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Polymeric imidazolium ionic liquid-tagged manganese Schiff base complex: an efficient catalyst for the Biginelli reaction

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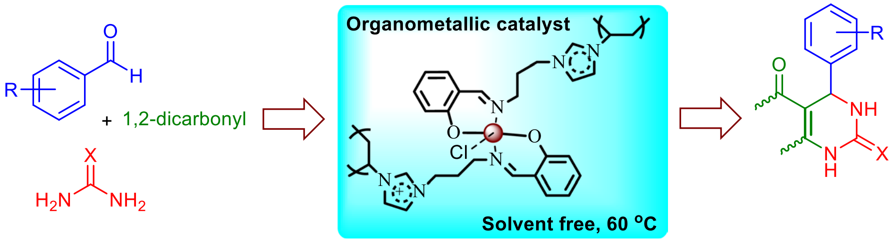
Abstract

In this study, a new organometallic catalyst including polymeric imidazolium ionic liquid-functionalized Mn(III) Schiff base complex (PIL-SB-Mn(III)) was prepared and characterized using various analyses like FTIR, H-NMR, FE-SEM, EDX, TGA, and ICP-OES. Then, the applications of catalyst were tested in the synthesis of 3,4-dihydropyrimidine-2(1*H*)-one/thiones under solvent-free conditions. This polymeric ionic liquid catalyst can carry out the Biginelli reaction in less than an hour in good to excellent yields. The recovered catalyst has been characterized by FTIR and EDX analyses; heterogeneous nature of this catalyst has been confirmed successfully.

Graphic abstract



Keywords Polymer · Ionic liquid · Schiff base · Biginelli reaction · 3,4-Dihydropyrimidine-2-one

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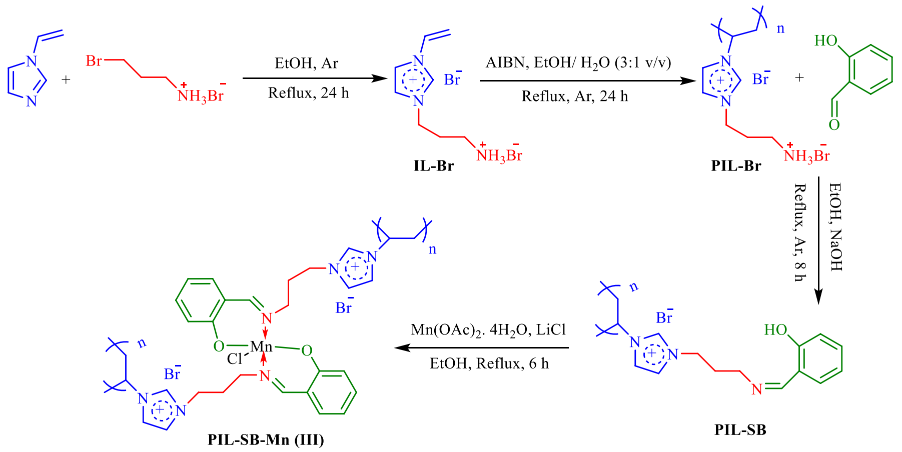
Introduction

Recently, discovering the more sustainable catalytic system is the most important challenge in modern chemistry. In current research, multicomponent reactions (MCRs) are presented as a strong method to synthesis of a wide variety of organic compounds in a very fast and easy manner without the separation and purification of any intermediate [1–7]. Simple procedure, high atom economy and time-saving are the major advantages of MCRs. Combining of MCRs with separable and reusable catalysts is an attractive path to avoid the waste produced in regular syntheses and decrease the effect of chemistry on the environment [8–10].

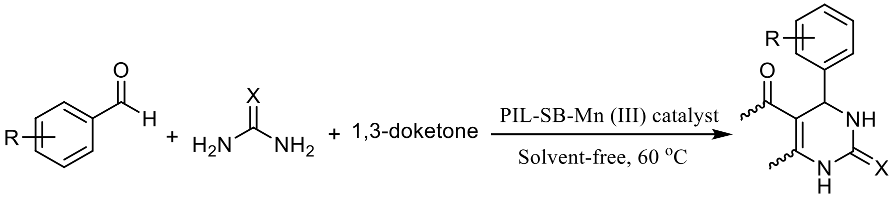
Ionic liquids (ILs) are a new class of ionic, salt-like materials which are liquid at room temperature or even below 0 °C. To date, these ionic compounds have been used in different applications like organic synthesis [11, 12], industrial processing [13], catalysis [14–16], nano-chemistry [17, 18] and other [19, 20]. These worthwhile materials can act as a solvent in organic synthesis, and usually they have been efficient and essential in several reactions to improve the yields of the reaction and also inducing selectivity [21–23]. Schiff bases complexes are well-known inorganic compounds that they have different biological and pharmaceutical properties such as antiviral [24], anticancer [25], antifungal [26] and antibacterial [27]. These inorganic complexes are increasingly applied as efficient catalysts due to their unbelievable catalytic activity in plenty of organic reactions [28–30].

