[34] TMSCl,[35] silica gel,[36] phosphomolybdic acid,[37] Cu NPs,[38] Thiamine hydrochloride,[39] ZnO NPs,[40] $FeCl_3/SiO_2$ NPs,[41] and silica supported Preyssler heteropoly acid.[42]

2. Experimental

2.1 *General*

Chemicals were purchased from Fluka, Merck and Aldrich Chemical Companies. All the products were characterized by comparison of their IR, ^{1}H NMR and ^{13}C NMR spectroscopic data and their melting points

*For correspondence



Scheme 1. The structure of silica functionalized catalysts which were used.

with reported values.[31–42] Solid acids **1**-**6** were prepared according to our previous reported methods.[6–8,12,19,23,24]

2.2 *General procedure for the synthesis of naphthoxazinones*

A mixture of β-naphthol (1 mmol), aromatic aldehyde (1 mmol), urea (1.2 mmol), 1 (0.02 g, 0.68 mol%), under solvent-free conditions was heated at 150°C for the time specified in table 2. The reaction was followed by TLC. After completion of the reaction, ethanol (10 mL) was added and filtered. The remaining solid was washed with warm ethanol (3 × 5 mL) in order to separate catalyst. After cooling the organic phase, the crude product was precipitated and filtered. The crude sample was passed through a short column chromatography using n-hexane/ethyl acetate as eluent. The recovered catalyst was dried and reused for subsequent runs.

2.2a *1,2-Dihydro-1-(phenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4a**)*: M.p. 220-222°C, (Lit.[31] M.p. 218-220°C); ^{1}H NMR (400 MHz, DMSO-d$_6$): δ (ppm) 6.20 (d, 1H, J = 2.7 Hz, CH), 7.23-7.35 (m, 5H, Ar), 7.39 (d, 1H, J = 7.1 Hz, Ar), 7.43-7.51 (m, 2H, Ar), 7.82 (d, 1H, J = 6.6 Hz, Ar), 7.95 (d, 1H, J = 7.3 Hz, Ar), 8.00 (d, 1H, J = 7.3 Hz, Ar), 8.86 (d, 1H, J = 2.2 Hz, NH); ^{13}C NMR (100 MHz, DMSO-d$_6$): δ (ppm) 54.23, 114.52, 117.33, 123.58, 125.55, 127.43, 127.83, 128.48, 129.09, 129.35, 129.41, 130.69, 130.88, 143.34, 147.89, 149.77.

2.2b *1,2-Dihydro-1-(4-chlorophenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4b**)*: M.p. 208-210°C, (Lit.[34] M.p. 212-214°C); ^{1}H NMR (400 MHz, DMSO-d$_6$): δ (ppm) 6.25 (s, 1H, CH), 7.32-7.35 (m, 2H, Ar), 7.38-7.41 (m, 3H, Ar), 7.44-7.51 (m, 2H, Ar), 7.79 (d, 1H, J = 6.3 Hz, Ar), 7.96 (d, 1H, J = 6.3 Hz, Ar), 8.01 (d, 1H, J = 7.1 Hz, Ar), 8.91 (s, 1H, NH); ^{13}C NMR (100 MHz, DMSO-d$_6$): δ (ppm) 53.43, 114.04, 117.36, 123.51, 125.63, 127.93, 129.14, 129.38, 129.43, 130.89, 142.24, 147.92, 149.62.

2.2c *1,2-Dihydro-1-(4-bromophenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4c**)*: M.p. 218-220°C, (Lit.[38] M.p. 218-219°C); ^{1}H NMR (400 MHz, DMSO-d$_6$): δ (ppm) 6.23 (d, 1H, J = 2.4 Hz, CH), 7.27 (dt, 2H, J_1 = 6.8 Hz, J_2 = 1.8 Hz, Ar), 7.38 (d, 1H, J = 7.3 Hz, Ar), 7.44-7.51 (m, 2H, Ar), 7.54 (dt, 2H, J_1 = 6.8 Hz, J_2 = 1.8 Hz, Ar), 7.79 (d, 1H, J = 6.6 Hz, Ar), 7.96 (d, 1H, J = 7.3 Hz, Ar), 8.01 (d, 1H, J = 7.3 Hz, Ar), 8.90 (d, 1H, J = 2.4 Hz, NH); ^{13}C NMR (100 MHz, DMSO-d$_6$): δ (ppm) 53.53, 113.97, 117.35, 121.66, 123.50, 125.64, 127.93, 129.15, 129.25, 129.71, 130.90, 132.36, 142.64, 147.93, 149.61.

