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Iron(III)–salen complex on a polymer scaffold as heterogeneous catalyst for synthesis of benzimidazoles

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Abstract

Benzimidazoles are important bioactive compounds with diverse applications in the medicinal, industrial, as well as agrochemical fields. In this study, an iron–salen complex on a polymer scaffold was synthesized and characterized, and its performance assessed as a heterogeneous catalyst for synthesis of benzimidazoles. Formation of the metal complex was well confirmed by Fourier-transform infrared spectroscopy (FT-IR) analysis, and the surface morphology and elemental composition was verified by scanning electron microscopy and energy-dispersive X-ray spectroscopy, respectively. The surface area and pore size distribution were determined by Brunauer–Emmett–Teller analysis, and the high thermal stability of the catalyst was revealed by thermogravimetric analysis. Its general potential for synthesis of benzimidazoles from *o*-phenylenediamine with aldehydes containing various electron-withdrawing and electron-donating substituents was confirmed. The effects of different solvents, catalyst loadings, temperatures, and reaction durations were also studied. The present protocol is found to be beneficial in terms of excellent yield, adequate reaction time, and simple workup. Also, hot filtration tests confirmed that the catalyst was truly heterogeneous and could be readily recycled and reused several times, making this protocol attractive, commercial, and environmentally friendly.

Keywords Polymer scaffold–Fe–salen · Heterogeneous catalyst · Benzimidazole synthesis · Thermally stable

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Introduction

Benzimidazole derivatives have been revealed as pharmaceutically significant compounds that exhibit comparatively high biological activities, e.g., antifungal, antiviral, and antihypertension properties [1]. The best apparent benzimidazole complex in Nature is *N*-ribosyldimethylbenzimidazole, which acts as an essential ligand for cobalt in vitamin B_{12} [2]. Beside their use as market drugs such as telmisartan and dexlansoprazole, benzimidazoles are privileged scaffold structures that show a wide spectrum of biological activity, e.g., as antiulcer, antitumor, anti-human immunodeficiency virus (HIV), and antihistaminic agents as well as veterinary medicines [3–5]. In addition, benzimidazoles are essential intermediates in synthesis of dyes and polymers [6, 7] and also find common uses in corrosion science [8], chemosensing [9], and fluorescence [10]. Due to their widespread use in various fields of science and technology, a number of procedures have been described for their synthesis. They are usually obtained by condensation of aromatic 1,2-diamine with aldehydes [11], using oxidants or carboxylic acid derivatives.

To achieve mild reaction conditions and improve the yield of benzimidazoles, a variety of homogeneous systems have been reported. Homogeneous catalytic systems based on oxidants include H_2O_2 with ceric ammonium nitrate (CAN) for synthesis of 2-arylbenzimidazoles [12], $PhI(OAc)_2$/(2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO) for synthesis of multisubstituted benzimidazoles via iodine-promoted oxidation reaction [13], iodobenzene for synthesis of 1,2-disubstituted benzimidazoles with *meta*-chloroperoxybenzoic acid (mCPBA) as terminal oxidant [14], hypervalent iodine as oxidant [15], potassium salt of peroxymonosulfuric acid (oxone) [16], and TEMPO with air for synthesis of benzimidazoles [17]. Copper halide or oxide catalytic systems used for synthesis of benzimidazoles include CuI with ligand [18], CuI/tetramethylethylenediamine (TMEDA) [19], CuI/trimethylsilyl azide ($TMSN_3$)/*tert*-butyl hydroperoxide (TBHP) [20], CuO/1,2-dimethylethylenediamine (DMEDA) [21], $CuOAc_2$/TBHB [22], and $Cu(OTF)_2$ [23]. Cu systems with amino acids such as CuI/L-proline catalyst have also been reported for preparation of 1*H*-benzimidazoles and 1,3-dihydrobenzimidazol-2-ones [24]. Metal salt ($FeCl_3$) with sulfur has been used as an iron–sulfur system for the reaction between *o*-nitroanilines and alcohols to obtain benzimidazoles [25], while the elemental sulfur system has been applied to obtain benzimidazole from aliphatic amines and *o*-amino/mercaptan/hydroxyanilines without any catalyst [26], as well as the $CoBr_2$/$FeCl_3$ system to obtain 2-aryl benzimidazoles [27]. Metal-free KOH/dimethyl sulfoxide (DMSO) has been reported as catalyst for synthesis of benzimidazoles [28]. *p*-Toluenesulfonic acid was applied as Brønsted acid catalyst for convenient synthesis of benzimidazoles [29]. Subsequently, various reagents such as $Yb(OTf)_3$ [30], $Sc(OTf)_3$ [31], $Bi(OTf)_3$ [32], and ionic liquids [33] have been considered as catalysts for synthesis of benzimidazoles. However, the main difficulty with such homogeneous catalysts is the difficult retrieval from the reaction mixture. The product is separated from the reaction medium either by extraction and/or precipitation by using other organic solvents [34].