The Biginelli reaction is one of the MCRs carried out from three-components condensation reaction of aromatic and aliphatic aldehydes with 1,3-dicarbonyl compounds and urea/thiourea to produce 3,4-dihydropyrimidine-2(1*H*)-one/thiones [31, 32]. The products of Biginelli reaction are extremely significant in organic synthesis, because they have various pharmacological and biological properties like anti-inflammatory, antibacterial, antiviral, anti-HIV activity and anticancer [33–38]. The synthesis of 3,4-dihydropyrimidine-2(1*H*)-one/thiones has been traditionally done under Brønsted and Lewis acidic catalysts such as para-toluene sulfonic acid [39], trifluoroacetic acid [40], trifluoromethanesulfonic acid [41], $TiCl_3$ [42], $ZrCl_4$ [43], $FeCl_3 \cdot 6H_2O$ [44], $CoCl_2 \cdot 6H_2O$ [45], and some heterogeneous catalytic systems like silica-supported materials [46–49], supported magnetic nanoparticles [50] and carbon-based materials [51, 52]. However, most of these Brønsted and Lewis acidic catalytic systems are not eco-friendly and have some drawbacks like using toxic solvents and harmful conditions and problems in recyclability of catalyst and also product separation and purification. To overcome these restrictions, introducing new and applicable methods is still recommended.

In this study, a new heterogeneous polymer catalyst (PIL-SB-Mn(III)) has been synthesized by the covalent bonding of polymeric ionic liquid to salicylaldehyde, followed by complex formation via the reaction with manganese acetate (Scheme 1). Furthermore, the catalytic application of this Schiff bases complex catalyst has been investigated in the synthesis of 3,4-dihydropyrimidine-2(1*H*)-one/thiones through the three-component condensation reaction of different aldehydes with various 1,3-dicarbonyl compounds and urea or thiourea in solvent-free conditions (Scheme 2).



Scheme 1 Synthesis of PIL-SB-Mn(III) catalyst



1a-j **2a-b** **3a-c** **4a-z**

Scheme 2 Synthesis of 3, 4-dihydropyrimidin-2-ones in the presence of PIL-SB-Mn(III) catalyst

Experimental

Chemicals and instruments

All solvents were purchased from Merck and were dried by standard procedures. N-Vinyl imidazole (VIM), azobisisobutyronitrile (AIBN), 3-bromopropylamine hydrobromide, salicylaldehyde and manganese acetate were purchased from Sigma-Aldrich. ^{1}HNMR, spectra were recorded on a Bruker Avance DPX-250 using deuterated DMSO as solvent and TMS as internal standard. FTIR spectra were recorded on a PerkinElmer FTIR spectrometer (KBr tablets). The morphology and elementary analysis (EDS) of the catalyst were determined by using FE-SEM-FEI Nova nanoSEM 450 instrument. Thermogravimetric analysis (TGA) was performed on a Q600 TA instrument at 30–700 °C with a heating gradient of 20 °C min^{-1} in argon atmosphere. ICP-OES analysis was performed using a simultaneous VISTA-PRO instrument.

Preparation of ionic liquid (IL)

To flask that contains an ethanolic solution of 3-bromopropylamine hydrobromide (10 mmol, 2.2 g) was added N-Vinyl imidazole (10 mmol, 0.8 mL) and refluxed under argon atmosphere for 24 h. Then, the reaction mixture was cooled to room temperature and the solvent removed by rotary. The obtained viscous liquid was changed to white-yellow sediment after washing with dry acetonitrile, ethyl ether and chloroform and dried in a vacuum oven for 12 h at 60 °C. Melting point: 123–124 °C. ^{1}H-NMR (300 MHz, DMSO, TMS) δ (ppm) = 2.2 (m, 2H, $-CH_2$), 2.9 (m, 2H, $-CH_2$), 4.4 (t, 2H, $-CH_2$), 5.4 (dd, 1H, –CH vinyl), 6.0 (dd, 1H, –CH vinyl), 7.3 (dd, 1H, –CH vinyl), 7.9 (m, 3H, $-NH_3^+$), 8.0 (s, 1H, –CH), 8.3 (s, 1H, –CH), 9.61 (s, 1H, –CH) (Fig. 1). FTIR (KBr): ν_{max} = 3416, 3058, 2984, 1656, 1601, 1569, 1549, 1492, 1446, 1371, 1176, 1147, 1058, 830 cm^{-1}.

Preparation of polymeric ionic liquids (PIL)

The polymerization reaction was carried out by reaction of the ionic liquid monomer of vinyl imidazolium salt (10 mmol, 3.2 g) in the presence of AIBN initiator (10 mol%) and the mixture of ethanol/water (40 mL, 3:1 v/v) for 24 h under argon atmosphere. After completion of the reaction, the reaction mixture was cooled to room temperature and after removal of the solvent with rotary, the obtained product was washed with dry