2.2d *1,2-Dihydro-1-(4-fluorophenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4d**)*: M.p. 200-202°C, (Lit.[42] M.p. 201-203 °C); ^{1}H NMR (400 MHz, DMSO-d$_6$): δ (ppm) 6.25 (s, 1H, CH), 7.16 (t, 2H, J = 6.8 Hz, Ar), 7.34-7.40 (m, 3H, Ar), 7.44-7.53 (m, 2H, Ar), 7.80 (d, 1H, J = 6.4 Hz, Ar), 7.96 (d, 1H, J = 6.1 Hz, Ar), 8.00 (d, 1H, J = 7.1 Hz, Ar), 8.89 (s, 1H, NH); ^{13}C NMR (100 MHz, DMSO-d$_6$): δ (ppm) 53.39, 114.32, 116.14, 116.32, 117.36, 123.54, 125.60, 127.89, 129.13, 129.26, 129.54, 129.61, 130.82, 130.89, 147.86, 149.68, 162.05 (d, J_{C-F} = 194.3 Hz).

2.2e *1,2-Dihydro-1-(3-fluorophenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4e**)*: M.p. 217-219°C, (Lit.[40] M.p. 218-220 °C); ^{1}H NMR (400 MHz, DMSO-d$_6$): δ (ppm) 6.26 (d, 1H, J = 2.4 Hz, CH), 7.06-7.14 (m, 2H, Ar), 7.21 (dt, 1H, J_1 = 7.3 Hz, J_2 = 1.7 Hz, Ar), 7.35-7.41 (m, 2H, Ar), 7.45-7.54 (m, 2H, Ar), 7.83 (d, 1H, J = 6.8 Hz, Ar), 7.97 (dd, 1H, J_1 = 6.6 Hz, J_2 = 1.0 Hz, Ar), 8.02 (d, 1H, J = 7.3 Hz, Ar), 8.92 (d, 1H, J = 2.4 Hz, NH); ^{13}C NMR (100 MHz, DMSO-d$_6$): δ (ppm) 53.58, 113.90, 114.37, 114.54, 115.28, 115.45, 117.36, 123.35, 123.52, 125.66, 127.98, 129.14, 129.31, 130.88, 130.94, 131.59, 131.65, 145.94, 145.99, 147.99, 149.64, 162.62 (d, J_{C-F} = 194.3 Hz).

2.2f *1,2-Dihydro-1-(3-nitrophenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4f**)*: M.p. 210-212°C; ^{1}H NMR (400 MHz, DMSO-d$_6$): δ (ppm) 6.48 (s, 1H, CH), 7.41-7.54 (m, 3H,

Ar), 7.61-7.68 (m, 2H, Ar), 7.85 (d, 1H, $J = 6.6$ Hz, Ar), 7.98 (d, 1H, $J = 6.3$ Hz, Ar), 8.05 (d, 1H, $J = 7.3$ Hz, Ar), 8.15 (d, 1H, $J = 7.9$ Hz, Ar), 8.29 (s, 1H, Ar), 9.03 (s, 1H, NH). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 52.78, 112.91, 116.91, 121.87, 122.98, 123.08, 125.27, 127.64, 128.72, 130.43, 130.75, 133.45, 144.68, 147.71, 147.98, 149.01. Elemental analysis: for $C_{18}H_{12}N_2O_4$ calculated: C, 67.50; H, 3.78; N, 8.75. Found: C, 67.29; H, 3.89; N, 8.59.