In modern synthetic organic chemistry, development of reusable protocols is one of the most essential topics. Over more than two decades, a variety of solid-supported metal catalysts have been developed by immobilizing metal on various supports, representing an environmentally friendly approach. In contrast to homogeneous catalysis, heterogeneous catalysts can be simply separated from the reaction mixture [35, 36]. Applications of polymer-supported reagents in organic synthesis have grown over the years due to their convenient handling, reusability, and easy workup procedures. Moreover, polymers have been preferred to immobilize metal complexes due to their functionalization, good accessibility, better control over the catalytic activity, and excellent thermal stability. It is well known that hydrophilic catalysts suffer deactivation by water due to capillary condensation and slow water desorption. However, this problem can be avoided by use of a hydrophobic catalyst [37]. Additionally, there are many reports involving application of hydrophobic styrene-divinylbenzene copolymer in reactions including water as byproduct [38, 39]. In coordination chemistry, salen [*N*,*N*ethylenebis(salicylimine)], a tetradentate symmetric ligand system, plays a vital role as an advantageous chelating ligand due to its high stability under a variety of reaction conditions and the ease of preparation with different substituents. Transition metal–salen complexes have been effectively used in a wide range of heterogeneous catalytic reactions [40, 41]. Representing an advantage over homogeneous catalysts, such heterogeneous catalysts have been reported for synthesis of benzimidazoles. Materials such as copper(II) oxide nanoparticles [42] and Zn^{2+}-K10-clay (clayzic) have been reported as heterogeneous solid acid catalysts for synthesis of benzimidazoles [43]. However, polymer scaffold–Fe–salen complex (PS–Fe–salen) complexes have not been reported for synthesis of benzimidazoles. In continuation of our efforts towards development of efficient methods for synthesis of heterogeneous catalysts for use in organic transformations [44, 45], we report herein synthesis and characterization of a polymer scaffold–Fe–salen (PS–Fe–salen) complex and its application as heterogeneous catalyst for synthesis of benzimidazoles via reaction of *o*-phenylenediamine and benzaldehyde.

Experimental

Materials

All chemicals were procured at reagent or analytical grade with the maximum purity available. 4-Vinylbenzyl chloride (used by washing with dil. NaOH), DMSO-d_6, and $CDCl_3$ were obtained from Sigma Aldrich (India). $FeCl_3$, ethylenediamine, *o*-phenyldiamine, benzaldehydes, and azobisisobutyronitrile (AIBN) were obtained from SDFCL and Avra Synthesis Pvt. Ltd. Ethanol was purchased from Changshu Yangyuan Chemical China. Acetonitrile, chloroform, tetrahydrofuran (THF), and benzimidazole were acquired from Spectrochem Pvt. Ltd. and used directly as received unless otherwise stated.

Characterization techniques

Nuclear magnetic resonance (NMR) spectra were acquired using a Bruker 400 MHz instrument with tetramethylsilane (TMS) as internal standard in DMSO-d_6 and $CDCl_3$. FT-IR spectra were recorded using a Shimadzu spectrometer from KBr pellets. Thermogravimetric analysis was carried out using a thermal gravimetric analysis instrument (TG/DTA thermoanalyser SII, 7200, Seiko, Japan) under nitrogen atmosphere at heating rate of 10 °C min^{-1} in the temperature range of 30–800 °C. Brunauer–Emmett–Teller (BET) surface area was measured at temperature of 77 K in liquid N_2 using a Quantachrome Nova 1000 analyzer. Specific surface area, average pore diameter, and pore volume were measured using N_2 adsorption–desorption isotherms. The surface morphology and elemental composition of the complex were assessed by scanning electron microscopy (Carl Zeiss EVO/18SH, UK) equipped with energy-dispersive X-ray (EDX) facility.

Synthesis of polymer scaffold–Fe–salen (PS–Fe–salen) complex

The polymer scaffold–salen ligand was prepared based on our previous report; details regarding synthesis and characterization are provided in the Electronic Supporting Information [46]. Synthesis of PS–Fe–salen complex was performed with slight modification from literature [47]. $FeCl_3$ (0.162 g, 1 mmol) in 10 mL methanol was added to a suspension of PS–salen ligand (0.893 g, 1 mmol) in 20 mL methanol. The reaction mixture was stirred for 2 h at 60 °C, then cooled, and the solid was separated by filtration followed by washing with methanol, then dried in a hot-air oven to obtain dark-brown PS–Fe–salen complex (Fig. 1) with yield of 74 %.

