FULL PAPER



Preparation and characterization of magnetically separable $MgFe_2O_4/Mg(OH)_2$ nanocomposite as an efficient heterogeneous catalyst for regioselective one-pot synthesis of β -chloroacetates from epoxides

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Ronak Eisavi, Department of Chemistry, Payame Noor University, PO Box 19395-3697, Tehran, Iran. Email: roonak.isavi@gmail.com Magnetically separable MgFe₂O₄/Mg(OH)₂ nanoparticles were fabricated and characterized using various techniques. These nanoparticles were used as a new catalyst for regioselective one-pot synthesis of β -chloroacetates from epoxides in the presence of NiCl₂·6H₂O and acetic anhydride. All reactions were carried out in ethanol at room temperature within 22–80 min giving the β -chloroacetates in high to excellent yields. The nanocatalyst was easily separated using an external magnet and reused several times without any significant loss of efficiency or magnetic property.

KEYWORDS

 β -chloroacetates, epoxides, MgFe₂O₄/Mg(OH)₂, nanocomposite

1 | INTRODUCTION

One-pot synthesis as a green and simple method in which several transformations are carried out in the same reaction vessel provides unique advantages such as simple work-up procedures, fewer purification steps and increasing of product yields.

Recently, magnetic nanoparticles due to their easy magnetic separation property^[1–4] have received special attention in biomedicine,^[5–7] biosensors, biochips^[8] and material sciences.^[9–11] However, the use of these materials always shows adsorption problems, because they have a strong tendency of self-aggregation and fewer functional groups.^[12,13] Nanostructures containing cores of magnetic ferrites provide a helpful solution for efficiency improvement of nanoferrites.^[14] These nanoparticles are stable in air and easily separable catalysts^[15] which have attracted much attention in organic reactions,^[16] drug targeting, magnetic cell separation and magnetic sealing in recent years.^[17,18]

 β -Halohydrins are some of the most important intermediates for the synthesis of biologically active compounds^[19,20] such as lipid mediators,^[21–23] marine natural compounds^[24,25] and a specific group of enzymes named halohydrin dehalogenases. Also, β -haloesters as protected halohydrins with easily removable protecting groups are essential building blocks in the synthesis of natural products,^[26,27] carbohydrates, steroids^[28,29] and bioconjugate structures of importance to drug designing,^[30,31] gene therapy,^[32] membranology^[33] and enzymology.^[34,35]

Although ring-opening of epoxides to β -halohydrins has been extensively studied in recent years, the conversion of epoxides to β -chloroesters has been rarely studied. Synthesis of β -chloroesters from epoxides has been reported with TiCl₄/EtOAc/imidazole,^[36] trimethylsilyl halides/pyridine/TFAA,^[37] ^tBuCH₂COCl/BiCl₃^[38] and acyl chlorides in combination with CrO₂Cl₂,^[39] CoCl₂,^[40] Bu₂SnCl₂/Ph₃P,^[41] hexaalkylguanidinium chloride,^[42] LiClO₄,^[43] Zn,^[44] Bi (NO₃)₃·5H₂O^[45] and TMSCl-SnCl₂.^[46] Some of these procedures suffer from disadvantages such as high temperatures, long reaction times, the use of harmful reagents, low efficiency and regioselectivity, formation of by-products, incapability of catalyst

recycling and the risk of metal remaining in the obtained product in pharmaceutical synthesis. Therefore, in order to overcome these problems and in connection with our recent works on nanoferrites,^[47–49] we describe here a green and efficient method for the regioselective one-pot synthesis of β -chloroacetates from epoxides with nickel chloride and acetic anhydride in the presence of a catalytic amount of MgFe₂O₄/Mg(OH)₂ magnetic nanoparticles in ethanol solvent at room temperature.