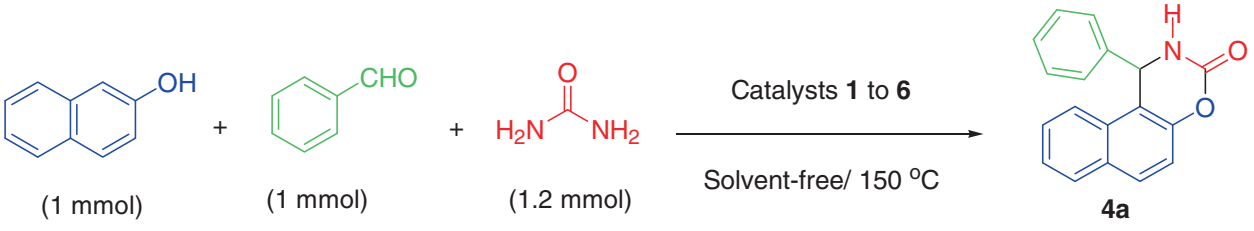
2.2g *1,2-Dihydro-1-(4-methoxyphenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4g**)*: M.p. 186-188°C, (Lit.[40] M.p. 188-190°C); ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 3.69 (s, 3H, OMe), 6.14 (d, 1H, $J = 2.4$ Hz, CH), 6.88 (dt, 2H, $J_1 = 7.1$ Hz, $J_2 = 2.1$ Hz, Ar), 7.22 (dt, 2H, $J_1 = 7.1$ Hz, $J_2 = 2.1$ Hz, Ar), 7.37 (d, 1H, $J = 7.1$ Hz, Ar), 7.43-7.51 (m, 2H, Ar), 7.80 (d, 1H, $J = 6.6$ Hz, Ar), 7.94 (d, 1H, $J = 7.6$ Hz, Ar), 7.98 (d, 1H, $J = 7.3$ Hz, Ar), 8.79 (d, 1H, $J = 2.4$ Hz, NH); ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 53.65, 55.56, 114.70, 114.77, 117.32, 123.62, 125.49, 127.75, 128.66, 129.06, 129.34, 130.55, 130.87, 135.50, 147.77, 149.80, 159.31.

2.2h *1,2-Dihydro-1-(4-iso-propylphenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4h**)*: M.p. 172-174°C, (Lit.[41] M.p. 171-172°C); ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 1.13 (d, 3H, $J = 5.5$ Hz, Me), 1.14 (d, 3H, $J = 5.5$ Hz, Me), 2.81 (h, 1H, $J = 5.5$ Hz, CH), 6.15 (d, 1H, $J = 2.4$ Hz, CH), 7.20 (d, 2H, $J = 6.6$ Hz, Ar), 7.23 (d, 2H, $J = 6.4$ Hz, Ar), 7.38 (d, 1H, $J = 7.1$ Hz, Ar), 7.43-7.52 (m, 2H, Ar), 7.84 (d, 1H, $J = 6.8$ Hz, Ar), 7.95 (d, 1H, $J = 7.3$ Hz, Ar), 7.99 (d, 1H, $J = 7.3$ Hz, Ar), 8.80 (d, 1H, $J = 2.4$ Hz, NH); ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 24.18, 24.24, 33.54, 53.94, 114.75, 117.33, 123.59, 125.53, 127.31, 127.36, 127.83, 129.08, 129.36, 130.58, 130.87, 140.87, 147.81, 148.67, 149.86.

2.2i *1,2-Dihydro-1-(4-methylphenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4i**)*: M.p. 167-169°C, (Lit.[34] M.p. 169-171°C); ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 2.22 (s, 3H, Me), 6.14 (s, 1H, CH), 7.12 (d, 2H, $J = 6.1$ Hz, Ar), 7.19 (d, 2H, $J = 6.1$ Hz, Ar), 7.37 (d, 1H, $J = 7.1$ Hz, Ar), 7.43-7.51 (m, 2H, Ar), 7.80 (d, 1H, $J = 7.2$ Hz, Ar), 7.94 (d, 1H, $J = 6.4$ Hz, Ar), 7.98 (d, 1H, $J = 7.1$ Hz, Ar), 8.82 (s, 1H, NH); ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 21.09, 53.96, 114.64, 117.31, 123.60, 125.50, 127.34, 127.77, 129.06, 129.34, 129.90, 130.59, 130.85, 137.77, 140.47, 147.81, 149.79.

