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Authors name: Saima Tarannum and Zeba N. Siddiqui*

Affiliations: *Department of Chemistry, Aligarh Muslim University, Aligarh, 202002, India.*

E-mail address of Corresponding author*: siddiqui_zeba@yahoo.co.in

Phone no: Tel. +91 9412653054

Address for correspondence: Prof. Zeba N. Siddiqui
Department of Chemistry,
Aligarh Muslim University,
Aligarh-202002, India.

$Fe(OTs)_3/SiO_2$: A novel catalyst for the multicomponent synthesis of dibenzodiazepines under solvent-free conditions

Saima Tarannum and Zeba N. Siddiqui*

Department of Chemistry, Aligarh Muslim University, Aligarh, 202002, India

*Corresponding author. Email: *siddiqui_zeba@yahoo.co.in*

Abstract

A novel heterogeneous catalyst $Fe(OTs)_3/SiO_2$ was synthesized and identified using FT-IR, XRD, SEM, EDX, XRF and TG analyses. The catalyst was successfully applied as a highly effective catalyst for the synthesis of a series of dibenzodiazepines under solvent-free condition. This protocol has the advantages of convenient one-pot operation, atom-economy, excellent yields in short reaction time, reusability of catalyst and environmental friendliness.

Keywords: $Fe(OTs)_3/SiO_2$, Heterogeneous catalyst, Benzodiazepine, Solvent-free reaction.

Introduction

Easy availability of Lewis acids has prompted investigations on their applications in the field of catalysis. Several reports have shown an amazing level of their performance as catalysts in terms of selectivity, reactivity, and improved yields of products. In recent years, iron salts as well as complexes have emerged as efficient catalysts in organic synthesis for the construction of different heterocycles from academic research laboratories to the large-scale chemical industries.[1] The use of iron salts for mild and eco-friendly reactions has attracted attention due to their inexpensiveness and environmental benignity. Recently, iron tosylate has been found as a very effective catalyst for useful chemical transformations.[2-5] The application of iron tosylate for organic synthesis provides advantages such as lack of sensitivity to moisture, low toxicity and ease in handling. However, the use of iron tosylate is limited in organic synthesis due to difficulties in isolation and recovery of catalyst from the reaction mixture. These limitations hamper the economic viability and sustainability of catalytic protocols. The catalytic applications of iron tosylate in organic reactions can be improved if its recovery and reuse procedure becomes facile.

Multicomponent reactions (MCRs) have significant economic and ecological impacts as they address the unique, versatile and highly convergent reaction design.[6] Moreover, the incorporation of solvent-free methods in MCRs makes the process cleaner, safer, and easier to perform.[7] Thus, the utilization of MCRs coupled with environmentally benign solvent-free condition is highly desirable.

Benzodiazepines have got extensive attention owing to their broad variety of biological activities, such as analgesic, anti-inflammatory, antipyretic, anti-cancer, anticonvulsant, antimicrobial, anthelmintic, antianxiety and anti-depressive activities.[8-12] Dibenzodiazepines also show potential activities such as antianaphylactic, antipsychotic, and anxiolytic activities.[13-15] Classically they are synthesized by tedious processes using acetic acid/ethanol,

oxalic acid/water, acetic acid/*i*-propanol and sulphuric acid/ethanol which have drawbacks like use of non-recyclable catalyst, long reaction time and environmental hazards.[14-17] However, some improved methods are also reported which includes use of ZnS NPs and chitosan-Fe_3O_4, etc.[18,19] In this regard, exploring alternative catalysts for synthetic improvement of this reaction, we have synthesized a novel catalyst $Fe(OTs)_3/SiO_2$ and analysed its catalytic potential for the synthesis of dibenzodiazepines *via* three-component reaction of dimedone, *o*-phenylenediamine and aldehydes/hetero aldehydes. The newly synthesized catalyst has been characterized with the help of FT-IR spectra, powder X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX) and X-ray fluorescence (XRF) techniques. Thermal stability of the catalyst is examined by TG analysis.

Results and Discussion

Characterization of catalyst $Fe(OTs)_3/SiO_2$

FT-IR spectrum of $Fe(OTs)_3/SiO_2$

The FT-IR spectrum of SiO_2 (Fig. 1a) showed a broad OH stretching absorption band in the region of 3422 cm^{-1}. The bands at 1110 cm^{-1} and 808 cm^{-1} were attributed to anti-symmetric and symmetric Si–O–Si stretching vibrations. Si–O–Si bending mode appeared near 473 cm^{-1}. For comparative analysis, the FT-IR spectrum of $Fe(OTs)_3$ is also included (Fig. 1b). The spectrum exhibited characteristic peaks at 3071 cm^{-1} and 1037 cm^{-1} for C-H stretching and bending vibrations. The peaks at 1262 and 1158 cm^{-1} were indicative of the O=S=O asymmetric and symmetric stretching vibrations, respectively. C–S stretching mode was observed at 567 cm^{-1}.[20]

In IR spectrum of catalyst (Fig. 1c), a broad absorption band at 3600 to 2800 cm^{-1} was attributed to OH stretching of SiO_2 moiety. The spectrum showed C-H stretching and bending vibrations at 3092 and 1042 cm^{-1}, respectively. The presence of SO_2 group was confirmed by

asymmetric and symmetric stretching vibrations at 1184 and 1124 cm^{-1} respectively. However, a band at 1093 cm^{-1} was attributed to anti symmetric Si–O–Si stretching. Further, symmetric Si–O–Si stretching and bending vibrations appeared near 813 and 465 cm^{-1}. The absorption peak at 570 cm^{-1} was indicative of C–S stretching mode of iron tosylate. The peaks corresponding to both SiO_2 and iron tosylate in the spectrum of catalyst justify the successful adsorption of tosylate group on silica surface.

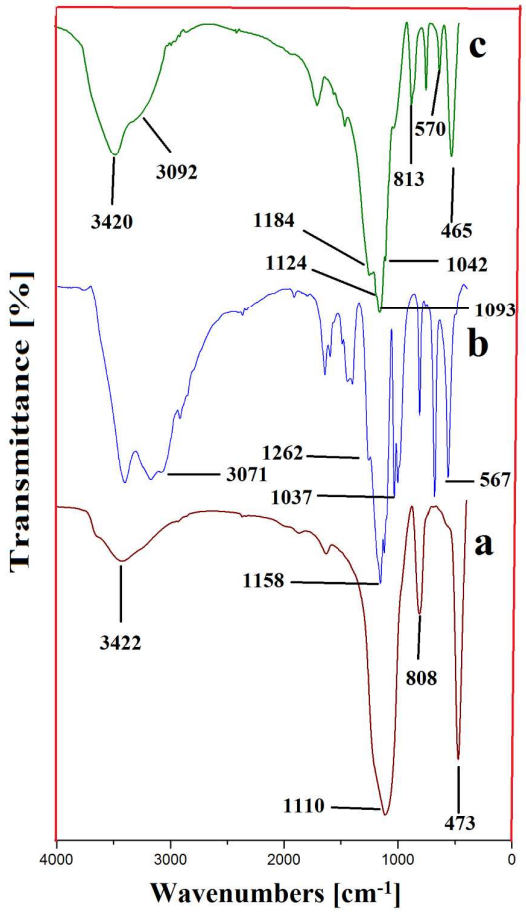


Fig. 1. FT-IR Spectra of (**a**) SiO_2, (**b**) $Fe(OTs)_3$ and (**c**) $Fe(OTs)_3/SiO_2$.