General procedure for one-pot synthesis of benzimidazoles

In a typical experiment, 30 mg PS–Fe–salen was added to a mixture of *o*-phenylenediamine (1 mmol, 0.108 g) and benzaldehyde (1 mmol, 0.106 g) in 10 mL ethanol. The reaction mixture was allowed to reflux for 24 h. The heterogeneous catalyst was isolated by simple filtration and washed twice with methanol and used for the next cycle; the product was recovered by simple extraction of the reaction mixture with chloroform (10 mL × 3). The isolated combined layer was washed with water and dried over Na_2SO_4. Solvent was removed under reduced pressure on a rotatory evaporator and purified to obtain corresponding benzimidazoles. The obtained reaction products were confirmed by ^1H and ^{13}C NMR (Electronic Supporting Information).

2-Phenyl-1*H*-benzo[*d*]imidazole (2a) Yield (90 %); ^1H NMR (400 MHz, DMSOd_6) $\delta = 12.92$ (s, 1H), 8.19 (d, J = 8.30 Hz, 2H), 7.68 (m, 5H), 7.24 (m, 2H). ^{13}C NMR (100 MHz, DMSOd_6) $\delta = 151.6$, 144.2, 135.4, 130.6, 130.3, 129.4, 126.8, 123, 122.1, 119.3, 111.7.

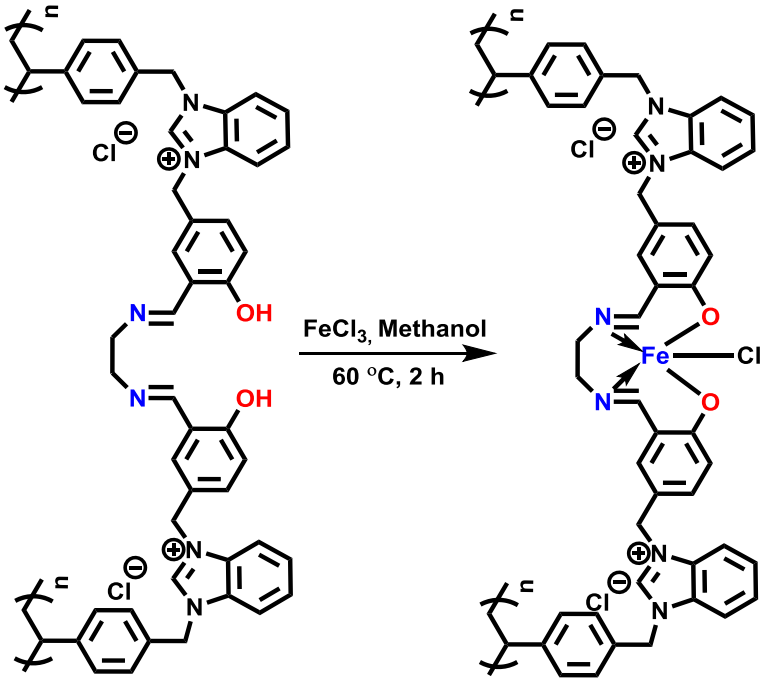


Fig. 1 Synthesis of polymer scaffold–Fe–salen (PS–Fe–salen) complex **1f**

2-(*p*-Tolyl)-1*H*-benzo[*d*]imidazole (2b) Yield (80 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 12.89 (s, 1H), 8.20 (m, 2H), 7.62 (m, 4H), 7.22 (m, 2H), 2.49 (s, 3H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 152.6, 152.9, 130.5, 128.4, 126.9, 122.6, 115.8, 21.5.

2-(4-Methoxyphenyl)-1*H*-benzo[*d*]imidazole (2c) Yield (84 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 8.16 (m, 2H), 7.67 (m, 2H), 7.40 (m, 2H), 7.22 (m, 2H), 3.86 (s, 3H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 159.9, 151.9, 142.6, 136.1, 133, 122.7, 122.5, 119.1, 115.9, 55.6.

2-(2-Methoxyphenyl)-1*H*-benzo[*d*]imidazole (2d) Yield (79 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 8.15 (d, J = 7.2 Hz, 1H), 7.57 (dd, J = 3.2, 5.6 Hz, 2H), 7.40 (t, J = 8.0 Hz, 1H), 7.15 (m, 3H), 7.04 (t, J = 7.2 Hz, 1H), 3.90 (s, 3H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 157.4, 149.6, 138.6, 132.4, 130.2, 123, 121.7, 118.0, 115.6, 112.7, 56.4.

2-(3,4,5-Trimethoxyphenyl)-1*H*-benzo[*d*]imidazole (2e) Yield (85 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 7.85 (m, 2H), 7.65 (s, 2H), 7.43 (m, 2H), 4.0 (s, 6H) 3.89 (s, 3H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 159.9, 151.9, 142.5, 139.1, 124.7, 123.5, 115.9, 55.6.