2.2j *1,2-Dihydro-1-(3-methylphenyl)naphtho[1,2-e][1,3]oxazine-3-one (**4j**)*: M.p. 206-208°C, (Lit.[41] M.p. 206-208°C); ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 2.23 (s, 3H, Me), 6.15 (s, 1H, CH), 7.05-7.13 (m, 2H, Ar), 7.15 (s, 1H, Ar), 7.21 (t, 1H, $J = 6.8$ Hz, Ar), 7.39 (d, 1H, $J = 7.1$ Hz, Ar), 7.43-7.52 (m, 2H, Ar), 7.81 (d, 1H, $J = 6.8$ Hz, Ar), 7.92-7.96 (m, 1H, Ar), 7.99 (dd, 1H, $J_1 = 7.2$ Hz, $J_2 = 1.0$ Hz, Ar), 8.82 (brs, 1H, NH); ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 21.50, 54.33, 114.50, 117.34, 123.56, 124.58, 125.53, 127.81, 127.89, 129.08, 129.17, 129.31, 129.39, 130.66, 130.87, 138.61, 143.33, 147.88, 149.79.

Table 1. The reaction of β-naphthol, benzaldehyde, and urea, in the presence of solid acids **1**-**6** under solvent-free conditions.



(1 mmol) (1 mmol) (1.2 mmol) **4a**

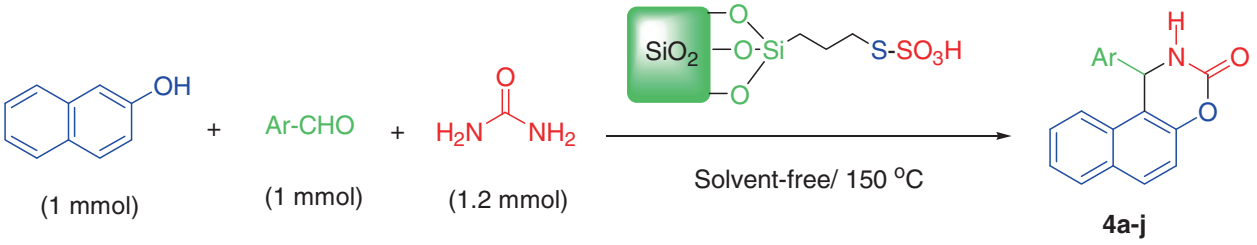
Entry	Catalyst	Catalyst loading (g)	Time (min)	Yield%[a]
1	No catalyst	–	720	trace
2	**1**	0.01	90	70
3	**1**	0.02	60	90
4	**1**	0.03	60	90
5	**2**	0.02	60	85
6	**3**	0.02	60	70
7	**4**	0.02	60	60
8	**5**	0.02	60	50
9	**6**	0.02	60	55

[a]Isolated yield.

3. Results and Discussion

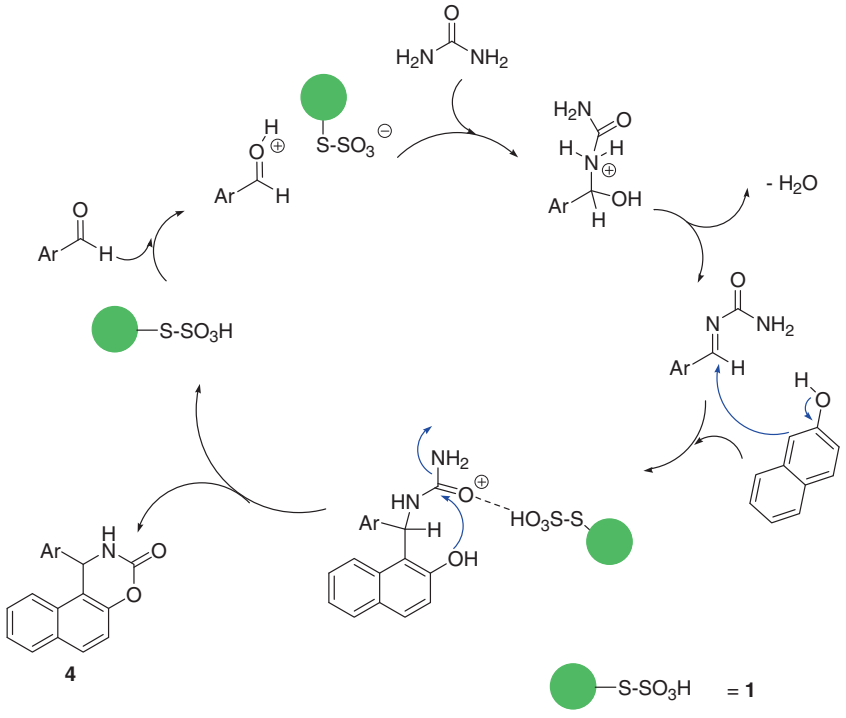
In our initial study, evaluation of a series of silica immobilized acids [silica-bonded propyl *S*-sulfonic acid (**1**), silica-bonded *N*-propyl sulfamic acid (**2**), silica supported tin chloride (**3**), silica supported titanium chloride (**4**), silica-bonded n-propyl-imidazolium hydrogen sulfate (**5**), and silica-bonded n-propyl-methylimidazolium hydrogen sulfate (**6**)] was carried out for the synthesis of naphthoxazinones under thermal and solvent-free conditions. After some preliminary experiments, it was found that a mixture of β-naphthol, benzaldehyde, and urea at 150°C under solvent-free conditions in the presence of a catalytic amount of these heterogeneous solid acids could afford 1,2-dihydro-1-(phenyl)naphtho[1,2-*e*][1,3]oxazine-3-ones (**4a**) in very good yield (table 1).