Powder X-ray diffraction (XRD) analysis of catalyst

The XRD analysis showed that the XRD patterns of the catalyst (Fig. 2b) were similar to that of the support (Fig. 2a). The catalyst showed a broad peak around 10–30° which was attributed to SiO_2.

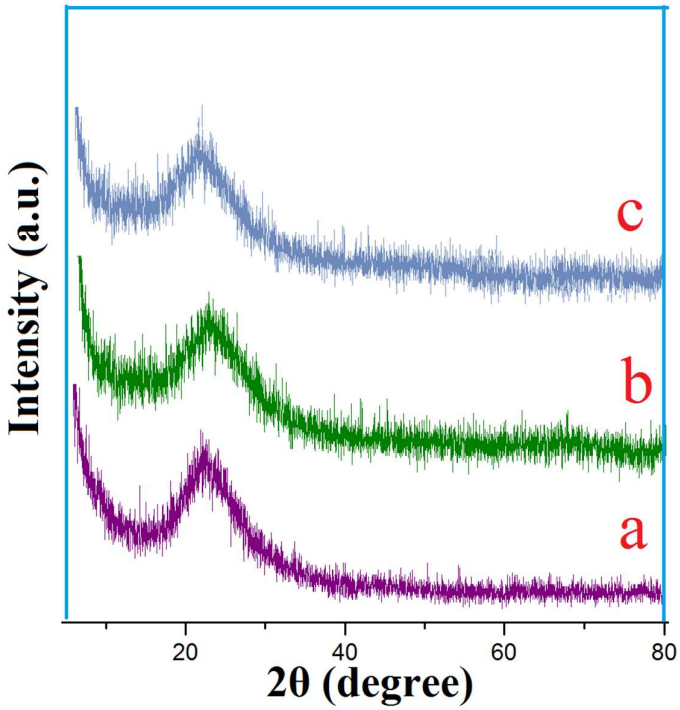


Fig. 2. Powder XRD pattern of (a) SiO_2 (b) fresh catalyst $Fe(OTs)_3/SiO_2$ (c) $Fe(OTs)_3/SiO_2$ after five catalytic cycles.

SEM-EDX analysis of the $Fe(OTs)_3/SiO_2$

Morphological structure and particle distribution of the catalyst were revealed by scanning electron microscopy. The particles of $Fe(OTs)_3$ were well dispersed and no agglomeration was found on the surface of silica gel (Fig. 3a and 3b). EDX analysis of the catalyst showed peaks for Si, Fe, S and O elements confirming formation of $Fe(OTs)_3/SiO_2$ (Fig. 4).

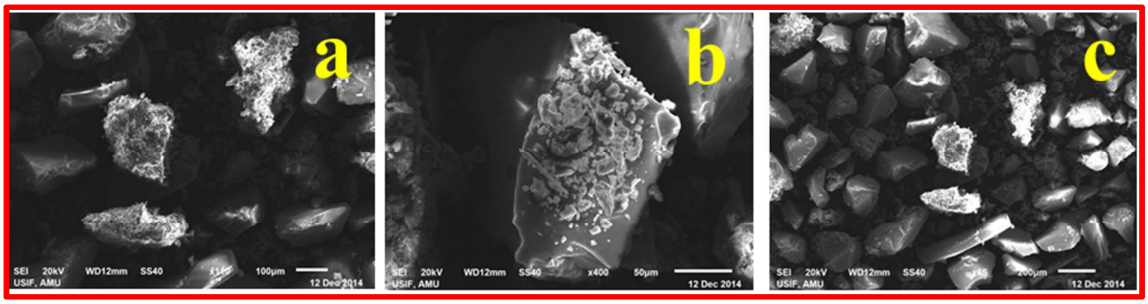


Fig. 3. SEM images of (**a,b**) freshly synthesized $Fe(OTs)_3/SiO_2$ at different magnifications **(c)** $Fe(OTs)_3/SiO_2$ after five catalytic cycles.

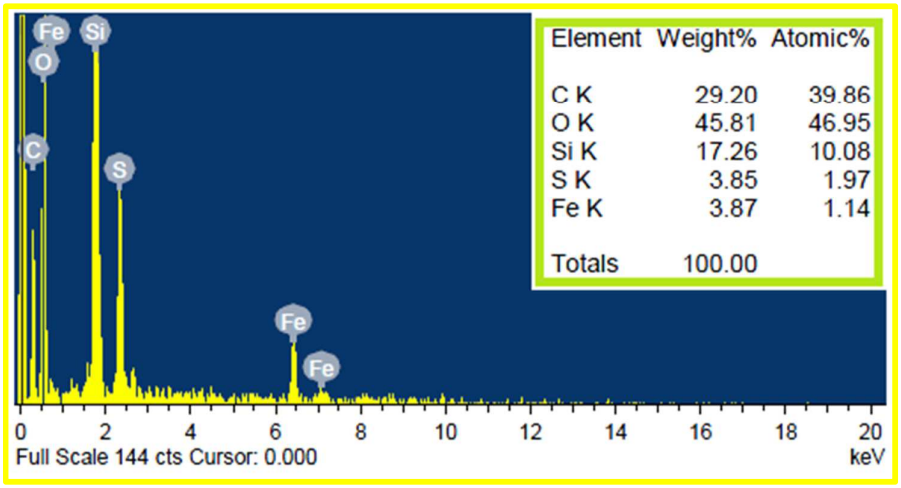


Fig. 4. EDX spectrum of the $Fe(OTs)_3/SiO_2$

XRF analysis of the catalyst

The chemical composition of $Fe(OTs)_3/SiO_2$ was determined by XRF analysis (Table 1). The analysis confirmed the presence of $Fe(OTs)_3$ on the surface of silica. The actual composition of the catalyst has been found as, SiO_2 84.72 (%w/w), C 7.71 (%w/w), S 3.57 (%w/w), and Fe 3.21 (%w/w).