2 | EXPERIMENTAL

2.1 | Instrumentation and Materials

All materials were purchased from Merck and Aldrich with the best quality and they were used without further purification. The synthesized nanocatalyst was characterized using X-ray diffraction (XRD) with a Bruker D8 Advance diffractometer with graphite-monochromatized Cu K aradiation (λ = 1.54056 Å) at room temperature. Scanning electron microscopy (SEM) images were obtained using an FESEM-TESCAN. The magnetic property of the synthesized nanocatalyst was measured using a vibrating sample magnetometry (VSM) instrument (Meghnatis Daghigh Kavir Co., Kashan Kavir, Iran) at room temperature. Transmission electron microscopy (TEM) images were recorded using an EM10C 100 kV series microscope from Zeiss (Germany). Energy-dispersive X-ray spectrometry (EDS) analysis was conducted with a MIRA3 FE-SEM microscope (TESCAN, Czech Republic) equipped with an EDS detector (Oxford Instruments, UK). Fourier transform infrared (FT-IR) and ¹H NMR/13C NMR spectra were recorded with Thermo Nicolet Nexus 670 FT-IR and 300 MHz Bruker Avance spectrometers, respectively. The products were characterized using their spectra data and comparison with the data reported in the literature. All yields refer to isolated pure products.

2.2 | Preparation of MgFe₂O₄ Nanoparticles

MgFe₂O₄ nanoparticles were prepared by a solid-state procedure. Briefly, in a mortar, Mg(CH₃COO)₂·4H₂O, Fe (NO₃)₃·9H₂O, NaOH and NaCl were mixed in a molar ratio of 1:2:8:2 and ground together for 50 min. The reaction started quickly along with the release of heat. The mixture colour changed from blue to brown after 4 min. Then the mixture was washed with double-distilled water several times. After removing the additional salts by washing, the product was dried at 80 °C for 2 h. The produced powder was calcined at 300, 500, 700 and 900 °C for 2 h to obtain final magnesium nanoferrite.

2.3 | Synthesis of MgFe₂O₄/Mg(OH)₂ Nanocomposite

In a two-neck round-bottom flask, a solution of Mg $(NO_3)_2 \cdot 6H_2O$ (1.28 g, 5 mmol) in distilled water (30 ml) was prepared and then MgFe₂O₄ (0.85 g, 4.3 mmol) was added. The mixture was stirred vigorously for 15 min and followed by dropwise addition of NaOH solution (2 M) in order to alkalize the mixture up to pH ~ 12. The stirring of alkali mixture was continued at room temperature for 24 h. The dark brown MgFe₂O₄/Mg(OH)₂ nanocomposite was separated using a magnet, washed with distilled water and then dried under air atmosphere.

2.4 | One-pot Synthesis of β-Chloroacetates Catalysed by MgFe₂O₄/Mg(OH)₂ Nanocomposite: A General Procedure

In a round-bottomed flask equipped with a magnetic stirrer, a solution of epoxide (1 mmol), NiCl₂·6H₂O (0.47 g, 2 mmol) and Ac₂O (0.51 g, 5 mmol) in EtOH (2 ml) was prepared. MgFe₂O₄/Mg(OH)₂ nanocomposite (0.02 g, 0.07 mmol) was then added to the solution and the resulting mixture was stirred magnetically for 22-80 min at room temperature. The progress of the reaction was monitored by TLC using *n*-hexane–EtOAc (10:4) as an eluent. After completion of the reaction, in order to neutralize the reaction mixture, an aqueous solution of NaHCO₃ (10%, 10 ml) was added and followed by stirring for additional 10 min. The magnetic nanocatalyst was separated using an external magnet and accumulated for the next run. The reaction mixture was extracted with EtOAc $(3 \times 5 \text{ ml})$ and then dried over anhydrous Na₂SO₄. After evaporating the organic solvent and short-column chromatography of the obtained crude product over silica gel, pure β -chloroacetate was obtained as a pale yellow oil (80–98% yield). The collected MgFe₂O₄/Mg(OH)₂ nanoparticles were washed with distilled water and dried for the next cycle. All products are known compounds and were characterized by comparison of their spectra (FT-IR, ¹H NMR and ¹³C NMR) with those of valid samples.^[36,41,43] These data are given in the supporting information.