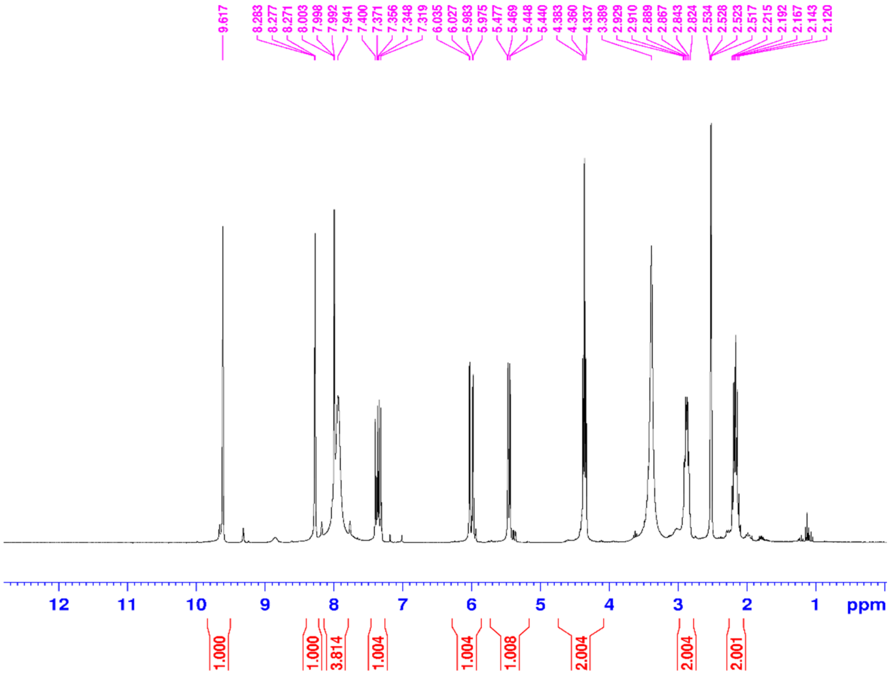


Fig. 1 ^{1}H-NMR spectrum of IL

tetrahydrofuran and acetone. The desired polymer is obtained by adding dry ethanol and dried in a vacuum oven for 12 h at 60 °C. ^{1}H-NMR (300 MHz, DMSO, TMS) δ (ppm) = 3.47 (m, 2H, –CH_2), 4.58 (m, 2H, –CH_2), 5.40 (d, 1H, –CH), 5.81 (d, 1H, –CH), 7.13 (m, 1H, –CH), 7.66 (s, 1H, –CH), 7.81 (s, 1H, –CH), 9.18 (s, 1H, –CH) (Fig S1 B in SM). FTIR (KBr): ν_{max} = 3416, 3152, 2924, 2867, 1637, 1618, 1568, 1505, 1470, 1163, 624, 502 cm^{-1}.

Preparation of PIL-functionalized Schiff base (PIL-SB)

Salicylaldehyde (10 mmol, 1.12 mL) dropwise was added to the ethanolic polymer solution (10 mmol, 3.23 g). Then, the aqueous solution of sodium hydroxide (10 mmol, 0.4 g) was added to the solution and refluxed in argon atmosphere for 8 h. After completion of the reaction, the reaction was cooled to room temperature and the solvent was evaporated with rotary. Finally, after washing the residue with ethyl ether and water and drying in vacuum oven for 12 h at 60 °C, the product was obtained. ^{1}H-NMR (300 MHz, DMSO, TMS) δ (ppm) = 3.47 (m, 2H, –CH_2), 4.58 (m, 2H, –CH_2), 5.40 (d, 1H, –CH), 5.81 (d, 1H, –CH), 7.13 (m, 1H, –CH), 7.66 (s, 1H, –CH), 7.81 (s, 1H, –CH), 9.18 (s, 1H, –CH) (Fig S1 C in SM). FTIR (KBr): ν_{max} = 3424, 3416, 3152, 2914, 2867, 1631, 1618, 1568, 1505, 1470, 1287, 1163, 1100, 762 cm^{-1}.

Preparation of polymeric IL-functionalized SB Manganese complex (PIL-SB-Mn)

PIL-SB-Mn(III) catalyst was prepared according to the method described as follows. To the ethanolic solution of PIL-SB (10 mmol, 3.3 g), Mn $(OAc)_2 \cdot 4H_2O$ (5.0 mmol, 1.2 g) dissolved in ethanol was added and the mixture was refluxed for 4 h at 80 °C. Then, LiCl (5.0 mmol, 0.2 g) was added and reflux was contained for further 2 h. After completion of the reaction, the reaction mixture was cooled to room temperature and the synthesized precipitate was separated by centrifugation, washed successively with ethanol and finally dried at 60 °C for 12 h in vacuum oven to obtain the greenish solid product. FTIR (KBr): ν_{max} = 3424, 3416, 3152, 2914, 2867, 1631, 1618, 1568, 1505, 1470, 1287, 1163, 1100, 762 cm^{-1}.

Typical procedure for synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones

A mixture of aromatic aldehyde **1** (1.0 mmol), urea/thiourea **2** (1.5 mmol), diketone **3** (1.0 mmol), and PIL-SB-Mn(III) catalyst (1.0 mol%) was heated at 60 °C in solvent-free condition for the appropriate time mentioned in Table 2. The progress of the reaction was monitored by thin-layer chromatography (ethyl acetate/*n*-hexane, 4:1). Upon completion of the reaction, hot ethanol (10 mL) was added to reaction mixture and the catalyst was separated from the reaction mixture by centrifugation. The solvent evaporated under reduced pressure and the crude product was purified by recrystallization with ethanol to give compounds **4a–z** in good to excellent yields (Table 2).

Spectral data of products

Ethyl 6-methyl-2-oxo-4-phenyl-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4a**): white solid, Mp = 207–208 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.10 (3H, CH$_3$, t), 2.28 (3H, CH$_3$, s), 4.00 (2H, CH$_2$, q), 5.18 (1H, CH, s), 7.22–7.34 (3H, ArH, m), 7.36–7.37 (2H, ArH, m), 7.82 (1H, NH$_1$, s), 9.26 (1H, NH$_1$, s); IR (KBr, ν_{max}/cm^{-1}): 3245.11, 3113.28, 2979.01, 1725.27, 1699.43, 1648.39, 1221.47, 1090.60, 699.40.

Ethyl 6-methyl-4-phenyl-2-thioxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4b**): Yellow solid, Mp = 205–207 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.19 (3H, CH$_3$, t), 2.26 (3H, CH$_3$, s), 4.18 (2H, CH$_2$, q), 5.42 (1H, CH, s), 7.24–7.34 (3H, ArH, m), 7.36–7.37 (2H, ArH, m), 8.97 (1H, NH$_1$, s), 9.98 (1H, NH, s); IR (KBr, ν_{max}/cm^{-1}): 3243.21, 3118.70, 2980.63, 1728.04, 1703.88, 1648.61, 1221.19, 1089.05, 781.41.