Table 1 Composition of $Fe(OTs)_3/SiO_2$ determined by XRF analysis

Entry	Compound/ Element	Concentration (%w/w)	
		Fresh catalyst	Recycled catalyst (after 5 runs)
1	SiO_2	84.72	85.08
2	C	7.71	7.54
3	S	3.57	3.36
4	Fe	3.21	3.11
5	Cl	0.62	0.65
6	Ca	0.05	0.07
7	Others	0.10	0.14

TG analysis of $Fe(OTs)_3/SiO_2$

The thermal stability of $Fe(OTs)_3/SiO_2$ was examined by thermogravimetric analysis. According to TG curve, the weight loss process of catalyst could be divided into three stages (Fig. 5). The first weight loss of 12.15% around 66.8 °C was due to loss of surface physisorbed water. The second weight loss of 4.58% in the range of 180-400 °C was due to degradation of SO_3 groups of tosylate moiety. The third weight loss of 12.01% in the range of 400-600 °C was attributed to the decomposition of organic residue.

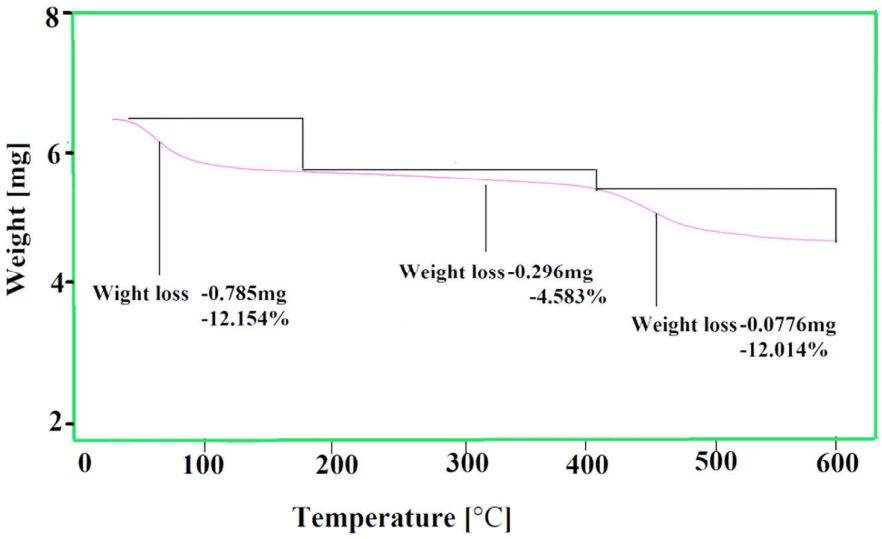


Fig. 5. TG curve of $Fe(OTs)_3/SiO_2$

Optimization of reaction conditions

In order to explore the optimum conditions for the synthesis of dibenzodiazepines, the reaction of dimedone **1** (1mmol), *o*-phenylenediamine **2** (1 mmol) and 3-formyl chromone **3a** (1 mmol) was selected as model reaction. The effect of various reaction conditions, different supports, amount of catalyst and temperature were studied to optimize the reaction condition. At first, the reaction was carried out in the absence of catalyst. The reaction did not take place even after prolonged heating (Table 2, entry 1). When $ZnCl_2$, $NiCl_2$, $AlCl_3$, $CuCl_2$ and $MgCl_2$ were employed as catalyst, low yield of product was obtained (Table 2, entries 2-6). Using $FeCl_3$, $Fe(NO_3)_3$ and $Fe_2(SO_4)_3$, moderate yield of product was observed (Table 2, entries 7-

9). However, the use of $Fe(OTs)_3$ increased the efficiency, and produced high yield of product (Table 2, entry 10). In order to further improve efficiency of our protocol, $Fe(OTs)_3/SiO_2$ was tested for the model reaction and substantial increase in yield of the product in short reaction time was observed (Table 2, entry 11). The reaction was also carried out with SiO_2 in order to evaluate role of $Fe(OTs)_3$ and no reaction occurred (Table 2, entry 12). Afterward, the effect of different solvents was investigated for the model reaction in the presence of $Fe(OTs)_3/SiO_2$. Protic solvents such as C_2H_5OH, $(CH_3)_3COH$ and CH_3OH, yielded the moderate yield in long reaction time (Table 2, entries 13-15). Whereas, green solvents (ethylene glycols, water) also did not work-out for the said reaction (Table 2, entries 16-19). These results clearly indicated solvent-free condition as the best reaction condition for the model reaction using $Fe(OTs)_3/SiO_2$ as catalyst.

Table 2 Effect of various reaction media for the model reaction[a]

Entry	Catalyst	Condition	Time[b]	Yield[c]
1	No catalyst	Solvent-free/80 °C	24 h	No reaction
2	$ZnCl_2$ (10 mol%)	Solvent-free/80 °C	7.5 h	32
3	$NiCl_2$ (10 mol%)	Solvent-free/80 °C	7.5 h	30
4	$AlCl_3$ (10 mol%)	Solvent-free/80 °C	9 h	26
5	$CuCl_2$ (10 mol%)	Solvent-free/80 °C	8.4 h	30
6	$MgCl_2$ (10 mol%)	Solvent-free/80 °C	9.2 h	34
7	$FeCl_3$ (10 mol%)	Solvent-free/80 °C	6 h	64
8	$Fe(NO_3)_3$ (10 mol%)	Solvent-free/80 °C	6.4 h	60
9	$Fe_2(SO_4)_3$ (10 mol%)	Solvent-free/80 °C	4.5 h	68
10	$Fe(OTs)_3$ (10 mol%)	Solvent-free/80 °C	3 h	74
11	$Fe(OTs)_3/SiO_2$ (100 mg)	Solvent-free/80 °C	10 min	93
12	SiO_2	Solvent-free/80 °C	24 h	No reaction

13	$Fe(OTs)_3/SiO_2$ (100 mg)	Ethanol/Reflux	15 h	64
14	$Fe(OTs)_3/SiO_2$ (100 mg)	Isopropanol/Reflux	17.5 h	60
15	$Fe(OTs)_3/SiO_2$ (100 mg)	Methanol/Reflux	14 h	64
16	$Fe(OTs)_3/SiO_2$ (100 mg)	Ethylene glycol/100 °C	20 h	Trace
17	$Fe(OTs)_3/SiO_2$ (100 mg)	PEG-200/100 °C	20 h	Trace
18	$Fe(OTs)_3/SiO_2$ (100 mg)	PEG-400/100 °C	20 h	Trace
19	$Fe(OTs)_3/SiO_2$ (100 mg)	Water/Reflux	20 h	Trace

[a] Reaction of dimedone (1mmol), *o*-phenylenediamine (1 mmol) and 3-formyl chromone (1 mmol) in the presence of different catalysts/solvents. [b] Reaction progress monitored by TLC. [c] Isolated yield.