4-(1*H*-Benzo[*d*]imidazol-2-yl)-*N*,*N*-dimethylaniline (2f) Yield (86 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 8.8 (m, 2H), 8.2 (m, 2H), 8.0 (d, J = 8.9 Hz, 2H) 7.5

(d, J = 5.4 Hz, 1H) 6.8 (d, J = 8.9, 2H), 3.0 (s, 6 H) 13C NMR (100 MHz, DMSOd_6) δ = 151.6, 140.7, 128.2, 116.7, 54.8, 45.5.

5-(1*H*-Benzo[*d*]imidazol-2-yl)-2-methoxyphenol (2g) Yield (70 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 7.7 (m, 2H), 7.40 (m, 2H), 7.2 (m, 2H), 6.9 (s, 1H), 3.8 (S, 1H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 159.9, 151.9, 142.6, 136.1, 133, 122.7, 122.5, 119.1, 115.9, 55.6.

4-(1*H*-Benzo[*d*]imidazol-2-yl)phenol (2h) Yield (84 %); ^{1}H NMR (400 MHz, DMSOd_6)) δ = 7.7 (d, 2H), 7.15 (m, 4H), 6.9 (d, 1H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 159.1, 151.1, 142, 134.4, 128.1, 123.2, 116.

2-(4-Nitrophenyl)-1*H*-benzo[*d*]imidazole (2i) Yield (89 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 8.0 (m, 2H), 7.1 (m, 2H), 6.7 (m, 4H), ^{13}C NMR (100 MHz, DMSOd_6) δ = 151, 149.5, 148.3, 135.3, 127.8, 124.8, 117.7, 115.

4-(1*H*-Benzo[*d*]imidazol-2-yl)benzonitrile (2j) Yield (73 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 13.17 (s, 1H), 8.3 (d, 2H), 8.0 (d, 2H), 7.7 (m, 1H), 7.5 (m, 1H), 7.3 (m, 2H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 149.7, 144.2, 135.4, 134.4, 127.4, 123.9, 122.7, 119.8, 119.1, 112.1, 39.5.

2-(4-Bromophenyl)-1*H*-benzo[*d*]imidazole (2k) Yield (71 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 13.01 (s, 1H), 8.1 (d, 2H), 7.7 (d, 2H), 7.6 (d, 2H), 7.2 (2H, m). ^{13}C NMR (100 MHz, DMSOd_6) δ = 150.1, 143.9, 134.3, 129.3, 123.2, 122.2, 115.

2-(4-Chlorophenyl)-1*H*-benzo[*d*]imidazole (2l) Yield (63 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 13.0 (s, 1H), 8.1 (d, 2H), 7.8 (m, 2H), 7.6 (2H, d), 7.2 (m, 2H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 150.2, 143.6, 134.6, 129.8, 128.9, 122.6, 118.5.

2-(Furan-2-yl)-1*H*-benzo[*d*]imidazole (2m) Yield (74 %); ^{1}H NMR (400 MHz, DMSOd_6) δ = 13.9 (s, 1H)7.95 (m, 1H), 7.5 (s, 2H), 7.2 (m, 3H), 6.7 (m, 1H). ^{13}C NMR (100 MHz, DMSOd_6) δ = 145.5, 144.6, 143.5, 134.3, 122.3, 121.6, 118.7, 112.3, 111.4, 110.5.

Results and discussion

Catalyst characterization

The FT-IR spectra of the ligand and metal complex were compared to confirm the coordination site that may be involved in the formation of the PS–Fe–salen complex from the PS–salen ligand (Fig. 2I). The FT-IR spectrum of **1f** showed the disappearance of the peak at 3358 cm^{-1} (–OH) compared with **1e**, confirming participation of OH group in the creation of Fe–O bond. Additional, it was found that the band of PS–salen ligand **1e** at 1631 cm^{-1} (C=N) shifted slightly to 1616 cm^{-1}, confirming effective participation of azomethine nitrogen in formation of the metal coordinate bond. These results confirm the formation of the PS–Fe–salen complex.