Ethyl 4-(4-methoxyphenyl)-6-methyl-2-oxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4c**): White solid, Mp = 205–206 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.12 (3H, CH$_3$, t), 2.27 (3H, CH$_3$, s), 3.73 (3H, OCH$_3$, s), 4.00 (2H, CH$_2$, q), 5.12 (1H, CH, s), 6.90 (2H, ArH, d), 7.18 (2H, ArH, d), 7.74 (1H, NH, s), 9.22 (1H, NH, s); IR (KBr, ν_{max}/cm^{-1}): 3242.83, 3112.54, 2956.13, 2835.11, 1705. 32, 1512.32, 1223.09, 1089.50, 791.91.

Ethyl 4-(4-methoxyphenyl)-6-methyl-2-thioxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4d**): Yellow solid, Mp = 170–173 °C, ^{1}H-NMR (DMSO-d6, 300 MHz): δ (ppm) 1.12 (3H, CH$_3$, t), 2.27 (3H, CH$_3$, s), 3.73 (3H, OCH$_3$, s), 4.00 (2H, CH$_2$, q), 5.22 (1H, CH, s), 6.90 (2H, ArH, d), 7.18 (2H, ArH, d), 9.78 (1H, NH, s), 10.37 (1H, NH, s); IR (KBr, ν_{max}/cm^{-1}): 3244.72, 3115.53, 2979.48, 17,059.44, 1649.05, 1223.03, 1088.93, 784.29.

Ethyl 6-methyl-2-oxo-4-(o-tolyl)-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4e**): Yellow solid, Mp = 207–208 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.10 (3H, CH$_3$, t), 2.30 (6H, 2CH$_3$, d), 4.01 (2H, CH$_2$, q), 5.14 (1H, CH, s), 6.90 (2H, ArH, d), 7.07 (1H, ArH, m), 7.24 (2H, ArH, m), 7.32 (1H, ArH, m), 7.82 (1H, NH, s), 9.19 (1H, NH, s); IR (KBr, ν_{max}/cm^{-1}): 3236.05, 3117.81, 2982.52, 2926.52, 1704.67, 1651.99, 1225.79, 1090.45, 767.76, 700.39.

Ethyl 4-(4-chlorophenyl)-6-methyl-2-oxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4l**): Yellow solid, Mp = 209–211 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.11 (3H, CH$_3$, t), 2.27 (3H, CH$_3$, s), 4.00 (2H, CH$_2$, q), 5.16 (1H, CH, s), 7.26 (2H, ArH, d), 7.42 (2H, ArH, d), 7.81 (1H, NH, s), 9.28 (1H, NH, s); IR (KBr, ν_{max}/cm^{-1}): 3243.21, 3118.70, 2980.63, 2853.92, 1728. 04, 1703.88, 1648.61, 1221.19, 1089.05, 781.41.

Ethyl 4-(4-hydroxyphenyl)-6-methyl-2-oxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4m**): White solid, Mp = 230–232 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.16 (3H, CH$_3$, t), 2.27 (3H, CH$_3$, s), 4.05 (2H, CH$_2$, q), 5.12 (1H, CH, s), 6.90 (2H, ArH, d), 7.18 (2H, ArH, d), 7.74 (1H, NH, s), 9.22 (2H, NH and OH, s); IR (KBr, ν_{max}/cm^{-1}): 3251.38, 3120.98, 2982.03, 1697. 93, 1456.76, 1225.09, 1094.45, 777.82.

Ethyl 4-(3-bromophenyl)-6-methyl-2-oxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (**4n**): White solid, Mp = 185–187 °C, ^{1}H-NMR (DMSO-d$_6$, 300 MHz): δ (ppm) 1.12 (3H, CH_3, t), 2.29 (3H, CH_3, s), 4.01 (2H, CH_2, q), 5.18 (1H, CH, s), 7.37 (4H, ArH, m), 7.85 (1H, NH, s), 9.22 (1H, NH, s); IR (KBr, ν_{max}/cm^{-1}): 3233.30, 3119.57, 2976.76, 2929.40, 1705. 51, 1653.91, 1226.19, 1090.96, 767.69.

Results and discussion

Preparation and characterization of the catalyst

This new polymeric ionic liquid-functionalized manganese Schiff base complex (PIL-SB-Mn(III)) was prepared according to Scheme 1. Firstly, the ionic liquid (IL) was prepared by the nucleophilic reaction of *N*-vinyl imidazole and 3-bromopropylamine hydrobromide. Then, the synthesized ionic liquid was polymerized by using azobisisobutyronitrile (AIBN) as the initiator to form polymeric IL (PIL) and followed by the reaction with salicylaldehyde to form the ionic liquid-functionalized Schiff base (PIL-SB). Finally, in order to prepare the manganese complex, the prepared polymeric ionic liquid Schiff base (PIL-SB) was added to the ethanolic solution of Mn $(OAc)_2 \cdot 4H_2O$ and LiCl with vigorous stirring and desired catalyst was produced (PIL-SB-Mn(III)). The structure of synthesized catalyst was characterized by various analyses like FTIR, H-NMR, ICP, TGA, FE-SEM and EDS.

