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Research Article

Design, Characterization, and Application of The SCMNPs@PC/VB1-Zn as A Green and Recyclable Biocatalyst for Synthesis of Pyrano[2,3-c]pyrazole and 4H-benzo-[b]-pyran Derivatives

Fang Hou[1,*], Wei Zheng[1], Nasser Yousefi[2]

[1]Jiyuan Vocational and Technical College, Jiyuan, Henan 459000, China.
[2]Islamic Azad University, Science and Research Branch, Tehran, Iran.

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Abstract

Eco-friendly and reusable solid acid catalysts (SCMNPs@PC/VB_1-Zn) were identified as one of the most effective basic catalysts for the composition of a pot, three-component pyrano[2,3-*c*]pyrazoles. Methyl-1-phenyl-1*H*-pyrazole-5(4*H*)-one, benzaldehyde and malononitrile in high yield at 80 °C. SCMNPs@ PC/VB_1-Zn reports the simple and efficient catalysis of a three-component pot reaction of dimedone, aldehydes, and malononitrile to 4*H*-benzo-[*b*]-pyran derivatives. This magnetic nanocatalyst can be recycled more than 6 times without dramatically reducing performance with respect to reaction time and efficiency. Copyright © 2020 BCREC Group. All rights reserved

Keywords: Recyclable biocatalyst; Magnetic nanocatalyst; Synthesis; Pyran derivatives; Eco-friendly

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1. Introduction

Iron oxide magnetic nanoparticles, especially magnetite (Fe_3O_4) as the most extensive investigated magnetic nanoparticles (MNPs), exhibit unique physical and chemical features compared to the bulk materials and their use is expanding quite rapidly. Various strategies have been used to prepare Fe_3O_4 core-shell nanocomposites including coprecipitation [1], thermal decomposition [2], ultrasound irradiation, microemulsion, and hydrothermal synthesis [3] of which thermal decomposition and co-precipitation are the most commonly used procedures. Fe_3O_4 MNPs are particularly prominent due to their distinctive characteristics (*e.g.* high surface area, high pressure, low blindness temperature, high stability, superconductivity, and low toxicity [4-9]) in various applications including medical diagnosis, drug delivery, color imaging, cancer treatment, information storage, catalyst, microwave absorption, biosensors and organic and inorganic transformations [10-17]. The magnetic nature of these nanoparticles enables them to be easily separated from the reaction solution using an external magnetic field to eliminate the need for filtration and reuse several runs with a slight decrease in product yield and reaction time [18-21].

As remarkable compounds, the substituted pyrano[2,3-*c*]pyrazoles have achieved considerable interest over the past years due to their perfect range of pharmacological and biological ac-

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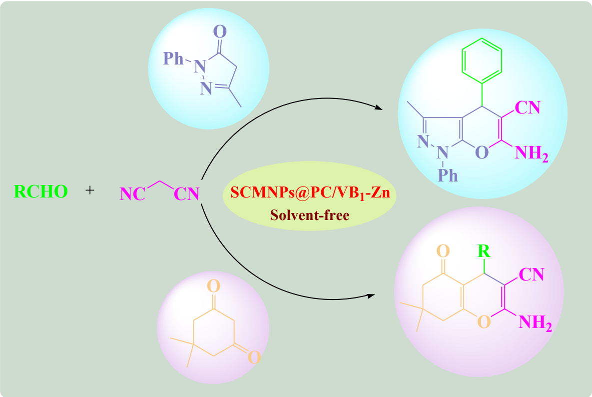
* Corresponding Author.
Email: jyhoufang@163.com (F. Hou);

tivities, including the inhibitors of human Chk1 kinase [22], antimicrobial [23], anti-inflammatory [24], and anticancer [25] activities. In one of the important ways, pyrano[2,3-*c*]pyrazole derivatives were synthesized by the three-component condensation reaction of pyrazolone, malononitrile, and aldehyde in the presence of various catalysts, such as: KF.2H_2O [26], BF_3/MNPs [27], *p*-dodecylbenzene sulfonic acid (DBSA) [28], $H_{14}[NaP_5W_{30}O_{110}]$ [29], triethylbenzylammonium chloride (TEBA) [30], MgO [31], and hexadecyltrimethylammonium bromide (HTMAB) [32]. Most of the procedures reported for the preparation of these kind of heterocyclic compounds are associated with demerits such as long reaction time, low yields, the use of hazardous organic solvents, lack of general applicability, tedious work-up methods, use of toxic catalysts, and harsh reaction conditions. Therefore, the introduction of new and efficient strategy for the synthesis of pyrano[2,3-c]pyrazole derivatives can be useful.

Over last decades, three-component one-pot condensation of dimedone, malononitrile, and aldehyde have been reported for the construction of substituted 4*H*-benzo-[*b*]-pyrans via several homogeneous and heterogeneous catalytic systems, such as: nanoparticles [33], microwave irradiation [34], ionic liquid [35], quaternary ammonium salt [36], TFE [37], TBAB [38], ultrasound irradiations [39], KF-alumina [40], rare earth perfluorooctanoate [41], IRA-400 (OH^-) [42], DMF [43], DABCO [44], urea [45], L-proline [46], HDMBAB [47], potassium phosphate [48], TBAF [49], and molecular iodine [50]. Although most of these procedures offer distinct advantages, they may have some limitations such as low yield of the products, long reaction times, use of hazardous organic solvents, harsh reaction conditions, difficult work-up, and use of toxic catalysts. Therefore, it is desirable to propose a new and efficient strategy for the preparation of the substituted 4*H*-benzo-[*b*]-pyrans.