The effect of different supports such as Al_2O_3 (acidic, basic, neutral), TiO_2, ZrO_2 and SiO_2 on the catalytic activity was also evaluated using the model reaction (Table 3). Among the various supports, silica gel proved to be an appropriate support in terms of reaction time and product yield (Table 3, entry 6) which may be due to good dispersion of $Fe(OTs)_3$ on the surface of silica gel.

Table 3 Effect of different supports on the synthesis of **4a** under thermal solvent-free condition[a]

Entry	Support	Time[b]	Yield[c] (%)
1	Acidic alumina	2.2 h	74
2	Basic alumina	2.8 h	62
3	Neutral alumina	2.8 h	60
4	Titania	4 h	38
5	Zirconia	3.8 h	40
6	Silica gel	10 min	93

[a]Reaction of dimedone (1mmol), *o*-phenylenediamine (1 mmol) and 3-formyl chromone (1 mmol) in the presence of 100 mg of catalyst. [b]Reaction progress monitored by TLC. [c]Isolated yield.

Further optimization related to temperature revealed that the temperature had a pronounced effect on the rate of the reaction. Only a trace amount of product was formed when model reaction was conducted at room temperature (Table 4, entry 1). Increasing the reaction temperature up to 60 °C again several hours were required for completion of the reaction (Table 4, entries 2-3). Maximum yield of the product was obtained in shortest time period when reaction was performed at 80 °C (Table 4, entry 4).

Table 4 Effect of temperature on the synthesis of **4a** under solvent-free condition[a]

Entry	Temperature	Time[b]	Yield[c]
1	RT	18 h	Trace
2	40 °C	4.5 h	42
3	60 °C	3.2 h	64
4	80 °C	10 min	93
5	100 °C	10 min	93

[a] Reaction of dimedone (1mmol), *o*-phenylenediamine (1 mmol) and 3-formyl chromone (1 mmol) in the presence of $Fe(OTs)_3/SiO_2$ (100 mg). [b] Reaction progress monitored by TLC. [c] Isolated yield.

In order to achieve highest yield of the desired product, the model reaction was optimized by varying the amount of catalyst (Table 5). The study showed that the catalyst had crucial role in the progress of reaction. The rate of reaction increased steadily with increasing the catalyst amount from 40 to 100 mg (Table 5, entries 1-4).

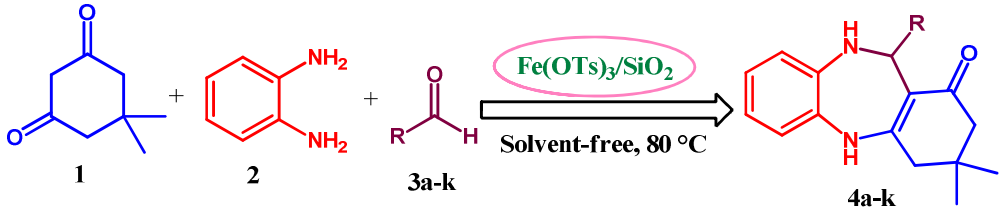
Table 5 Effect of amount of catalyst on the synthesis of **4a** under thermal solvent-free condition[a]

Entry	$Fe(OTs)_3/SiO_2$ (mg)	Time[b] (min)	Yield[c] (%)
1	40	55	54
2	60	40	68
3	80	25	80
4	100	10	93
5	120	10	93

[a]Reaction of dimedone (1mmol), *o*-phenylene diamine (1 mmol) and 3-formyl chromone (1 mmol) in the presence of $Fe(OTs)_3/SiO_2$. [b] Reaction progress monitored by TLC. [c] Isolated yield.

Catalytic reaction

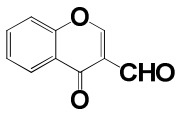
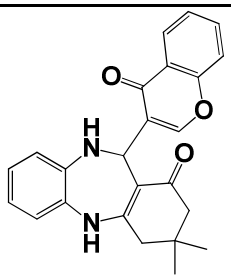
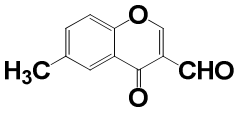
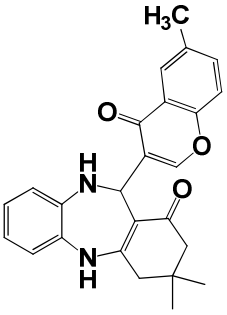
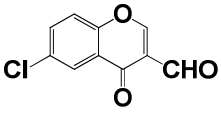
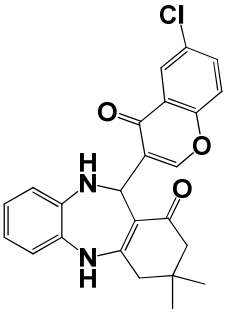
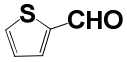
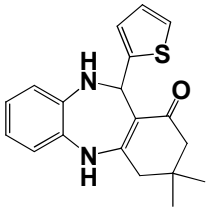
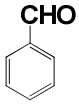
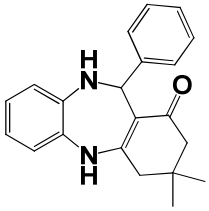
Under these optimized reaction conditions the scope of the reaction was explored for the synthesis of dibenzodiazepines **4a-k** (Scheme 1). A variety of functionalities were tolerated in hetero aldehydes as well as aromatic aldehydes under the present reaction conditions providing the corresponding products in excellent isolated yields in minimum time period (Table 6).

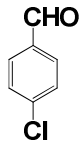
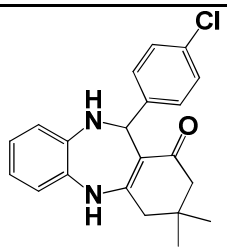
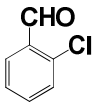
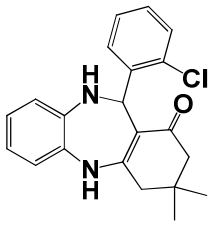
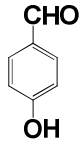
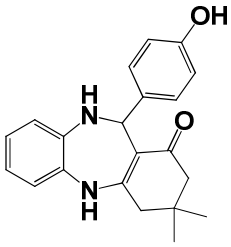
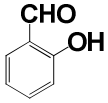
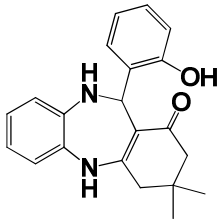
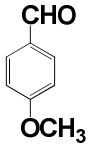
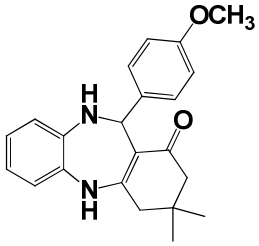
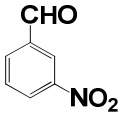
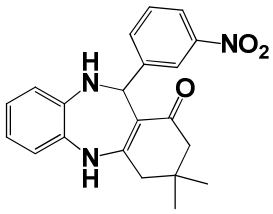