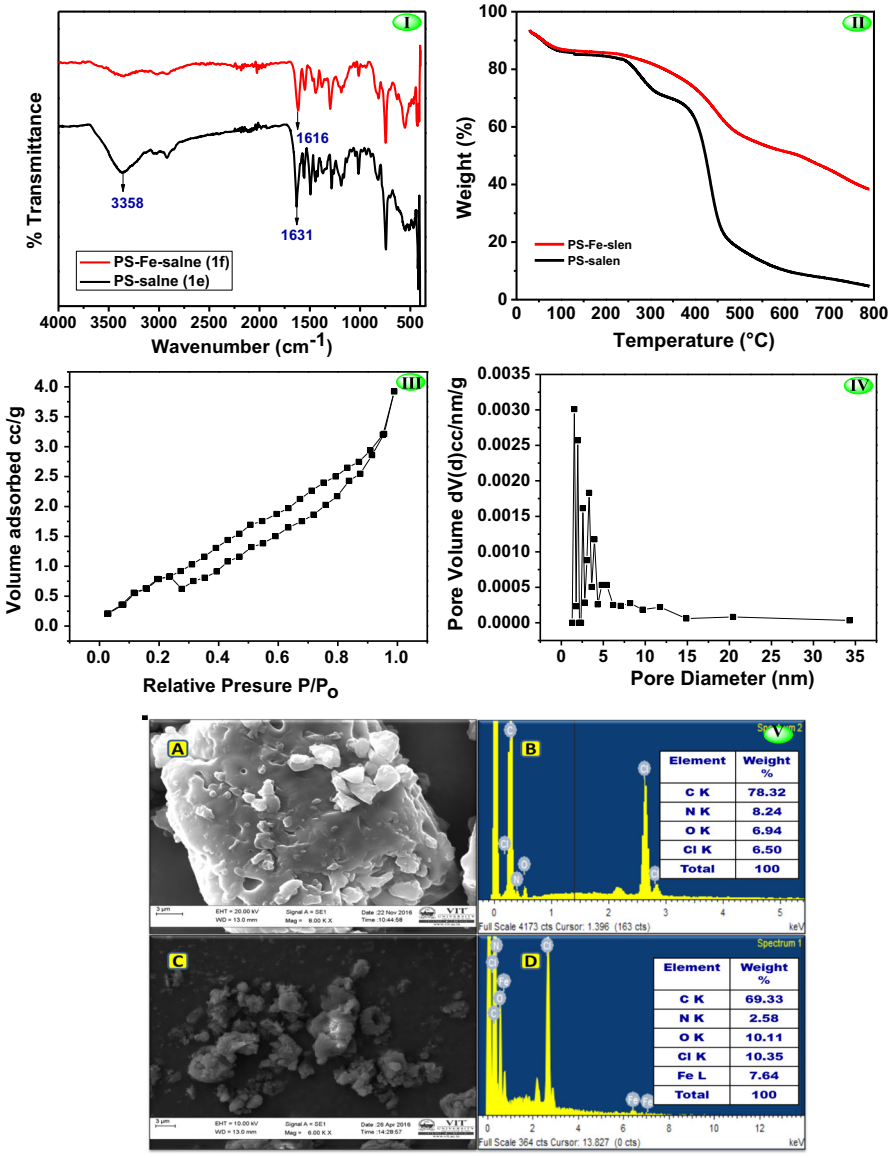


Fig. 2 **I** FT-IR spectrum of PS–salen ligand **1e** and PS–Fe–salen complex **1f**, **II** thermogravimetric analysis (TGA) thermogram of PS–salen (**1e**) and PS–Fe–salen (**1f**), **III** BET isotherm, **IV** pore diameter and pore volume of PS–Fe–salen, **V** SEM/EDX results of polymer scaffold–salen ligand **1e** (**A**, **B**) and polymer scaffold–Fe–salen complex **1f** (**C**, **D**)

Thermogravimetric analysis (TGA) of the PS–salen ligand (**1e**) and PS–Fe–salen complex (**1f**) was performed at heating rate of 10 °C min^{-1} in N_2 atmosphere over the temperature range of 30–800 °C (Fig. 2II). The results showed initial weight

loss from both the PS–salen ligand and PS–Fe–salen complex below 110 °C of around 8 %, which may be due to loss of physically adsorbed moisture. The weight loss behavior of the salen ligand (**1e**, 45 %) and salen metal complex (**1f**, 32 %) at the second decomposition temperature was substantially different, indicating that the PS–Fe–salen complex was more stable than the PS–salen ligand. These data reveal that the complex was stable and suitable for higher-temperature reaction. Furthermore, the weight loss observed from both the ligand and metal complex may be due to the polymer-scaffold benzimidazole group. These data confirm that the PS–Fe–salen complex was thermally stable.

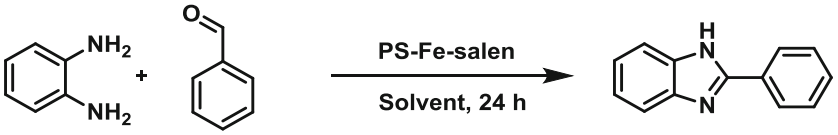
The surface area and pore size distribution of the PS–Fe–salen complex were confirmed by BET surface area analysis of the adsorption/desorption isotherm. The specific area of the PS–Fe–salen complex was found to be 3.856 m^2/g (Fig. 2III). The total volume and average pore diameter of PS–Fe–salen were found to be 0.007 cc/g and 1.560 nm, respectively (Fig. 2IV).

Scanning electron microscopy (SEM) images of the PS–salen ligand (Fig. 2V, A) and PS–Fe–salen (Fig. 2V, C) indicated a change in surface morphology due to the formation of the complex. Moreover, energy-dispersive X-ray spectroscopy (EDX) analysis for the PS–salen ligand (Fig. 2V, B) and PS–Fe–salen complex (Fig. 2V, B) revealed presence of Fe in the PS–Fe–salen complex. The SEM/EDX data confirm successful formation of the metal complex (PS–Fe–salen).