Scheme 1. Synthesis of pyrano[2,3-*c*]pyrazole and 4*H*-benzo-[*b*]-pyran derivatives using SCMNPs@PC/VB$_1$-Zn.

In this study, we reported our outcomes for the rapid and efficient preparation of pyrano[2,3-*c*]pyrazoles and 4*H*-benzo-[*b*]-pyran derivatives using SCMNPs@PC/VB$_1$-Zn as a green and recyclable heterogeneous magnetic biocatalyst under solvent-free conditions (Scheme 1).

2. Materials and Methods

2.1 Experimental

FT-IR spectra were collected with a PerkinElmer PXI spectrometer in the range 400-4000 cm^{-1} on KBr pellets. The X-ray diffraction patterns of samples were obtained in the 2θ range of 10-80° at room temperature on a Philips X-pert diffractometer (Holland) with Co-Kα (λ = 1.54 Å). Scanning electron microphotograph (SEM) was utilized to survey the catalyst morphology on an LEO 1430VP instrument. Thermal gravimetric analysis was performed using a Linseis STA PT 1000 instrument with a heating rate of 10 °C/min over a temperature range of 25-700 °C under N_2 atmosphere. The magnetic susceptibility measurements of the catalyst were obtained using a vibrating sample magnetometry (VSM; Lake Shore 7200 at 300 kVsm).

2.2 Catalyst Synthesis

2.2.1 Preparation of the Fe_3O_4 magnetic nanoparticles (Fe_3O_4 MNPs)

First, a mixture of 4.8 g $FeCl_3.6H_2O$ and 2.4 g $FeCl_2.4H_2O$ was added to 100 mL of deionized water and the contents of the reaction vessel were vigorously stirred under the argon atmosphere at 80 °C for 20 min. Then, 10 mL of concentrated solution of ammonia was added quickly to the reaction solution and stirred again for 30 min. To achieve the desired precursor, the reaction solution was cooled and the formed black magnetic nanoparticles were isolated by the magnetic decantation. The desired precipitates were consecutively washed with deionized water and dried overnight in the absence of temperature under vacuum.

2.2.2 Preparation of the silica-coated magnetic nanoparticles (SCMNPs)

First, the achieved black magnetic nanoparticles from the first step was dispersed in a mixture of ethanol (80 mL), deionized water

(25 mL) and concentrated aqueous ammonia (8 mL) and was sonicated for 30 min. Under continuous mechanical stirring, 20 mL of tetraethylorthosilicate (TEOS) was added to the reaction solution and was stirred for 24 h. The obtained $Fe_3O_4@SiO_2$ precipitate was separated by magnetic decantation and consecutively washed with deionized water and ethanol and dried under vacuum at 50 °C for 10 h.

2.2.3 Preparation of the silica-coated magnetic nanoparticles bonded 3-chloropropyltriethoxysilane (SCMNPs@PC)

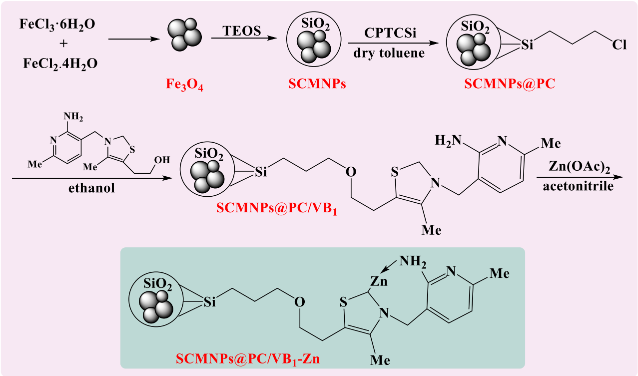
The 4 mL of 3-chloropropyltriethoxysilane (CPTCSi) was added to the reaction vessel containing 2 g of dispersed SC@Fe_3O_4 MNPs in 50 mL dry toluene and stirred at 60 °C for 24 h. The residue solid (SCMNPs@PC) was separated via the magnetic decantation, consecutively washed with ethanol to remove the excess CPTCSi, and dried in a vacuum oven at 60 °C for 12 h.

2.2.4 Preparation of the SCMNPs@PC/VB$_1$

The 2 g of SCMNPs@PC was added to the reaction vessel containing 50 mL of ethanol and dispersed for 30 min. Then, 1 mmol of thiamine hydrochloride (VB$_1$) and 3-4 drop of triethylamine were added to the reaction mixture and refluxed for 12 h. The solid residue was extracted by an appropriate magnetic field, consecutively washed with ethanol, and dried under the vacuum oven.

2.2.5 Preparation of SCMNPs@PC/VB$_1$-Zn.

The 2 g of the prepared SCMNPs@PC/VB$_1$ was dispersed in 50 mL of acetonitrile for 30 min. Then, 0.1 g of $Zn(OAc)_2$ was poured to the reaction solution. After that, the contents of the reaction vessel were refluxed for 24 h and the resulting nanoparticles were isolated using an external magnetic field. The solid residue was washed several times with dry ethanol and dried at 70 °C for 24 h. All stages of the SCMNPs@PC/VB$_1$-Zn synthesis are shown in Scheme 2.



Scheme 2. Preparation of SCMNPs@PC/VB$_1$-Zn core-shell catalyst.

2.2.6 Typical procedure for the preparation of 4*H*-benzo-[*b*]-pyran derivatives.

A mixture of 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one (1 mmol), aldehyde (1.1 mmol), malononitrile (1.1 mmol), and SCMNPs@PC/VB$_1$-Zn (10 mg) was stirred at 80 °C in the absence of any solvents for the appropriate time. The progress of the reaction was monitored by thin layer chromatography (TLC). In order to extraction of the catalyst, ethanol was added to the reaction vessel and stirred at 70 °C. After complete dissolution of the product in the desired solvent, the catalyst was isolated from reaction solution by an external magnetic field and rinsed several times with ethanol. The obtained products were crystallized from ethanol to give pure products.