Table 2. Synthesis of various naphthoxazinones in the presence of **1** under solvent-free conditions at 150°C.



Entry	Ar	Product	Time (min)	Yield (%)[a]	M.p. (°C)	Lit. M.p. (°C)
1	C_6H_5-	**4a**	60	90	220-222	218-220[31]
2	4-Cl-C_6H_4-	**4b**	50	92	208-210	212-214[34]
3	4-Br-C_6H_4-	**4c**	60	92	218-220	218-219[38]
4	4-F-C_6H_4-	**4d**	50	94	200-202	201-203[42]
5	3-F-C_6H_4-	**4e**	45	94	217-219	218-220[40]
6	3-O_2N-C_6H_4-	**4f**	45	92	210-212	–
7	4-MeO-C_6H_4-	**4g**	90	85	186-188	188-190[40]
8	4-iso-Pr-C_6H_4-	**4h**	60	90	172-174	171-172[41]
9	4-Me-C_6H_4-	**4i**	90	80	167-169	169-171[34]
10	3-Me-C_6H_4-	**4j**	80	82	206-208	206-208[41]

[a]Isolated yield.



Scheme 2. A plausible mechanism for the synthesis of naphthoxazinones using **1** as catalyst.

We examined this reaction in the absence of catalyst and it was found that when the reaction was carried out without any catalyst resulted in poor yield (table 1, entry 1). The best result was obtained when **1** was used for which the yield was up to 90% (table 1, entry 3). In addition, the result of this condensation in the presence of other silica immobilized acids (**2-6**) gave the corresponding product in slightly longer reaction time and lower yield (table 1, entries 5-9).

So, the optimal amount of **1** was 0.02 g (0.68 mol%[6,8] per 1 mmol of β-naphthol at 150°C under solvent-free conditions. The lower loading amounts of **1** gave the corresponding product in lower yield and longer reaction time (table 1, entry 2). Therefore, we employed the optimized conditions (0.02 g mmol^{-1} of **1** at 150°C under solvent-free conditions) for the condensation reaction of β-naphthol, urea with aromatic aldehydes into the corresponding naphthoxazinone derivatives (table 2).

A wide range of aromatic aldehydes were employed and all naphthoxazinones were obtained in good to high yields, demonstrating that this is a general method that tolerates bothelectron-withdrawing and electron-donating constituents. Aromatic aldehydes with electron-donating substituent such as MeO, iso-Pr, and Me, were reacted with β-naphthol and urea under optimized conditions in good to high yield (table 2, entries 7-10). Aromatic aldehydes with electron-deficient such as 4-F, 3-F, and 3-NO_2 groups reacted with β-naphthol and urea under optimized conditions in high yield (table 2, entries 4-6). This method not only affords the products in good to high yield but also avoids the problems associated with catalyst cost, handling, safety, and pollution.