Catalytic activity of polymer scaffold–Fe–salen complex

The parameters affecting the synthesis of benzimidazoles from benzaldehyde and *o*-phenyldiamine are: the nature of the catalyst, the solvent, the catalyst loading, the

Table 1 Effect of solvents on synthesis of benzimidazole



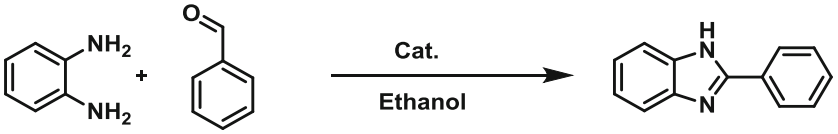
Entry	Solvent	Temperature (°C)	Yield (%)[a]
1	EtOH	Reflux	91
2	MeOH	Reflux	89
3	H_2O	Reflux	83
4	EtOH:H_2O	Reflux	70
5	MeOH:H_2O	Reflux	65
6	DMSO	100	86
7	DMF	100	80
8	Toluene	Reflux	71

Reaction condition: *o*-phenyldiamine = (2 mmol, 216 mg), benzaldehyde (2 mmol, 212 mg), cat = 60 mg, 24 h

[a]Isolated yield

temperature, the duration, and the substrate used. To initiate this study, we confirmed the effect of different solvents on the synthesis of benzimidazoles. Solvents such as EtOH, MeOH, H_2O, DMSO, tetrahydrofuran (THF), and toluene (Table 1, entries 1–3, 6–8) and cosolvents EtOH:H_2O and MeOH:H_2O (Table 1, entries 4, 5) revealed comparable effect on the reaction. The best solvent was selected as EtOH, showing the maximum product yield of 91 %. With the best solvent in hand, we started optimization of the catalyst loading, temperature, and time (Table 2). Initially, the model reaction was carried out in absence of catalyst, giving product yield of around 20 % (Table 2, entry 1). $FeCl_3$ and the ligand, i.e., PS–salen, showed isolated yield of 30 and 32 % (Table 2, entries 2 and 3). To confirm the effect of the catalyst loading on the product conversion, we tried the reaction, varying the amount of catalyst in the range of 10–40 mg (Table 2, entries 4

Table 2 Effect of amount of catalyst, temperature, and time on synthesis of benzimidazole



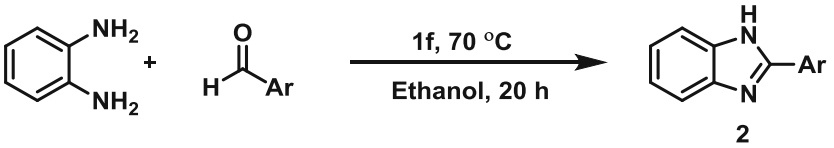
Entry	Catalyst	Catalyst amount (mg)	Temperature	Time (h)	Yield (%)[a]
1	–	30	70	24	20
2	$FeCl_3$	30	70	24	30
3	**1e**[b]	30	70	24	32
4	**1f**	10	70	24	62
5	**1f**	20	70	24	89
6	**1f**	25	70	24	90
7	**1f**	30	70	24	90
8	**1f**	40	70	24	88
9	**1f**	25	RT	24	50
10	**1f**	25	40	24	61
11	**1f**	25	50	24	73
12	**1f**	25	60	24	88
13	**1f**	25	70	24	90
14	**1f**	25	80	24	90
15	**1f**	25	70	4	40
16	**1f**	25	70	8	51
17	**1f**	25	70	16	72
18	**1f**	25	70	20	90
19	**1f**	25	70	24	88

Reaction conditions: *o*-phenyldiamine = (1 mmol, 108 mg), benzaldehyde (1 mmol, 106 mg)

[a]Isolated yield

[b]PS–salen ligand

Table 3 Synthesis of 2-arylbenzimidazoles



2

Entry	Ar	Product	Yield (%)[a]
1	Ph	**2a**	90
2	4-MeC_6H_4	**2b**	80
3	4-$MeOC_6H_4$	**2c**	84
4	2-OMe-C_6H_4	**2d**	79
5	3,4,5-$MeOC_6H_2$	**2e**	85
6	$(Me)_2N$-C_6H_4	**2f**	86
7	3-OH,4-$OMeC_6H_3$	**2g**	70
8	4-OHC_6H_4	**2h**	84
9	4-$NO_2C_6H_4$	**2i**	89
10	4-CNC_6H_4	**2j**	73
11	4-BrC_6H_4	**2k**	71
12	4-ClC_6H_4	**2l**	63
13	C_4H_3O	**2m**	74