2.2.7 Typical procedure for the preparation of pyrano[2,3-*c*]pyrazole derivatives.

A mixture of dimedone (1 mmol), aldehyde (1 mmol), malononitrile (1.2 mmol), and SCMNPs@PC/VB$_1$-Zn (10 mg) was stirred at 50 °C in the absence of any solvents for the appropriate time. After completion of the reaction, as it can be seen from thin layer chromatography (TLC), ethanol was added to the reaction vessel and stirred at 70 °C. After complete dissolution of the product in the desired solvent, the catalyst was isolated from reaction mixture by an external magnetic field and rinsed several times with ethanol. After evaporation of ethanol, the achieved products were washed with n-hexane to give appropriate compound in pure form.

3. Results and Discussion

3.1 FTIR Analysis of SCMNPs@PC/VB$_1$-Zn

Figure 1 shows the FT-IR spectra of Fe_3O_4 MNPs, SCMNPs, SCMNPs@PC, SCMNPs@PC/VB$_1$, and SCMNPs@PC/VB$_1$-Zn. As is clear from all of the spectra, the broad absorption of 3408 cm^{-1} belongs to the O-H stretching vibrations. In the spectrum of Fe_3O_4 MNPs, the characteristic absorption at 585 and 456 cm^{-1} are associated to Fe-O-Fe stretching vibrations related to the magnetite phase. As can be seen from the FT-IR spectrum of the SCMNPs, the introduction of a layer of SiO_2 to the surface of MNPs can be verified by band at 1103 cm^{-1} which is assigned to the stretching vibration of Si-O-Si group. After bonding the SCMNPs with 3-chloropropyltriethoxysilane (CPTCSi), the FT-IR spectrum of the SCMNPs@PC exhibits a new peak at 2985 cm^{-1} assigned to the C-H stretching vibration of the aliphatic group. The bands at 1533 and 1640 cm^{-1} are attributable to the C-N and N-H (NH_2) vibrations of the VB_1 group indicate that the SCMNPs@PC are functionalized with thiamine. It should be noted that the C-N and N-H signal of the SCMNPs@PC/VB_1-Zn are shifted to a lower wavenumber than the C-N and N-H signal of the SCMNPs@PC/VB_1 (1529 and 1637 cm^{-1} rather than 1533 and 1640 cm^{-1}).

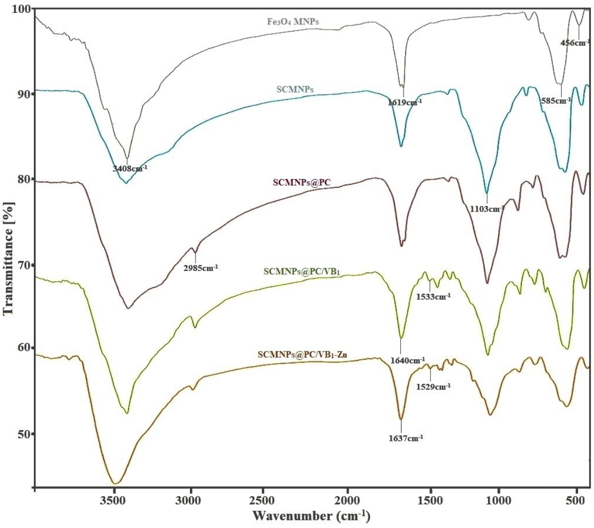


Figure 1. The FT-IR spectra of Fe_3O_4 MNPs, SCMNPs, SCMNPs@PC, SCMNPs@PC/VB_1, and SCMNPs@PC/VB_1-Zn.

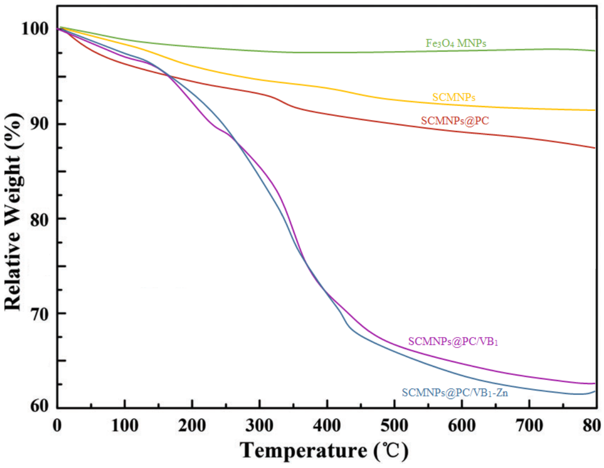


Figure 2. The TGA diagrams of Fe_3O_4 MNPs, SCMNPs, SCMNPs@PC, SCMNPs@PC/VB_1, and SCMNPs@PC/VB_1-Zn.

3.2 TGA Analysis of SCMNPs@PC/VB_1-Zn.

Using TGA, we investigated the thermal stability of the Fe_3O_4 MNPs, SCMNPs, SCMNPs@PC, SCMNPs@PC/VB_1, and SCMNPs@PC/VB_1-Zn were investigated. The outcomes of these analyses are exhibited in Figure 2. In the TGA curve of the all samples, the first small amount of weight loss in 100-150 °C is attributed to the both the physisorbed and chemisorbed solvents and hydroxyl groups on the surface of the magnetic nanoparticles. In the TGA curve of SCMNPs@PC, a weight loss below 350 °C is resulted from the decomposition of the coating organic layer of chloropropyl on the Fe_3O_4 MNPs surface. The weight loss of the SCMNPs@PC/VB_1, and SCMNPs@PC/VB_1-Zn at the temperature range of 150-450 °C are attributed to the decomposition of the organic parts of chloropropyl and thiamine on the surface of the magnetic phase.