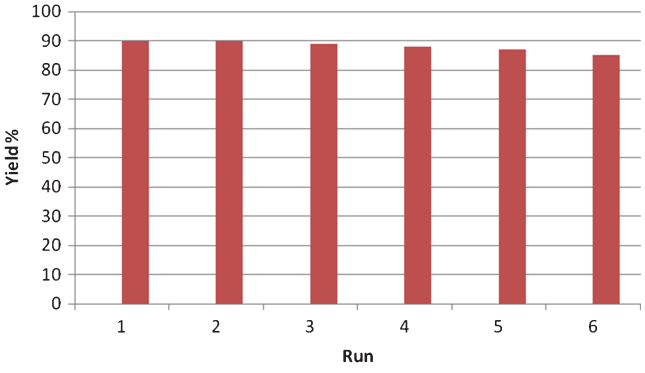


Figure 1. Recyclability of **1** (0.02 g) in the reaction of β-naphthol (1 mmol) with benzaldehyde (1 mmol) and urea (1.2 mmol) under solvent-free conditions at 150°C. Time = 60 min.

On the basis of the above observations and the literature reports,[31,40] a plausible reaction pathway for the formation of naphthoxazinone is depicted in scheme 2. The aryl aldehyde was protonated with solid acid **1** to generate the more electrophilic carbon center, followed by the nucleophilic attack of urea to give reactive acylimine intermediate. The resulting acylimine intermediate undergoes cyclization with 2-naphthol affording the corresponding desired naphthoxazinone followed by the elimination of ammonia.

The possibility of recycling the catalyst was examined using the reaction of benzaldehyde, β-naphthol and urea under optimized conditions. Upon completion, etha nol (10 mL) was added and the reaction mixture was filtered. The remaining solid was washed with warm ethanol, and the recycled catalyst was saved for the next reaction. The recycled catalyst could be reused five times without any further treatment. No observation of any appreciable loss in the catalytic activity of **1** was observed (figure 1).

Finally, a comparative study of **1** with other recently reported catalysts for the condensation of benzaldehyde and β-naphthol and urea as a model compound was made which revealed that **1** is an equally efficient and reusable catalyst (table 3).

4. Conclusion

In conclusion, we have shown that silica-bonded propyl-*S*-sulfonic acid (**1**), which can be prepared from commercially available and cheap starting materials, catalyzed efficiently this three-component condensation reaction for the synthesis of naphthoxazinones. The

Table 3. Comparison of the result of condensation reaction of benzaldehyde, β-naphthol and urea in the presence of different catalysts.

Entry	Catalyst	Catalyst loading (g)	Conditions	Time (min)	Yield (%)[a]	Ref.
1	*p*-TSA	0.052 (0.3 mmol)	Solvent-free/160°C	90	58	31
2	TMSCl/NaI	(1.5 equiv.)	DMF/140°C	90	81	33
3	$HClO_4/SiO_2$	0.04 (2 mol%)	Solvent-free/150°C	360	88	34
4	Cu NPs	0.001	K_2CO_3, PEG/rt	45	93	38
5	ZnO NPs	(0.3 equiv.)	Solvent-free/150°C	90	85	40
6	$FeCl_3/SiO_2$ NPs	10-4 (0.4 mol%)	Solvent-free/150°C	10	85	41
7	**1**	0.02 (0.68 mol%)	Solvent-free/150°C	60	90	Present work

[a]Isolated Yield.

simplicity of the eco-friendly and safe procedure, and reusability of catalyst are the advantages of this method.

Supplementary Information

Supplementary Information is available at www.ias.ac.in/chemsci.

Acknowledgements

We are thankful to Persian Gulf University Research Council for partial support of this work. Also, we are thankful to the School of Chemistry, Manchester University for NMR spectra.