The FTIR spectrum of all steps for preparation of catalyst is shown in Fig. 1. In the first FTIR spectrum of prepared imidazolium ionic liquid (Fig. 2, black), the peaks at 1178 and 1147 cm^{-1} are attributed to the stretching vibrations of C–N bond of imidazole ring and the sharp peaks at 1551 and 1658 cm^{-1} are assigned to C=N and C=C of this five-membered ring. The stretching vibrations of C–H bond of ring and alkyl chain appear at 3063 and 2984 cm^{-1}, respectively. The broad band at around 3416 cm^{-1} was ascribed to the N–H stretching vibration of amine

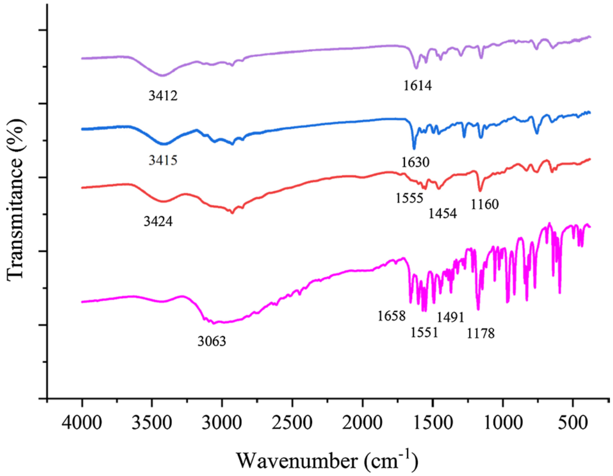


Fig. 2 FTIR spectra of IL (pink), PIL (red), PIL-SB (blue), PIL-SB-Mn(III) (purple). (Color figure online)

moiety [53]. After polymerization reaction of ionic liquid, there are not any significant changes or new peaks in FTIR spectrum (Fig. 2, red) [54]. The third spectrum belongs to the FTIR spectrum of papered polymeric ionic liquid-functionalized Schiff base (Fig. 2, blue). In this figure, the appeared absorption peak at 1630 cm^{-1} is assigned to the formation of imine bond in Schiff base molecule and broad peak at 3415 is attributed to the stretching vibration of O–H group on the aldehyde molecule [55]. In final spectrum related to polymeric ionic liquid-functionalized Schiff base manganese complex (PIL-SB-Mn(III)), Fig. 2, green), the C=N stretching frequency and O–H stretching vibration were shifted to the lower wave number (1614, 3412 cm^{-1}), which confirm successful coordination of nitrogen and oxygen to the metal center. Also, the stretching vibration of the OH group at 3412 cm^{-1} is becoming weak after coordinating with manganese ion [56, 57].

Scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX) analyses were applied for better perception of the morphology and elemental analysis of catalyst (PIL-SB-Mn(III)). SEM photograph of catalyst demonstrates irregular structure for the polymeric catalyst in micrometer size (Fig. 3), and EDX graph confirms the successful linkage of Schiff base manganese (III) complex on the polymeric imidazolium ionic liquid by the presence of all metallic and nonmetallic elements involved in the catalyst like carbon, nitrogen, oxygen, bromine, chlorine and manganese (Fig. 4). Furthermore, the best technique for confirmation of catalyst preparation particularly complex moiety is inductively coupled plasma atomic emission spectroscopy (ICP-OES) analysis. This technique gives the amount of manganese in fresh and reused catalysts. These amounts are 1.091 mmol (6.05 wt%) and 1.065 mmol (5.91 wt%) on 1.0 g of fresh and reused catalysts (PIL-SB-Mn(III)), respectively. This result demonstrates that approximately no leaching of manganese took place during the reaction and confirms the successful coordination of metal ion on the Schiff base molecule. The molecular weight of the synthesized polymeric catalyst was measured by GPC analysis, and its amount 12,500 g/mol was reported.