3.3 EDX analysis of SCMNPs@PC/VB_1-Zn

The results of the element distribution of SCMNPs@PC/VB_1-Zn were further surveyed by EDX analysis (Figure 3). The coating of SiO_2 on the Fe_3O_4 MNPs surface was verified by the presence of Si, Fe, and O signals. The existence of C, S, O, and N signals exhibits that the thiamine is loaded on the surface of SCMNPs@PC/VB_1. The EDX analysis also presents the existence of the zinc element indicating coordination of Zn with thiamine. The appearance of the zinc element in the EDX analysis is attributed to SCMNPs@PC/VB_1-Zn catalyst, indicating coordination of Zn with thiamine has been done successfully.

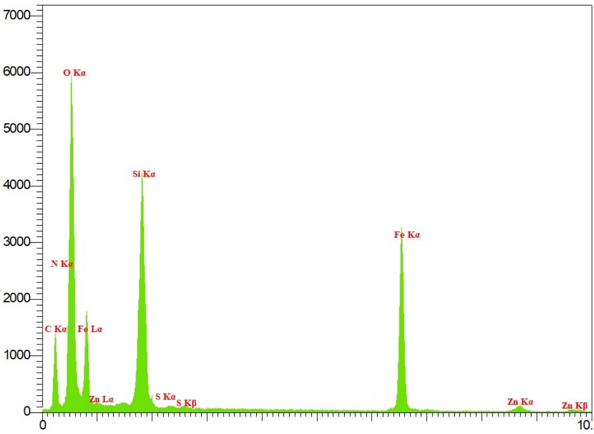


Figure 3. EDX image of SCMNPs@PC/VB_1-Zn.

3.4 VSM Analysis of SCMNPs@PC/VB$_1$-Zn

The magnetization curves of Fe_3O_4 MNPs and SCMNPs@PC/VB$_1$-Zn catalyst were investigated by vibrating sample magnetometry at room temperature (Figure 4). The curves show a decrease in the saturation magnetization (Ms) values from 61.38 emu/g (Fe_3O_4 MNPs) to 37.45 emu/g (SCMNPs@PC/VB$_1$-Zn) due to the successful grafting of non-magnetic silica layer and other functional groups (chloropropyl, thiamine-Zn) on the surface of Fe_3O_4 MNPs. Although the values of the catalyst saturation magnetization have decreased sequentially due to the magnetic nature of the SCMNPs@PC/VB$_1$-Zn, the achieved heterogeneous magnetic nanocatalyst can be separated from the reaction solution *via* an external magnetic field.

3.5 XRD Analysis of SCMNPs@PC/VB$_1$-Zn.

As shown in Figure 5, the X-ray diffraction (XRD) spectrum of the Fe_3O_4 MNPs, and SCMNPs@PC/VB$_1$-Zn was recognized by six characteristic peak positions at 2θ = 30.78, 36.84, 47.56, 56.85, 62.92, and 68.54 were indexed to the (220), (311), (400), (422), (511), and (440) planes, respectively, which are appropriately in line with the crystalline cubic spinel structure (JCPDS card no. 19-0629) of Fe_3O_4 magnetic nanoparticles. It has been verified that the surface modification of the Fe_3O_4 magnetic nanoparticles has not changed during the grafting of silica layer and other functional groups (chloropropyl, thiamine-Zn).

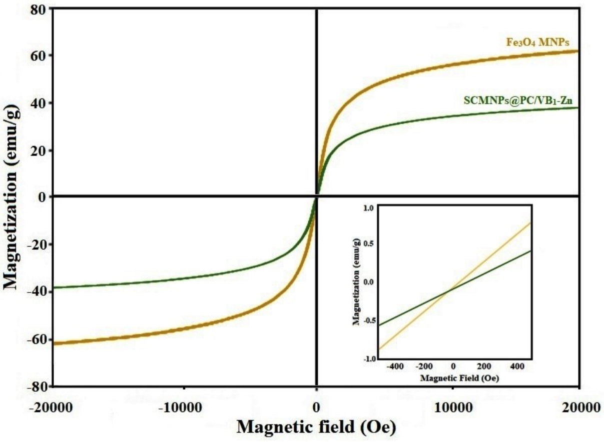


Figure 4. VSM analysis of SCMNPs@PC/VB$_1$-Zn.

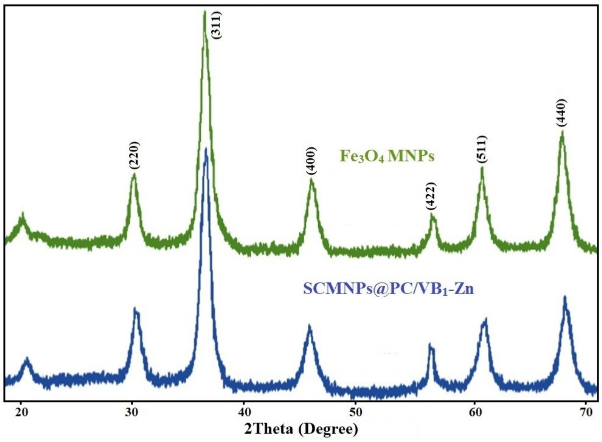


Figure 5. XRD pattern of Fe_3O_4 MNPs and SCMNPs@PC/VB$_1$-Zn.