[a]Isolated yield

and 8). The optimum amount of catalyst was found to be 25 mg, giving the highest yield of the desired product of 90 % (Table 2, entry 6). With the optimum solvent and catalyst amount in hand, we studied the effect of temperature on the reaction. Increasing the reaction temperature from room temperature to 80 °C (Table 2, entries 9–14), the optimum temperature was found to be 70 °C (Table 2, entry 13), while further increase in the temperature to 80 °C showed no effect on the yield (Table 2, entry 14). Furthermore, we confirmed the effect of the reaction duration on the product yield (Table 2, entries 15 and 19). The results indicated that 20 h was the optimum time to achieve the highest yield (Table 2, entry 18). Moreover, there was a slight decline in the product yield as the reaction duration was increased further (Table 2, entry 19). Finally, the results showed that the optimized reaction conditions were ethanol as reaction solvent, 25 mg of catalyst, temperature of 70 °C, and duration of 20 h.

With the optimum reaction condition in hand, we carried out the reaction between *o*-phenyldiamine and several substituted benzaldehydes with electron-donating and electron-withdrawing group (Table 3). Good to excellent yield of the desired products was obtained with both electron-rich and electron-deficient benzaldehydes (Table 3, entries 1–13). Aldehyde substrates bearing electron-donating substituent on the benzaldehyde showed good to excellent product yield (70–90 %) (Table 3, entries 1–8). Meanwhile, OMe *para*-substituent on

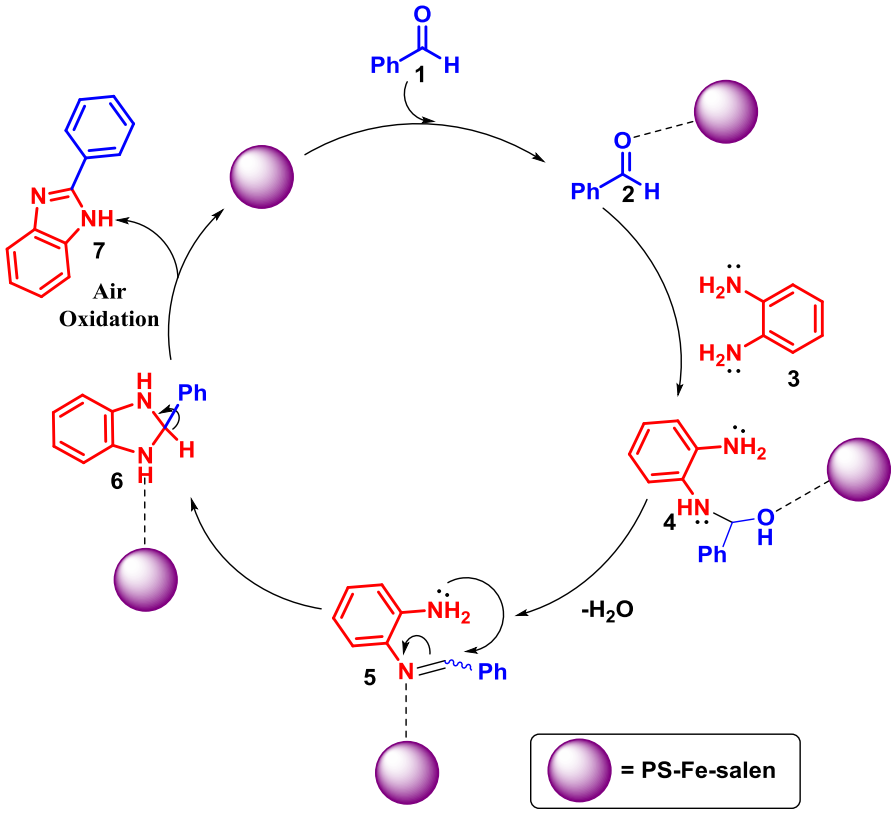


Fig. 3 Plausible mechanism for synthesis of 2-phenylbenzimidazole catalyzed by PS–Fe–salen

benzaldehyde showed slightly higher conversion compared with the *ortho*-substituent (Table 3, entries 3, 4). This may be due to the steric effect of the *ortho*-position, while the electron-donating nature of OH at *para* showed moderate yield of the desired product (Table 3, entry 8), compared with 3-OH,4-OMe-benzaldehyde (Table 3, entry 7). Furthermore, presence of strong electron-withdrawing substituent on benzaldehyde (4-NO_2) resulted in excellent product yield (Table 3, entry 9), compared with (CN) on benzaldehyde (Table 3, entry 10). However, attempts with halide-substituted benzaldehyde (Br, Cl) confirmed that the bromine substituent was advantageous over chlorine to form the benzimidazole (Table 3, entries 11, 12). Even heterocyclic aldehyde (furfural) produced the corresponding cyclized product without any difficulty (Table 3, entry 13). These results clearly confirm that electron-donating as well as electron-windrowing substituents on the benzaldehyde affected the product yield more or less in the reaction with *o*-phenyldiamine.