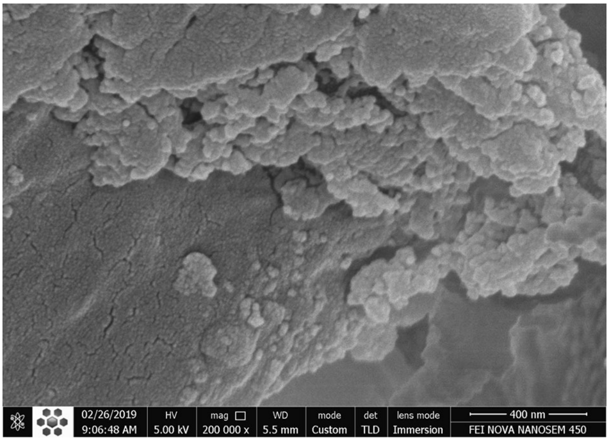


Fig. 3 SEM image of PIL-SB-Mn(III) catalyst

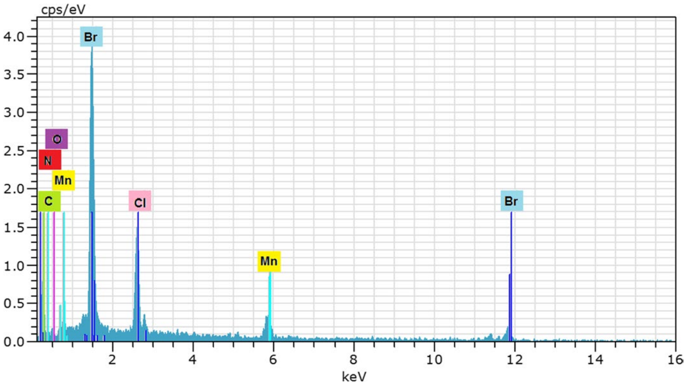


Fig. 4 EDX graph of PIL-SB-Mn(III) catalyst

The thermogravimetric (TGA) is another method for evaluation of the chemical structure of the catalyst. Thus, the TGA of the PIL-SB and final catalyst (PIL-SB-Mn) has been analyzed. As depicted in Fig. 5, there are three main weight losses in the TGA plot of PIL-SB. The first decrease in the weight of catalyst (about 5%) in the temperature between 40 and 120 °C is attributed to the removal of absorbed water to the PIL-SB. Then, the second weight loss about 40% that began from 150 °C and continued to about 500 °C is assigned to the decomposition of organic moieties of catalyst like ionic liquid part, and third weight losses after 500 °C (about 10%) are related to the complete decomposition of molecule (Fig. 5a). The TGA plot of final catalyst (PIL-SB-Mn) is similar to the previous plot with small changes about 5% that are probably attributed to the decomposition of organometallic complex (Fig. 5b) [54, 58].

In order to optimize the overall process, the reaction of benzaldehyde, ethyl acetoacetate and urea has been chosen as a model reaction. The influence of several critical reaction conditions like the amount of catalyst, solvent and

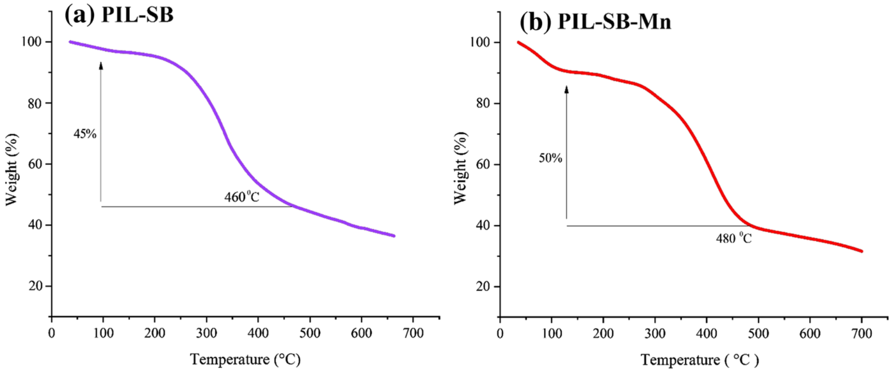


Fig. 5 Thermogravimetric analysis of **a** PIL-SB and **b** PIL-SB-Mn(III) catalyst

solvent-free condition, temperature and time has been analyzed on the Biginelli reaction (Table 1). First of all, the reaction was carried out without the catalyst, while other factors were constant; no product was observed after 3 h (entry 1). After that, the effect of the amount of catalyst (entries 2–5) was tested on reaction yield and time and 1.0 mol% of catalyst was the optimum amount (entry 4). Then, to investigate the influences of the solvent, a wide variety of solvents (entries 6–13) and solvent-free condition were applied in 1.0 mol% of catalyst for the synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones. The reaction in solvent-free conditions proceeds better than solvent (entry 4), although yield of the reaction in acetonitrile was good (entry 10). Another factor for checking the yield and time of the reaction was temperature which was important and effective. Thus, the effect of this factor was analyzed on the model reaction as well (entries 14–17). The reaction in mild temperature (60 °C) was done in the highest amount of yield and shorter time. Eventually, in order to find out the best time to progress the reaction, the time was optimized too (entries 18–20). The best yield was

Table 1 Optimization of the reaction conditions for Biginelli reaction

Entry	Condition	Catalyst (mol%)	Temperature (°C)	Time (min)	Yield (%)[a]	TON[b]	TOF[c]
1	Solvent-free	–	60	180	–	–	–
2	Solvent-free	0.1	60	60	30	30	30
3	Solvent-free	0.5	60	30	61	61	122
4	**Solvent-free**	**1.0**	**60**	**15**	**95**	**95**	**380**
5	Solvent-free	3.0	60	15	94	94	376
6	$CHCl_3$	1.0	60	15	35	35	140
7	CH_2Cl_2	1.0	60	15	40	40	160
8	Toluene	1.0	60	15	44	44	176
9	THF	1.0	60	15	60	60	240
10	CH_3CN	1.0	60	15	85	85	340
11	EtOH	1.0	60	15	80	80	320
12	MeOH	1.0	60	15	73	73	292
13	H_2O	1.0	60	15	76	76	304
14	Solvent-free	1.0	rt	15	55	55	220
15	Solvent-free	1.0	40	15	72	72	288
16	Solvent-free	1.0	80	15	95	95	380
17	Solvent-free	1.0	100	15	94	94	376
18	solvent-free	1.0	60	5	68	68	816
19	solvent-free	1.0	60	10	84	84	504
20	solvent-free	1.0	60	30	92	92	184

Benzaldehyde (1.0 mmol), ethyl acetoacetate (1.0 mmol), urea (1.5 mmol) and PIL-SB-Mn(III)

[a] Isolated yield

[b] Turnover numbers (TONs) defined as mmol of products reacted per mmol of catalyst

[c] Turnover frequencies (TOFs) defined as mmol of products reacted per mmol of catalyst per hour

Table 2 Synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones in the presence of PIL-SB-Mn(III) catalyst