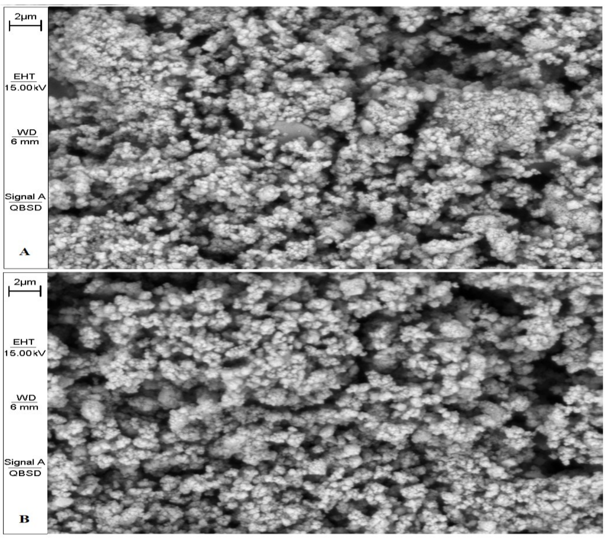


Figure 6. SEM pattern of SCMNPs@PC/VB$_1$-Zn (A) and recovered SCMNPs@PC/VB$_1$-Zn (B).

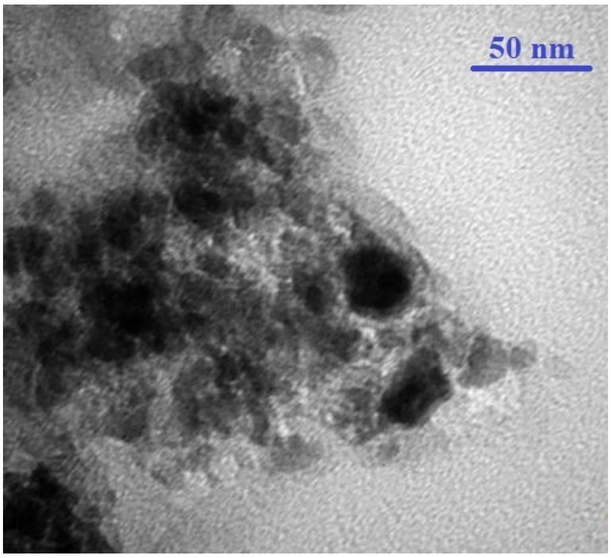


Figure 7. TEM image of SCMNPs@PC/VB$_1$-Zn.

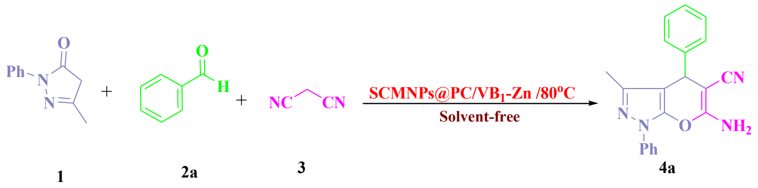
3.6 SEM Analysis of SCMNPs@PC/VB$_1$-Zn

As shown in Figure 6, in order to determine the variations in the surface of the prepared magnetic nanoparticles, the morphology and size of the SCMNPs@PC/VB$_1$-Zn (A) and recovered SCMNPs@PC/VB$_1$-Zn (B) were studied by scanning electron microscopy (SEM). The SCMNPs@PC/VB$_1$-Zn (A) exhibits a nearly spherical structure with an average particle diameter about 32 nm. As is clear from SEM images, the diameters of the recovered SCMNPs@PC/VB$_1$-Zn (B) are about 38-46 nm with a negligible increase in the size.

3.7 TEM Analysis of SCMNPs@PC/VB$_1$-Zn

The TEM image of the SCMNPs@PC/VB$_1$-Zn exhibits that the dark Fe_3O_4 MNPs cores have an almost spherical shape with a narrow size distribution and surrounded by the grey silica shell (the average particle size is 50 nm, Figure 7). In the first study, the condensation of 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one (1 mmol), benzaldehyde (1.1 mmol), and malononitrile (1.1 mmol) for the synthesis of pyrano[2,3-*c*]pyrazoles was selected as a model reaction. The effects of amounts of SCMNPs@PC /VB$_1$-Zn, reaction temperature, different sol-

Table 1. Optimization of the three-component reaction of 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one, benzaldehyde, and malononitrile under various conditions[a].