Scheme 1. Synthesis of dibenzodiazepines (**4a-k**) using $Fe(OTs)_3/SiO_2$ under thermal solvent-free conditions

Table 6 The reaction of dimedone, *o*-phenylenediamine and aldehydes in presence of $Fe(OTs)_3/SiO_2$ under thermal solvent-free conditions

Entry	Aldehyde	Product	Time[a] (min)	Yield[b] (%)	Melting point	
					Observed	Reported

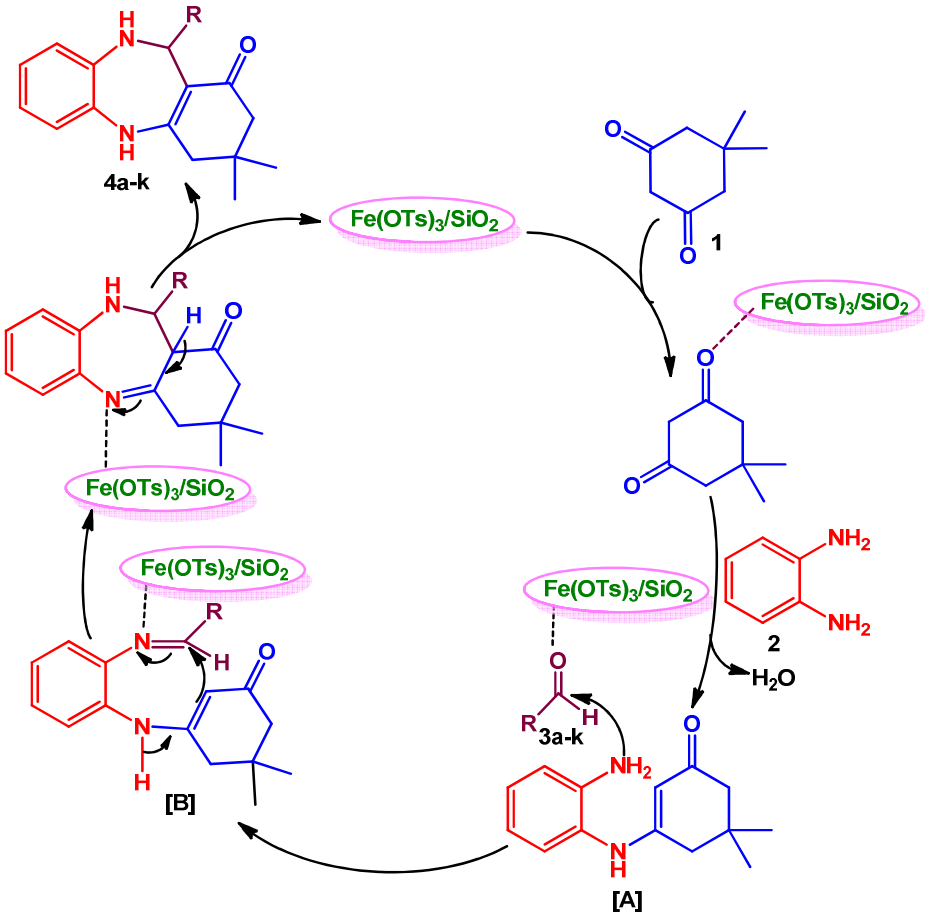
1		 **4a**	10	93	215-217	-
2		 **4b**	10	93	240-242	-
3		 **4c**	10	92	235-237	-
4		 **4d**	10	90	228-230	226-228[19]
5		 **4e**	5	94	243-245	246-248[18]

6		 **4f**	5	96	238-240	235-237[19]
7		 **4g**	7	92	235-237	232-233[18]
8		 **4h**	7	92	220-222	225[19]
9		 **4i**	10	90	205-207	201-202[18]
10		 **4j**	5	93	226-228	229-231[18]
11		 **4k**	10	88	190-192	195-197[18]

[a] Reaction progress monitored by TLC. [b] Isolated yield.

Reaction mechanism

A plausible mechanism for the formation of 4-substituted-1,5- benzodiazepine is proposed in scheme 2. First, the $Fe(OTs)_3/SiO_2$ activated carbonyl group of dimedone **1** undergoes Michael addition with *o*-phenylenediamine **2** to form imine intermediate [**A**]. The NH_2 group of [**A**] reacts with $Fe(OTs)_3/SiO_2$ activated carbonyl group of aldehydes **3a-k**, to form [**B**], which undergoes intramolecular cyclization to afford products **4a-k**.[18]

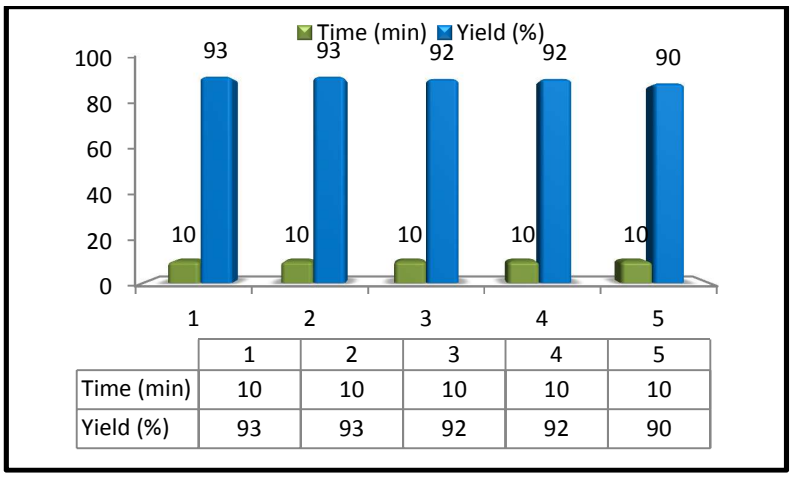


Scheme 2. Proposed mechanism for the formation of **4a-k**

Recyclability of catalyst

One of the most important advantages of heterogeneous catalyst $Fe(OTs)_3/SiO_2$ over the homogeneous counterpart is the possibility of reusing the catalyst by simple procedure. Therefore, recovery and reusability of the catalyst was also investigated for the model reaction. The catalyst $Fe(OTs)_3/SiO_2$ was recovered by filtration, washed 3 times with 5 mL

ethanol, dried at 100 °C and reused in the next run. The data (Fig. 6) demonstrated practical recyclability of the catalyst with a slight loss of its activity. The XRF analysis of the catalyst after 5 runs showed the chemical composition as, SiO_2 85.08 (%w/w), C 7.54 (%w/w), S 3.36 (%w/w), and Fe 3.11 (%w/w) (Table 1). This indicates that $Fe(OTs)_3$ is tightly bound to the support and leaching of Fe does not takes place during the course of reaction. The XRD and SEM images of the catalyst after 5 runs (Figs. 2c and 3c) showed no significant changes in the morphology indicating substantial retention of the catalytic activity during its reuse.