References

1. Melero J A, Grieken R V and Morales G 2006 *Chem. Rev.* **106** 3790
2. Karimi B and Zareyee D 2008 *Org. Lett.* **10** 3989
3. Niknam K and Saberi D 2009 *Appl. Catal. A Gen.* **366** 220
4. Shakeri M S, Tajik H and Niknam K 2012 *J. Chem. Sci.* **124** 1025
5. Choudhary D, Paul S, Gupta R and Clark J H 2006 *Green Chem.* **8** 479
6. Niknam K, Saberi D and Nouri Sefat M 2009 *Tetrahedron Lett.* **50** 4058
7. Niknam K and Saberi D 2009 *Tetrahedron Lett.* **50** 5210
8. Niknam K, Saberi D and Baghernejad M 2009 *Chin. Chem. Lett.* **20** 1444
9. Niknam K, Saberi D, Sadegheyan M and Deris A 2010 *Tetrahedron Lett.* **51** 692
10. Niknam K, Saberi D and Nouri Sefat M 2010 *Tetrahedron Lett.* **51** 2959
11. Niknam K, Deris A, Naeimi F and Majleci F 2011 *Tetrahedron Lett.* **52** 4642
12. Nouri Sefat M, Saberi D and Niknam K 2011 *Catal. Lett.* **141** 1713
13. Tayebi S, Baghernejad M, Saberi D and Niknam K 2011 *Chin. J. Catal.* **32** 1477
14. Niknam K, Jafarpour N and Niknam E 2011 *Chin. Chem. Lett.* **22** 69
15. Iravani N, Mohammadzade N S and Niknam K 2011 *Chin. Chem. Lett.* **22** 1151
16. Rahi T, Baghernejad M and Niknam K 2012 *Chin. J. Catal.* **33** 1095
17. Niknam K, Jamali A, Tajaddod M and Deris A 2012 *Chin. J. Catal.* **33** 1312
18. Tavakoli Z, Baghernejad M and Niknam K 2012 *J. Heterocycl. Chem.* **49** 634
19. Baghernejad M and Niknam K 2012 *Int. J. Chem.* **4** 52
20. Pargaleh Brojeni S, Baghernejad M, Saberi D and Niknam K 2013 *Green Chem. Lett. Rev.* **6** 69
21. Niknam K and Piran A 2013 *Green Sustainable Chem.* **3** 2A 1
22. Ghasemi S, Baghernejad M and Niknam K 2013 *Iran. J. Catal.* **3** 165
23. Niknam K, Zolfigol M A, Saberi D and Molaee H 2009 *J. Chin. Chem. Soc.* **56** 1257
24. Niknam K, Hasaninejad A and Arman M 2010 *Chin. Chem. Lett.* **21** 399
25. Waxman L and Darke P L 2000 *Antiviral Chem. Chemother.* **11** 1
26. Latif N, Mishriky N and Assad F M 1982 *Aust. J. Chem.* **35** 1037
27. Wang Y, Li X and Ding K 2002 *Tetrahedron Asymmet.* **13** 1291
28. Holly F W and Cope A C 1944 *J. Am. Chem. Soc.* **66** 1875
29. Szatmari I, Hetenyi A, Lazar L and Fulop F 2004 *J. Heterocycl. Chem.* **41** 367
30. Cimarelh C, Palmieri G and Volpini E 2004 *Can. J. Chem.* **82** 1314
31. Dabiri M, Delbari A S and Bazgir A 2007 *Synlett* 821
32. Dabiri M, Delbari A S and Bazgir A 2007 *Heterocycles* **71** 543
33. Sabitha G, Arundhathi K, Sudhakar K and Sastry B S 2010 *J. Heterocycl. Chem.* **47** 272
34. Abbastabar Ahangar H, Mahdavinia G H, Marjani K and Hafezian A 2010 *J. Iran. Chem. Soc.* **7** 770
35. Chenggang J, Xin G, Zonglei Zh, Hangxian X and Cunde W 2010 *J. Chem. Res.* **34** 19
36. Kottawar S S, Siddiqui S A and Bhusare S R 2010 *RASAYAN J. Chem.* **3** 646
37. Chaskar A, Vayavhare V, Padalkar V, Phatangare K and Deokar H 2011 *J. Serb. Chem. Soc.* **76** 21
38. Kumar A, Saxena A, Dewan M, De A and Mozumdar S 2011 *Tetrahedron Lett.* **52** 4835
39. Lei M, Ma L and Hu L 2011 *Synth. Commun.* **41** 3424
40. Rao D G B, Kaushik M P and Halve A K 2012 *Tetrahedron Lett.* **53** 2741
41. Safaei-Ghomi J, Zahedi S and Ghasemzadeh M A 2012 *Iran. J. Catal.* **2** 27
42. GharibA Khorasani B R H Jahangir M and Roshani M 2013 *Bulgarian Chem. Commun.* **45** 59