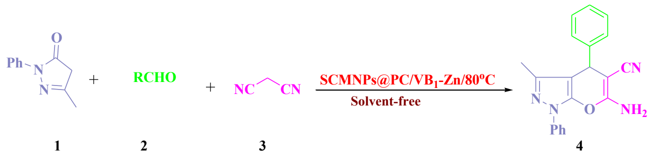


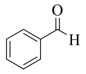
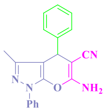
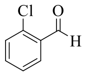
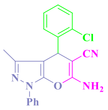
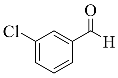
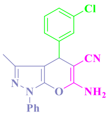
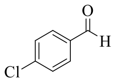
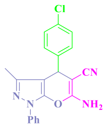
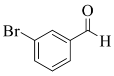
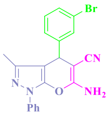
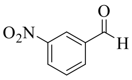
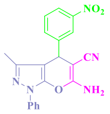
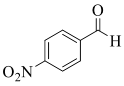
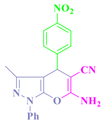
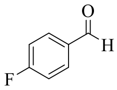
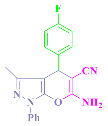
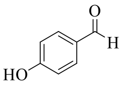
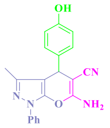
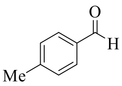
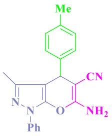
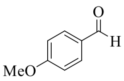
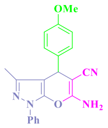
Entry	Solvent	Catalyst (mg)	Temp.	Time (min)	Yield (%)[b]	Ref.
1	H_2O	SCMNPs@PC/VB$_1$-Zn/10	Reflux	65	80	This work
2	EtOH	SCMNPs@PC/VB$_1$-Zn/10	Reflux	30	89	This work
3	MeOH	SCMNPs@PC/VB$_1$-Zn/10	Reflux	35	87	This work
4	$CHCl_3$	SCMNPs@PC/VB$_1$-Zn/10	Reflux	90	82	This work
5	CH_2Cl_2	SCMNPs@PC/VB$_1$-Zn/10	Reflux	150	79	This work
6	CH_3CN	SCMNPs@PC/VB$_1$-Zn/10	Reflux	35	86	This work
7	Solvent- free	SCMNPs@PC/VB$_1$-Zn/10	80 °C	15	96	This work
8	Solvent- free	SCMNPs@PC/VB$_1$-Zn/10	25 °C	70	52	This work
9	Solvent- free	SCMNPs@PC/VB$_1$-Zn/10	60 °C	30	85	This work
10	Solvent- free	SCMNPs@PC/VB$_1$-Zn/10	70 °C	20	91	This work
11	Solvent- free	SCMNPs@PC/VB$_1$-Zn/10	90 °C	15	95	This work
12	Solvent- free	SCMNPs@PC/VB$_1$-Zn/10	100 °C	15	93	This work
13	Solvent- free	SCMNPs@PC/VB$_1$-Zn/15	80 °C	15	94	This work
14	Solvent- free	SCMNPs@PC/VB$_1$-Zn/5	80 °C	35	75	This work
15	H_2O	DBSA	60 °C	180	88	[28]
16	EtOH	$NH_4H_2PO_4/Al_2O_3$	Reflux	15	84	[51]
17	EtOH	Sulfamic acid	Reflux	600	82	[52]
18	H_2O	HTMAB	85 °C	180	89	[32]
19	H_2O	TEBA	90 °C	360	99	[30]

[a] Reaction conditions: 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one (1 mmol), benzaldehyde (1.1 mmol), malononitrile (1.1 mmol), and required amount of the catalyst.

[b] The yields refer to the isolated product.

Table 2 SCMNPs@PC/VB$_1$-Zn -Catalyzed synthesis of pyrano[2,3-*c*]pyrazole derivatives[a]



Entry	RCHO (2)	Product	Yield (%)^b / Time (min)	M.P (Obsd) (°C)	M.P (Lit)$^{Ref.}$ (°C)
1		 **4a**	96/15	170-173	172-174[27]
2		 **4b**	94/20	146-148	145-146[53]
3		 **4c**	94/17	157-159	158-160[28]
4		 **4d**	92/10	179-182	178-180[27]
5		 **4e**	93/18	162-164	160-161[27]
6		 **4f**	93/12	190-192	190-191[27]
7		 **4g**	95/17	193-195	192-194[27]
8		 **4h**	92/12	173-176	175-177[27]
9		 **4i**	90/20	211-214	213-214[27]
10		 **4j**	91/25	174-176	175-177[27]
11		 **4k**	90/30	169-171	172-173[27]

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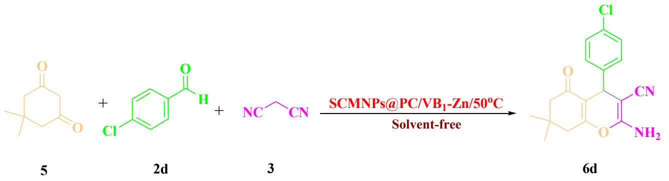
[a] Reaction conditions: 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one (1 mmol), aldehyde (1.1 mmol), malononitrile (1.1 mmol), and SCMNPs@PC/VB$_1$-Zn (10 mg).

vents and solvent-free conditions were surveyed to optimize the reaction conditions. To study the role of solvent, the model reaction was carried out under different solvents such as $CHCl_3$, CH_2Cl_2, CH_3CN, EtOH, MeOH, and H_2O. The best catalytic activity of SCMNPs@PC/VB_1-Zn was obtained in the absence of solvent (Table 1, Entry 7. Also, the SCMNPs@PC/VB_1-Zn catalyst in ethanol played a very important role in catalyzing the reaction (Table 1, Entry 2). To evaluate the appropriate concentration of catalyst, the model reaction was performed in the presence of 5, 10 and 15 of SCMNPs@PC/VB_1-Zn (Table 1, Entries 7 and 13-14). In this reaction, the best results were achieved using 10 mg of catalyst (Table 1, Entry 7), while enhancing the amount of the catalyst did not affect the reaction times and yields (Table 1, Entry 13). When the model reaction was accomplished in the presence of 5 mg of catalyst under the optimized conditions for 35 minutes, the yield of the product was moderate (Table 1, Entry 14). To study the effect of temperature on this synthesis, the reaction was performed at 25, 60, 70, 80, 90, and 100 °C in the presence of 10 mg of SCMNPs@PC/VB_1-Zn catalyst under solvent-free conditions (Table 1, Entries 7-12). It was observed that the product yield was maximized at 80 °C (Table 1, Entry 7). To show the advantages of the our work in comparison with the other reported catalysts in the literature, we summarized some of the results for the preparation of pyrano[2,3-*c*]pyrazoles in this table (Table 1, Entries 15-19). The results showed that SCMNPs@PC/VB_1-Zn is a more efficient catalyst than the reported ones in the literature with respect to the easy work-up, using a reusable catalyst, low catalyst loading, short reaction time and high yield.