	1	2	3	4	5
Time (min)	10	10	10	10	10
Yield (%)	93	93	92	92	90

Fig. 6. Recyclability of the catalytic system.

Experimental

Chemicals and apparatus

Melting points of all synthesized compounds were taken in a Riechert Thermovar instrument and are uncorrected. The IR spectra (KBr) were recorded on Perkin Elmer RXI spectrometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker DRX-300 and Bruker Avance II 400 spectrometer using tetramethylsilane (TMS) as an internal standard and DMSO-d_6/$CDCl_3$ as solvent. ESI-MS were recorded on a Quattro II (ESI) spectrometer. Elemental analyses (C, H and N) were conducted using the Elemental vario EL III elemental analyzer and their results were found to be in agreement with the calculated values. All reagents were purchased from Merck and Aldrich and were used without further purification. The homogeneity of the

compounds was checked by thin layer chromatography (TLC) on glass plates coated with silica gel G254 (E. Merck) using chloroform-methanol (3:1) mixture as mobile phase and visualized using iodine vapors. X-ray diffractograms (XRD) of the catalyst were recorded in the 2θ range of 0-80° with scan rate of 4°/ min on a Rigaku Minifax X-ray diffractometer with Ni-filtered Cu Kα radiation at a wavelength of 1.54060 A°. SEM-EDX characterization of the catalyst was performed on a JEOL JSM-6510 scanning electron microscope equipped with energy dispersive X-ray spectrometer operating at 20 kV. X-ray fluorescence analysis was carried out with a PHILLIPS PW 2404. TGA data was obtained with DTG-60H (Simultaneous DTA-TG Apparatus), Shimadzu instrument.

Preparation of $Fe(OTs)_3$

In a round-bottomed flask equipped with a reflux condenser, a mixture of $FeCl_3$ (3.18 g, 19.6 mmol) and *p*-toluenesulfonic acid monohydrate (11.20 g, 58.9 mmol) was taken and heated under vacuum for 1 h in an oil bath at 160 °C. The resulting orange solid was washed with diethyl ether (30 mL), treated with methanol (30 mL), and refluxed for 20 min. The resulting solution was filtered and the remaining filtrate was dried under vacuum. Then, a 3:1 mixture of acetonitrile/methanol (30 mL) was added and refluxed for 20 min. The resulting suspension was then allowed to cool and the orange precipitate was collected by filtration, washed with diethyl ether (20 mL), and dried for 30 min under vacuum at 160 °C.[20]

Preparation of catalyst $Fe(OTs)_3/SiO_2$

$Fe(OTs)_3$ (2 g) was added to the suspension of silica gel G (Merck, 70-230 mesh, 8 g) in ethanol (50 mL). The mixture was stirred at 100 °C till the evaporation of the solvent and then allowed to cool at room temperature to afford $Fe(OTs)_3/SiO_2$ catalyst as free flowing powder.

General procedure for the synthesis of 4-substituted-1,5-benzodiazepine

A mixture of dimedone (5 mmol), *o*-phenylenediamine (5 mmol), aldehyde (5 mmol) and 0.5g of $Fe(OTs)_3/SiO_2$ was stirred at 80 °C under solvent-free condition for the appropriate time (Table 6). After completion of the reaction (monitored by TLC), the reaction mixture was cooled to room temperature and added ethyl acetate (5 mL). The catalyst was recovered by filtration, washed with ethanol (2×5 mL) and reused for next cycles. The filtrate was concentrated to furnish products (**4a-k)** which were then further purified by recrystallization from ethanol. The identity of the products was confirmed by ^{1}H NMR, ^{13}C NMR, and mass spectra.

Spectral data of synthesized compounds

4a 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[4-oxo-4H-chromen-3-yl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1637, 2933, 3316. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.05 (s, 6H, 2 x CH_3), 2.52 (ABq, 2H, J = 16.3 Hz, CH_2), 2.70 (s, 2H, CH_2), 5.37 (d, 1H, J = 5.4 Hz, CH), 5.82 (d, 1H, J = 5.0 Hz, NH), 6.45–8.12 (m, 9H, Ar–H), 8.93 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 27.85, 31.95, 43.34, 50.35, 55.89, 112.28, 118.82, 122.62, 124.12, 126.11, 127.14, 128.22, 132.52, 137.80, 145.23, 155.24, 182.70, 192.60; ESI-MS (m/z) 387.42 (M^++1). Anal. Calcd ($C_{24}H_{22}N_2O_3$): C, 74.59; H, 5.73; N, 7.24. Anal. Found ($C_{24}H_{22}N_2O_3$): C, 74.51; H, 5.69; N, 7.18.

4b 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[6-methyl-4-oxo-4H-chromen-3-yl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1645, 2925, 3436. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.05 (s, 6H, 2 x CH_3), 2.37 (s, 1H, CH_3), 2.46 (ABq, 2H, J = 16.3 Hz, CH_2), 2.62 (s, 2H, CH_2), 5.22 (d, 1H, J = 5.3 Hz, CH), 5.80 (d, 1H, J = 5.4 Hz, NH), 7.23–7.72 (m, 8H, Ar–H), 8.77 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 20.20, 28.16, 32.40, 44.56, 49.22, 57.18, 110.64, 121.46, 123.14, 125.08, 126.61, 127.42, 128.62, 132.10, 137.63, 145.34, 155.16, 180.24, 190.64; ESI-MS

(m/z) 401.82 (M^++1). Anal. Calcd ($C_{25}H_{24}N_2O_3$): C, 74.97; H, 6.04; N, 6.99. Anal. Found ($C_{25}H_{24}N_2O_3$): C, 74.90; H, 6.16; N, 6.87.