Entry	R	X	1,3-Diketone	Product	Time (min)	Yield (%)[a]	Melting point	
							Found	Reported [ref]
1	H	O	Ethyl acetoacetate	**4a**	15	95	207–208	209–210 [59]
2	H	S	Ethyl acetoacetate	**4b**	15	94	205–207	206–208 [60]
3	4-OCH_3	O	Ethyl acetoacetate	**4c**	20	86	205–206	203–204 [59]
4	4-OCH_3	S	Ethyl acetoacetate	**4d**	30	85	170–173	173–174 [59]
5	2-CH_3	O	Ethyl acetoacetate	**4e**	45	90	207–208	207–208 [59]
6	3-NO_2	O	Ethyl acetoacetate	**4f**	30	84	226–227	225–226 [59]
7	3-NO_2	S	Ethyl acetoacetate	**4g**	30	80	210–212	210–212 [60]
8	4-NO_2	O	Ethyl acetoacetate	**4h**	15	94	206–208	207–208 [60]
9	4-NO_2	S	Ethyl acetoacetate	**4i**	15	94	202–204	204–205 [60]
10	2-Cl	O	Ethyl acetoacetate	**4j**	30	85	206–207	227–229 [60]
11	3-Cl	O	Ethyl acetoacetate	**4k**	30	90	197–198	195–197 [60]
12	4-Cl	O	Ethyl acetoacetate	**4l**	15	92	209–211	210–212 [60]
13	4-OH	O	Ethyl acetoacetate	**4m**	30	88	230–232	232–233 [60]
14	3-Br	O	Ethyl acetoacetate	**4n**	45	86	185–187	185–186 [61]
15	H	O	Dimedone	**4o**	30	88	290–292	290–292 [61]
16	H	S	Dimedone	**4p**	30	85	282–284	283–285 [59]
17	4-NO_2	O	Dimedone	**4q**	20	92	300–302	302–304 [59]
18	4-NO_2	S	Dimedone	**4r**	20	92	295–297	295–297 [59]
19	4-Cl	O	Dimedone	**4s**	20	93	> 300	> 300 [59]
20	4-Cl	S	Dimedone	**4t**	20	90	295–297	295–296 [62]
21	3-Cl	O	Dimedone	**4u**	30	87	276–278	278–280 [62]
22	3-Cl	S	Dimedone	**4v**	30	88	270–272	271–272 [62]
23	3-OCH_3	O	Dimedone	**4w**	45	82	249–249	248–249 [59]
24	3-OCH_3	S	Dimedone	**4x**	45	80	238–241	240–241 [59]
25	H	O	1,3-Cyclohexanedione	**4y**	45	80	266–268	267–268 [63]
26	H	S	1,3-Cyclohexadione	**4z**	45	75	258–260	258–259 [63]

Reaction conditions: aromatic aldehydes (1.0 mmol), 1,3-diketones (1.0 mmol), urea/thiourea (1.5 mmol) and PIL-SB-Mn(III) (1.0 mol%) in solvent-free condition at 60 °C

[a] Isolated yield

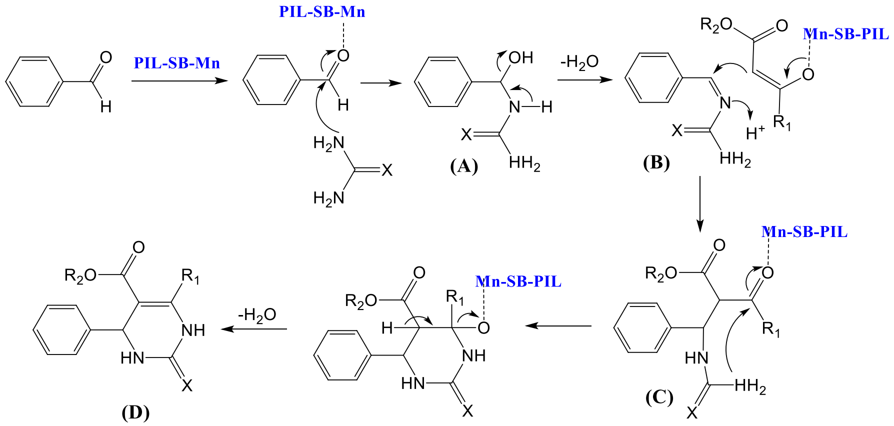
obtained after about 15 min and more, and less than of this time, the yield of the reaction was decreased. Thus, the best condition for the synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones was 1.0 mol% of catalyst in solvent-free condition at 60 °C (entry 4).

After optimization reaction conditions, the scope of the Biginelli reaction was investigated by the reaction of different aromatic aldehydes, three 1,3-diketones (ethyl acetoacetate, dimedone and 1,3-cyclohexanedione) and urea or thiourea in the presence of 0.01 g of catalyst in solvent-free condition at 60 °C (Table 2). All aromatic aldehydes with electron-donating and electron-withdrawing groups reacted well in Biginelli reaction and gave good to excellent isolated yields. In the case of 1,3-diketones, ethyl acetoacetate (entries 1–14) has the better yield and reacts in shorter reaction time compare to dimedone (entries 15–24) and 1,3-cyclohexanedione (entries 25, 26). The reaction also has the better condition, when we used urea compare to thiourea for the synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones.

Investigation of the reaction mechanism is a significant way to understand the effect of catalyst on the Biginelli reaction. For this purpose, a plausible mechanism for condensation of aromatic aldehyde, urea and 1,3-diketone in the presence of PIL-SB-Mn(III) as a Lewis acid catalyst for the synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones is proposed in Scheme 3. As shown in this scheme, in the first step, the Lewis acid catalyst can active the aldehyde to attack the urea and produce intermediate **A** and after loss of one molecule water, the intermediate **B** is formed. In this step, one molecule of 1,3-dicarbonyl is attacked to intermediate **B** in which the carbonyl parts are activated with catalyst and intermediate **C** is created and followed by loss of one molecule of water, the product is obtained (**D**).