To ascertain the scope and generality of the present system, various aromatic aldehydes

Table 3. Optimization of the three-component reaction of dimedone, 4-chlorobenzaldehyde, and malononitrile under various conditions[a].

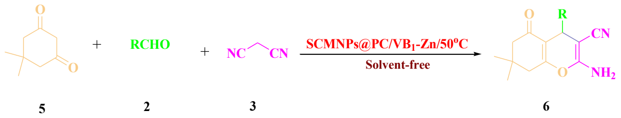


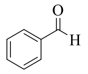
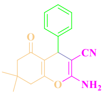
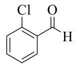
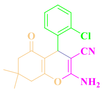
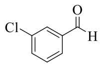
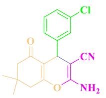
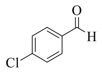
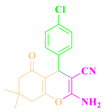
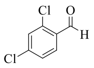
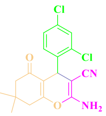
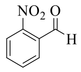
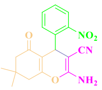
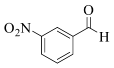
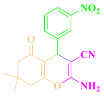
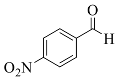
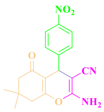
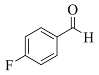
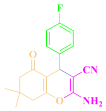
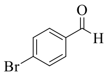
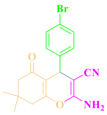
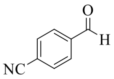
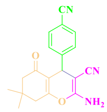
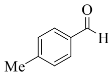
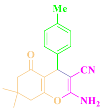
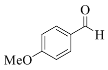
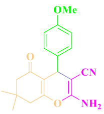
Entry	Solvent	Catalyst (mg)	Temp.	Time (min)	Yield (%)[b]	Ref
1	H_2O	SCMNPs@PC/VB_1-Zn/10	Reflux	10	89	This work
2	EtOH	SCMNPs@PC/VB_1-Zn/10	Reflux	15	86	This work
3	H_2O-EtOH	SCMNPs@PC/VB_1-Zn/10	Reflux	10	92	This work
4	Solvent- free	SCMNPs@PC/VB_1-Zn/10	50 °C	6	97	This work
5	Solvent- free	SCMNPs@PC/VB_1-Zn/10	25 °C	15	85	This work
6	Solvent- free	SCMNPs@PC/VB_1-Zn/10	40 °C	10	92	This work
7	Solvent- free	SCMNPs@PC/VB_1-Zn/10	60 °C	10	95	This work
8	Solvent- free	SCMNPs@PC/VB_1-Zn/10	70 °C	10	93	This work
9	Solvent- free	SCMNPs@PC/VB_1-Zn/10	80 °C	10	91	This work
10	Solvent- free	SCMNPs@PC/VB_1-Zn/15	50 °C	6	96	This work
11	Solvent- free	SCMNPs@PC/VB_1-Zn/5	50 °C	15	83	This work
12	H_2O	TBAB	Reflux	40	90	[54]
13	EtOH	RE(PFO)$_3$	60 °C	4 h	83	[55]
14	H_2O	POPINO	Reflux	10	92	[56]
15	H_2O-EtOH	Na_2SeO_4	Reflux	2.5 h	90	[57]
16	H_2O	AP-SiO_2	70 °C	60	92	[58]

[a] Reaction conditions: dimedone (1 mmol), 4-chlorobenzaldehyde (1 mmol), malononitrile (1.2 mmol), and required amount of the catalysts.

[b] The yields refer to the isolated product.

Table 4. SCMNPs@PC/VB$_1$-Zn -Catalyzed synthesis of 4*H*-benzo-[*b*]-pyran derivatives [a]

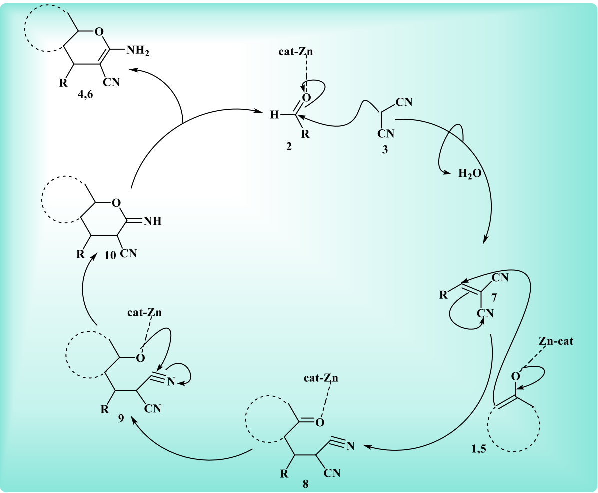


Entry	RCHO (2)	Product	Yield (%)^b / Time (min)	M.P(Obsd) (°C)	M.P (Lit)^{Ref} (°C)
1		 **6a**	94/8	226-228	227-229[54]
2		 **6b**	97/5	190-193	191-192[49]
3		 **6c**	92/6	227-230	228-229[59]
4		 **6d**	97/6	211-213	212-214[54]
5		 **6e**	98/6	181-184	182-183[54]
6		 **6f**	95/7	229-232	230[57]
7		 **6g**	96/6	209-211	210-212[54]
8		 **6h**	97/6	179-182	178-180[54]
9		 **6i**	97/7	209-212	210-211[49]
10		 **6j**	98/5	202-204	205-207[54]
11		 **6k**	97/5	229-232	227-230[60]
12		 **6l**	94/10	211-214	212-215[54]
13		 **6m**	95/10	200-202	201-203[54]

[a] Reaction conditions: dimedone (1 mmol), aldehyde (1 mmol), malononitrile (1.2 mmol), and SCMNPs@PC/VB$_1$-Zn (10 mg).

with both electron-withdrawing and electron-donating substituents were explored and the results of their reaction with 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one and malononitrile (or ethyl cyanoacetate) were summarized in Table 2. Aromatic aldehydes with both electron-withdrawing and electron-donating groups underwent smooth transformation to the corresponding pyrano[2,3-*c*]pyrazole derivatives, with no side products formation at high-to-excellent yields and in short reaction times.