4c 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[6-chloro-4-oxo-4H-chromen-3-yl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1622, 2930, 3433. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.06 (s, 6H, 2 x CH_3), 2.50 (ABq, 2H, J = 16.2 Hz, CH_2), 2.60 (s, 2H, CH_2), 5.37 (d, 1H, J = 5.2 Hz, CH), 5.82 (d, 1H, J = 5.0 Hz, NH), 6.45–8.10 (m, 8H, Ar–H), 8.90 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 27.95, 32.21, 45.14, 50.05, 56.49, 110.68, 119.87, 120.44, 121.24, 122.98, 126.11, 127.73, 129.12, 131.49, 138.84, 145.1, 155.12, 183.50, 191.42; ESI-MS (m/z) 421.32 (M^++1). Anal. Calcd ($C_{24}H_{21}ClN_2O_3$): C, 68.48; H, 5.02; N, 6.65. Anal. Found ($C_{24}H_{21}ClN_2O_3$): C, 68.34; H, 5.12; N, 6.58.

4d 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[2-thienyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1630, 2965, 3295. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.03 (s, 6H, 2 x CH_3), 2.10 (ABq, 2H, J = 16.2 Hz, CH_2), 2.58 (s, 2H, CH_2), 5.75 (d, 1H, J = 5.2 Hz, CH), 6.15 (d, 1H, J = 5.2 Hz, NH), 6.35–7.85 (m, 6H, Ar–H), 8.90 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 26.78, 33.14, 44.52, 50.26, 55.74, 110.65, 118.16, 121.36, 123.44, 126.59, 127.63, 131.45, 136.26, 144.24, 155.17, 180.18, 190.25; ESI-MS (m/z) 325.46 (M^++1). Anal. Calcd ($C_{19}H_{20}N_2OS$): C, 70.33; H, 6.21; N, 8.63. Anal. Found ($C_{19}H_{20}N_2OS$): C, 70.28; H, 6.27; N, 8.68.

4e 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1642, 2930, 3305. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.02 (s, 6H, 2 x CH_3), 2.12 (ABq, 2H, J = 16.2 Hz, CH_2), 2.64 (s, 2H, CH_2), 5.73 (d, 1H, J = 5.4 Hz, CH), 6.12 (d, 1H, J = 5.4 Hz, NH), 6.46–7.32 (m, 9H, Ar–H), 8.92 (s, 1H, NH); ^{13}C NMR (100

MHz): δ 27.52, 32.70, 44.50, 50.15, 55.95, 111.14, 119.12, 121.24, 123.22, 126.42, 126.74, 128.20, 130.52, 137.84, 145.10, 155.06, 182.74, 192.45; ESI-MS (m/z) 319.16 (M^++1). Anal. Calcd ($C_{21}H_{22}N_2O$): C, 79.21; H, 6.96; N, 8.79. Anal. Found ($C_{21}H_{22}N_2O$): C, 79.25; H, 6.93; N, 8.82.

4f 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[(4-chloro)phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1625, 2935, 3316. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.10 (s, 6H, 2 x CH_3), 2.10 (ABq, 2H, J = 16.4 Hz, CH_2), 2.50 (s, 2H, CH_2), 5.70 (d, 1H, J = 5.4 Hz, CH), 6.30 (d, 1H, J = 5.4 Hz, NH), 6.40–7.90 (m, 8H, Ar–H), 8.60 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 28.60, 32.32, 44.74, 49.30, 57.24, 110.26, 121.14, 123.46, 124.48, 126.50, 127.35, 128.24, 132.13, 137.32, 146.44, 148.12, 153.20, 190.64; ESI-MS (m/z) 353.84 (M^++1). Anal. Calcd ($C_{21}H_{21}ClN_2O$): C, 71.48; H, 5.99; N, 7.93. Anal. Found ($C_{21}H_{21}ClN_2O$): C, 71.42; H, 6.06; N, 7.88.

4g 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[(2-chloro)phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1640, 2924, 3345. ^{1}H NMR (DMSO-d_6, 400 MHz): δ 1.04 (s, 6H, 2 x CH_3), 2.10 (ABq, 2H, J = 16.0 Hz, CH_2), 2.58 (s, 2H, CH_2), 5.75 (d, 1H, J = 5.4 Hz, CH), 6.32 (d, 1H, J = 5.4 Hz, NH), 6.40–7.40 (m, 8H, Ar–H), 8.85 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 28.20, 32.32, 45.16, 50.12, 56.54, 110.14, 120.10, 121.44, 122,64, 123.17, 124.40, 125.82, 126.78, 128.14, 130.54, 138.24, 145.12, 155.12, 190.52; ESI-MS (m/z) 353.62 (M^++1). Anal. Calcd ($C_{21}H_{21}ClN_2O$): C, 71.48; H, 5.99; N, 7.93. Anal. Found ($C_{21}H_{21}ClN_2O$): C, 71.44; H, 6.04; N, 7.90.

4h 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[(4-hydroxy)phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1632, 2938, 3342, 3460. ^1H NMR (DMSO-d_6, 400 MHz): δ 1.05 (s, 6H, 2 x CH_3), 2.12 (ABq, 2H, J = 16.0 Hz, CH_2), 2.52 (s, 2H, CH_2), 5.75 (d, 1H, J = 5.2 Hz, CH), 6.32 (d, 1H, J = 5.2 Hz, NH), 6.35–7.20 (m, 8H, Ar–H), 8.65 (s, 1H, NH), 8.95 (s, 1H, O–H); ^{13}C NMR (100 MHz): δ 28.20, 32.46, 44.62, 49.90, 57.16, 110.74, 114.16, 117.14, 119.24, 120.52, 122.32, 123.42, 128.16, 132.13, 137.32, 146.44, 148.12, 154.12, 158.34, 190.64; ESI-MS (m/z) 335.46 (M^++1). Anal. Calcd ($C_{21}H_{22}N_2O_2$): C, 75.42; H, 6.63; N, 8.37. Anal. Found ($C_{21}H_{22}N_2O_2$): C, 75.48; H, 6.66; N, 8.42.

4i 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[(2-hydroxy)phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1644, 2920, 3364, 3432. ^1H NMR (DMSO-d_6, 400 MHz): δ 1.03 (s, 6H, 2 x CH_3), 2.10 (ABq, 2H, J = 16.2 Hz, CH_2), 2.50 (s, 2H, CH_2), 5.74 (d, 1H, J = 5.0 Hz, CH), 6.33 (d, 1H, J = 5.0 Hz, NH), 6.30–7.10 (m, 8H, Ar–H), 8.60 (s, 1H, NH), 9.20 (s, 1H, O–H); ^{13}C NMR (100 MHz): δ 28.16, 32.28, 44.82, 50.14, 57.05, 110.62, 113.96, 116.12, 119.26, 120.46, 121.49, 122.54, 123.10, 127.96, 130.37, 138.74, 146.40, 147.03, 154.65, 158.18, 191.32; ESI-MS (m/z) 335.82 (M^++1). Anal. Calcd ($C_{21}H_{22}N_2O_2$): C, 75.42; H, 6.63; N, 8.37. Anal. Found ($C_{21}H_{22}N_2O_2$): C, 75.45; H, 6.61; N, 8.39.