Regarding the principle of green chemistry, reusability and recyclability of the catalyst are highly preferable. Therefore, the reusability of prepared catalyst (PIL-SB-Mn(III)) for the synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones was also tested (Fig. 6). So, upon completion the reaction, hot ethanol was added to the reaction mixture and the catalyst was separated by centrifugation, dried in vacuum for 12 h and reused in next catalytic cycles under the optimum conditions. The recycled catalyst was successfully reused for five times, and the reaction yields were only decreased less than 5% in these five times using of catalyst. Also, the FTIR spectrum of the fresh and recovered catalyst (PIL-SB-Mn(III)) was compared and there was no change in the structure of catalyst and approximately the spectrums were similar (Fig. 7). These results confirm the structure of catalyst is stable after several times using.

To evaluate catalyst stabilization and metal leaching, the hot filtration test was performed in the model reaction under the optimized conditions. So, the mixture



Scheme 3 Proposed mechanism for synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones

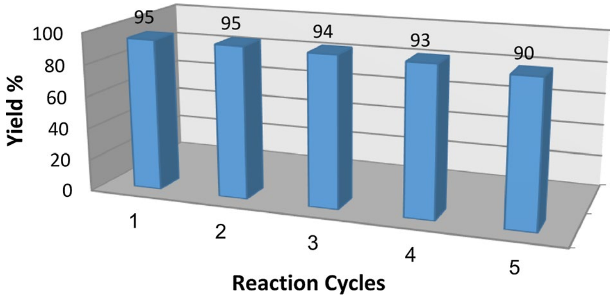


Fig. 6 Recycling test of PIL-SB-Mn(III) catalyst for synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones

of benzaldehyde (1.0 mmol), ethyl acetoacetate (1.0 mmol), urea (1.5 mmol) and PIL-SB-Mn(III) (1.0 mol%) was stirred at 60 °C under the solvent-free condition for 8 min. After proceeding the reaction about 50%, the catalyst was separated from the reaction mixture by centrifugation and then the reaction was continued for further reaction time (7 min). No increase in conversion was observed after catalyst separation. This result evidently shows that no leaching of Mn ion took place during the reaction and confirms the successful coordination of manganese ion on the Schiff base moiety and in agreement with ICP analysis.

It is necessary to compare the merit of our synthesized catalyst (PIL-SB-Mn(III)) with other catalytic systems published in previous works for better understanding of our methodology. Thus, the results of our catalyst for the synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones were finally compared with some other heterogeneous catalysts (Table 3). As seen in this table, our prepared heterogeneous organometallic

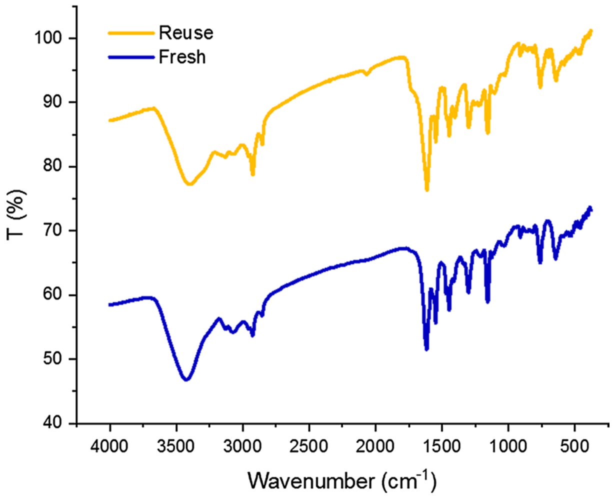


Fig. 7 FTIR spectra of PIL-SB-Mn(III) catalyst fresh (blue) and reuse (yellow). (Color figure online)

Table 3 Comparison of catalytic activity of PIL-SB-Mn(III) catalyst with other heterogeneous catalysts in Biginelli reaction

Entry	Catalyst	Conditions	Time (min)	Yield (%)[a]	References
1	SSA, [bmim]Br[b]	Solvent-free, 100 °C	60	68	[64]
2	Uranyl acetate, succinimide	Solvent-free, 90 °C	240	95	[65]
3	$[bmim]FeCl_4$	Solvent-free, 90 °C	120	90	[66]
4	Nano-AL_2O_3-SO_3H	Solvent-free, 120 °C	5.0	87	[67]
5	Fe_3O_4@MCM-41-OB$(OH)_2$	Ultrasonic, 50 °C	30	95	[68]
6	$GaCl_3$	Solvent-free, 80 °C	360	96	[69]
7	PIL-SB-Mn(III)	Solvent-free, 60 °C	15	95	This work[c]

[a] Isolated yield

[b] Ionic liquid silica sulfuric acid

[c] Benzaldehyde (1.0 mmol), ethyl acetoacetate (1.0 mmol), urea (1.5 mmol) and PIL-SB-Mn(III) (1.0 mol%)

catalyst (PIL-SB-Mn(III)) is more efficient than other catalysts regarding yield and time.

Conclusion

For the first time, a novel polymeric organometallic catalyst (PIL-SB-Mn(III) has been prepared and after full characterization, its applications were investigated for the synthesis of different derivatives of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones via Biginelli reaction. The main advantages of this method are the use of polymeric ionic liquid Schiff base manganese complex for synthesis of 3,4-dihydropyrimidin-2(1*H*)-ones/thiones with good to excellent yields and short reaction time in solvent-free condition and mild temperature (60 °C). Moreover, the catalyst could separate from the reaction mixture by centrifuging and be reused more than five times without any significant decrease in catalytic activity.

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