The catalytic activity of SCMNPs@PC/VB$_1$-Zn was investigated for the synthesis of 4*H*-benzo-[*b*]-pyran derivatives via one-pot three-component reactions of dimedone, aldehydes, and malononitrile. To optimize the reaction conditions, we investigated the condensation among dimedone, 4-chlorobenzaldehyde, and malononitrile as a model reaction in the presence of various conditions (Table 3). In the best reaction condition, we used 10 mg of the SCMNPs@PC/VB$_1$-Zn for 1 mmol of any substrates at 50°C under solvent-free conditions (Table 3, Entry 4). Moreover, in order to compare the efficiency of this prepared catalyst with that of some previously reported catalysts for the synthesis of 4*H*-benzo-[*b*]-pyran derivatives (see Table 3, Entries 12-16), we bring the results for these catalysts in the synthesis of 6d as a model reaction.



Scheme 3. A plausible mechanism for the one-pot three-component reaction of 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one 1/dimedone 5, aldehyde 2, and malononitrile 3, catalyzed by SCMNPs@PC/VB$_1$-Zn under solvent-free conditions.

After optimizing the conditions, the efficiency and versatility of the SCMNPs@PC/VB$_1$-Zn as a catalyst for the preparation of 4*H*-benzo-[*b*]-pyran derivatives were evaluated by different aromatic aldehydes with both electron-withdrawing and electron-donating substituents. In all the studied cases, the reaction proceeded smoothly to give the desired products 6a-m (Table 4).

Scheme 3 illustrates a mechanism proposed for one-pot three-component condensation of 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one 1 /dimedone 5, aldehyde 2, and malononitrile 3 in the presence of SCMNPs@PC/VB$_1$-Zn. Initially, the Knoevenagel condensation of aromatic aldehyde and malononitrile in the presence of SCMNPs@PC/VB$_1$-Zn formed alkylidene malononitrile as an intermediate (7). After that, in the presence of SCMNPs@PC/VB$_1$-Zn, Michael addition reaction between C-H-activated acids 1 and 5 and alkylidene malononitrile 7, intramolecular cyclization (8, 9), and aromatization (10), lead to desired products 4 and 6.

The reusability of the SCMNPs@PC/VB$_1$-Zn was studied for the reaction between 3-methyl-1-phenyl-1*H*-pyrazol-5(4*H*)-one/dimedone, benzaldehyde, and malononitrile under solvent-free conditions. The catalyst was recovered by an external magnetic field and washed with

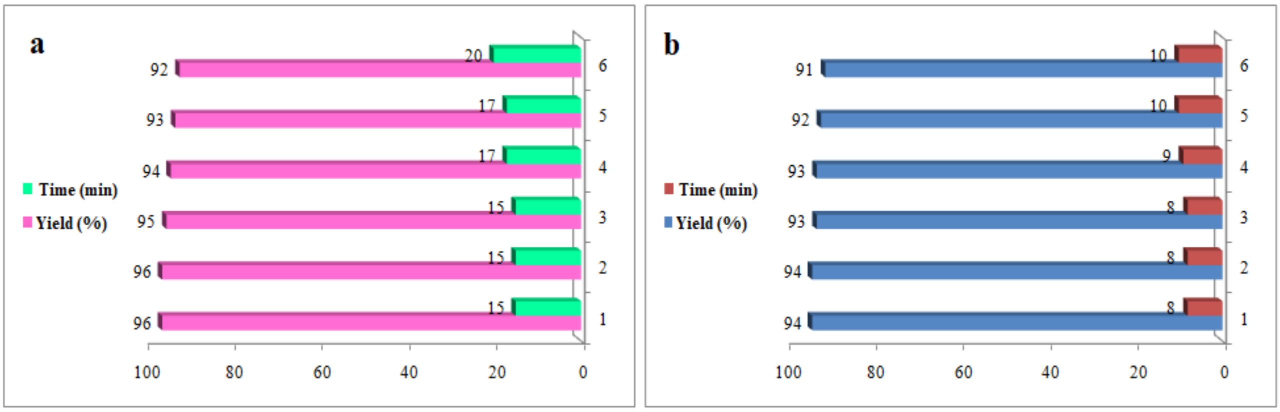


Figure 8. The recycling of SCMNPs@PC/VB$_1$-Zn in the preparation of pyrano[2,3-*c*]pyrazole (a) and 4*H*-benzo-[*b*]-pyran (b) derivatives.

ethanol. After that, SCMNPs@PC/VB$_1$-Zn was dried and reused over 6 runs with some decrease in the catalytic activity (Figure 8).

4. Conclusion

A simple method for the immobilization of Fe_3O_4 MNPs by functional groups was introduced via the reaction of OH groups on Fe_3O_4 level. Innovative SCMNPs@PC/VB$_1$-Zn has been utilized as an effective and reusable catalyst for one-pot synthesis of pyrano[2,3-*c*]pyrazoles and 1,8-dioxooctahydroxanthene derivatives. Serious analyses, such as: FTIR, XRD, VSM, EDX, TGA, and SEM, investigated the structure of the synthesized catalysts. The significant advantages of our protocol include high-to-excellent yields, short reaction time, simple separation and reusability of the catalyst.

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