A plausible mechanism for the construction of 2-substituted benzimidazoles (**7**) under the optimized reaction conditions is shown in Fig. 3. Herein, PS–Fe–salen

acts as Lewis acid as well as oxidative agent. It is assumed that the reaction proceeds via activation of aldehyde (**2**) by PS–Fe–salen followed by condensation reaction with *o*-phenylenediamine (**3**), which is important for formation of the imine derivative (**5**) stabilized by the PS–Fe–salen complex. The resulting imine finally undergoes ring closure by intramolecular attack of the second amino group on C=N double bond (**5**) to obtain hydrobenzimidazole (**6**) that subsequently undergoes aromatization by oxidation to afford the desired product 2-substituted benzimidazole (**7**). This proposed mechanism is supported by the control experiment under nitrogen atmosphere, which led to trace of product [48].

Stability and recyclability

As a benefit of heterogeneous catalysts is the ability to recycle them for the next run, a model reaction was performed under the optimum reaction conditions. At the end of the reaction, the catalyst was separated by simple filtration, washed with methanol, and dried in a hot-air oven. The recovered PS–Fe–salen complex was compared with fresh PS–Fe–salen catalyst (Fig. 4). From the FT-IR spectra, it was concluded that the catalyst was stable with no alteration of the structure of the complex during the course of the reaction. The catalyst was successively utilized in up to five successive runs with appreciable product conversion (Fig. 5). Furthermore, the slight decline in the activity of the catalyst with each recycle may be due to loss of catalyst during the workup procedure. To confirm the heterogeneous nature of the catalyst, we performed a hot filtration test for the catalyst with the optimum reaction conditions. In this test, the reaction was carried out at the optimum conditions for 2 h, then the catalyst was filtered off from the reaction mixture by filtration, and the reaction continued using the filtrate under the same conditions. After removing the catalyst from the reaction mixture, it was found that

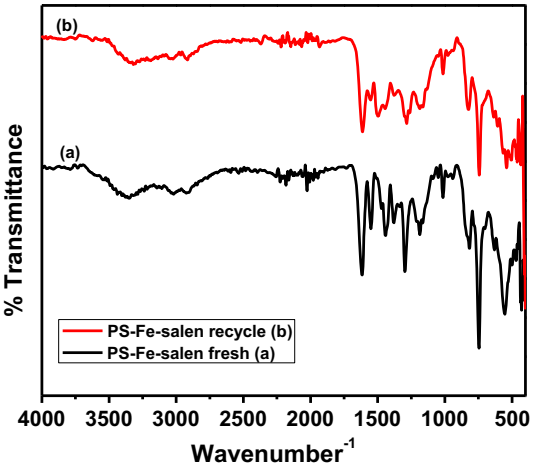


Fig. 4 FT-IR spectra of PS–Fe–salen before and after reaction

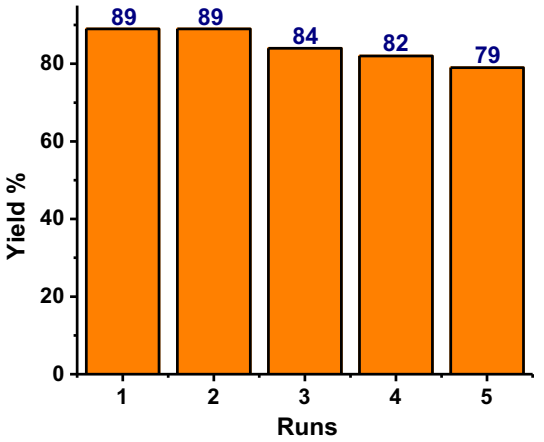


Fig. 5 Recyclability of PS–Fe–salen catalyst up to fifth run

there was no acceptable progress in the yield, verifying that the catalyst was heterogeneous.

Conclusions

We synthesized and characterized a novel polymer scaffold–Fe–salen (PS–Fe–salen) catalyst and used it for synthesis of benzimidazoles in good to excellent yield. The catalyst was characterized by NMR, SEM/EDX, and FT-IR, and its thermal stability confirmed by TGA analysis, demonstrating its applicability for high-temperature reactions. The true heterogeneous nature of the PS–Fe–salen catalyst was confirmed by hot filtration test, and it was recycled up to five cycles. Comparison of the FT-IR spectra of fresh and recycled catalyst confirmed that the functionality of the complex remained intact after the catalytic reaction. The main advantages of the protocol are the highest yield of 2-phenyl-1*H*-benzo[*d*]imidazole obtained with low catalyst loading, easy workup, and mild reaction conditions. Further study on use of this catalyst in organic syntheses is ongoing in our laboratory.

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