4j 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[(4-methoxy)phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1638, 2936, 3304. ^1H NMR (DMSO-d_6, 400 MHz): δ 1.05 (s, 6H, 2 x CH_3), 2.12 (ABq, 2H, J = 16.0 Hz, CH_2), 2.51 (s, 2H, CH_2), 3.70 (s, 3H, CH_3), 5.72 (d, 1H, J = 5.4 Hz, CH), 6.33 (d, 1H, J = 5.4 Hz, NH), 6.30–7.14 (m, 8H, Ar–H), 8.64 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 27.64, 32.36, 44.75, 49.86, 54.88, 56.82, 110.90, 112.43, 113.58, 118.45, 119.53, 120.75, 121.54, 123.57, 128.14, 130.65, 138.05, 146.16, 147.18, 154.86, 191.50; ESI-MS (m/z) 349.24 (M^++1). Anal. Calcd ($C_{22}H_{24}N_2O_2$): C, 75.83; H, 6.94; N, 8.04. Anal. Found ($C_{22}H_{24}N_2O_2$): C, 75.89; H, 6.96; N, 8.10.

4k 3,3-Dimethyl-2,3,4,5,10,11-hexahydro-11-[(4-nitro)phenyl]-1H-dibenzo-[*b,e*][1,4]diazepin-1-one

IR (KBr) (υ_{max}, cm^{-1}): 1634, 2942, 3298. ^1H NMR (DMSO-d_6, 400 MHz): δ 1.11 (s, 6H, 2 x CH_3), 2.12 (ABq, 2H, J = 16.0 Hz, CH_2), 2.53 (s, 2H, CH_2), 5.74 (d, 1H, J = 5.4 Hz, CH), 6.35 (d, 1H, J = 5.4 Hz, NH), 6.40–8.00 (m, 8H, Ar–H), 8.65 (s, 1H, NH); ^{13}C NMR (100 MHz): δ 28.55, 32.16, 44.36, 49.95, 56.73, 110.05, 120.64, 121.17, 122.24, 123.40, 124.53, 127.34, 130.28, 131.93, 137.87, 146.13, 153.20, 154.68, 191.74; ESI-MS (m/z) 364.16 (M^++1). Anal. Calcd ($C_{21}H_{21}N_3O_3$): C, 69.40; H, 5.82; N, 11.56. Anal. Found ($C_{21}H_{21}N_3O_3$): C, 69.46; H, 5.88; N, 11.60.

Conclusion

In summary, we have successfully prepared iron tosylate from low cost starting material and synthesized its heterogeneous version by supporting on silica gel. It conveniently catalysed the reaction affording products in excellent yield and preserving atom economy. The catalyst does not need special precautions for preparation and can be stored at an ambient temperature without losing its catalytic activity. The prominent advantages of this new protocol are the recyclability of the catalyst, operational simplicity, high yields of the products in short reaction times, and environmentally friendly synthesis avoiding toxic reagents and volatile solvents.

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References

1. K.C. Majumdar, N. De, T. Ghosh and B. Roy, *Tetrahedron,* 2014, **70**, 4827.
2. N.J. Baldwin, A.N. Nord, B. D. O'Donnell and R.S. Mohan, *Tetrahedron Lett*., 2012, **53**, 6946.
3. J.M. Bothwell, V.V. Angeles, J.P. Carolan, M.E. Olson and R.S. Mohan, *Tetrahedron Lett*., 2010, **51**, 1056.
4. M.E. Olson, J.P. Carolan, M.V. Chiodo, P.R. Lazzara and R.S. Mohan, *Tetrahedron Lett*., 2010, **51**, 3969.
5. J.T. Starcevich, T.J. Laughlin and R.S. Mohan, *Tetrahedron Lett*., 2013, **54**, 983.
6. R.C. Cioc, E. Ruijter and R.V.A. Orru, *Green Chem*., 2014, **16**, 2958.
7. M.S. Singh and S. Chowdhury, *RSC Adv*., 2012, **2**, 4547.
8. G. Grossi, M.D. Braccio, G. Roma, V. Ballabeni, M. Tognolini, F. Calcina and E. Barocelli, *Eur. J. Med. Chem*., 2002, **37**, 933.
9. A. Kamal, V. Devaiah, K.L. Reddy and M.S. Kumar, *Bioorg. Med. Chem*., 2005, **13**, 2021.
10. G.D. Sarro, A. Chimirri, R. Mckernan, K. Quirk, P. Giusti and A.D. Sarro, *Pharmacol. Biochem. Be*., 1997, **58**, 281.
11. R. Kumar and Y.C. Joshi, *Arkivoc* 2007, **xiii**, 142.
12. G.B. Cassano and L. Conti, *Br. J. clin. Pharmac*., 1981, **11**, 23S.
13. M.E. Greig, A.J. Gibbons and G.A. Young, *J. Med. Chem*., 1971, **14**, 153.
14. O.I. El-Sabbagh and S.M. El-Nabtity, *Bull. Korean Chem. Soc*., 2009, **30**, 1445.
15. J.N. Sangshetti, R.S. Chouthe, M.R. Jadhav, N.S. Sakle, A. Chabukswar, I. Gonjari, S. Darandale and D.B. Shinde, *Arabian J. Chem*., 2013, doi.org/10.1016/j.arabjc.2013.04.004.

16. N.N. Kolos, E.N. Yurchenko, V.D. Orlov, S.V. Shishkina and O.V. Shishkin, *Chem. Heterocycl. Compd*., 2004, **40,** 1550.

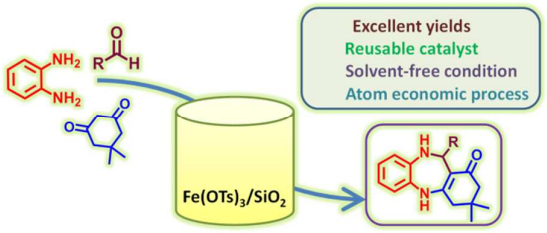
17. N. N. Tonkikh, A. Strakovs, K. V. Rizhanova and M.V. Petrova, *Chem. Heterocycl. Compd*., 2004, **40**, 949.

18. H. Naeimi and H. Foroughi, *New J. Chem*., 2015, **39**, 1228.

19. A. Maleki and M. Kamalzare, *Tetrahedron Lett*., 2014, **55**, 6931.

20. D. Coucouvanis, Inorganic Syntheses, Volume 33, 2002 John Wiley & Sons, Inc.

Graphical Abstract



$Fe(OTs)_3/SiO_2$ catalyst was used as an efficient, recyclable, heterogeneous catalyst for the multicomponent synthesis of dibenzodiazepines.