3 | **RESULTS AND DISCUSSION**

3.1 | Synthesis and Characterization of Magnetic Nanocatalyst

 $MgFe_2O_4/Mg(OH)_2$ nanoparticles were synthesized in a two-step procedure. Nano- $MgFe_2O_4$ was first prepared by a solid-state reaction of inorganic reagents

Mg(CH₃COO)₂·4H₂O, Fe (NO₃)₃·9H₂O, NaCl and NaOH (Scheme 1). In order to decompose and completely remove the excess salts used in the preparation of nanoferrite and produce the MgFe₂O₄ nanoparticles with high crystallinity, phase purity and increased saturation magnetization (M_s), the obtained powder was calcined at various temperatures (300 to 900 °C).^[4,50] Then, MgFe₂O₄ was added to an aqueous solution of Mg(NO₃)₂·6H₂O and followed by dropwise addition of NaOH solution under vigorous stirring and a brown suspension was prepared (Scheme 2). The obtained nanocatalyst was characterized using FT-IR spectroscopy, XRD, SEM, EDS, TEM and VSM.





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3.2 | Catalyst Characterization

3.2.1 | XRD analysis

The XRD patterns of nano-Mg(OH)₂, ferromagnetic MgFe₂O₄ nanoparticles and MgFe₂O₄/Mg(OH)₂ are displayed in Figure 1. The main peaks located at $2\theta =$ 30.47°, 35.82°, 43.48°, 53.77°, 57.32°, 62.88°, 71.36° and 74.35° are assigned to the diffraction of MgFe₂O₄ crystal with spinel structure. This pattern is in agreement with that of pure spinel MgFe₂O₄ in the standard data (JCPDS no. 01-036-0398). The average crystallite size of the MgFe₂O₄ sample was calculated using the Scherrer equation (38 nm). In the XRD pattern of MgFe₂O₄/Mg(OH)₂, all the peaks of $MgFe_2O_4$ and $Mg(OH)_2$ are observed. The sharp peaks at $2\theta = 18.49^{\circ}$, 38.21° , 50.99° , 58.85° , 68.37° and 75.08° correspond to hexagonal phase of magnesium hydroxide crystal, which are very close to those of standard data (JCPDS no. 84-2164). The peaks at 62.53° and 72.50° for magnesium hydroxide overlap with the 62.88° and 71.36 peaks of MgFe₂O₄.



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3.2.2 | VSM analysis

Figure 2 shows magnetization curves of MgFe₂O₄ and MgFe₂O₄/Mg(OH)₂ nanoparticles at room temperature. The narrow cycles and hysteresis loops show the behaviour of soft ferromagnetic particles with low coercivity. Also, the decrease of saturation magnetization (M_s) from 48.82 emu g⁻¹ of MgFe₂O₄ to 23.95 emu g⁻¹ of MgFe₂O₄/Mg(OH)₂ is related to the presence of Mg(OH)₂.



FIGURE 2 Magnetization curves of (a) $MgFe_2O_4$ nanoparticles and (b) $MgFe_2O_4/Mg(OH)_2$ nanoparticles

3.2.3 | SEM analysis

The morphology of the synthesized nanoparticles was investigated using the SEM technique. Figure 3 shows SEM images of $MgFe_2O_4/Mg(OH)_2$ nanocomposite that confirm the presence of irregular nanoparticles with diameters ranging from 23 to 39 nm.

3.2.4 | FT-IR spectroscopy

Figure 4 shows the FT-IR spectra of $MgFe_2O_4$, $Mg(OH)_2$ and $MgFe_2O_4/Mg(OH)_2$ nanoparticles. The sharp and strong absorption band at 3697 cm⁻¹ is related to the O–H stretching vibrations in the crystal structure of $Mg(OH)_2$.^[51] The broad absorption peaks at 3436 and 1647 cm⁻¹ correspond to the stretching and bending modes of hydroxyl group in surface adsorbed water, respectively. A broad band at 1509 cm⁻¹ is attributed to the O– H bending vibrations in Mg(OH)₂. The formation of tetrahedral–octahedral structures of the metal oxide



FIGURE 3 SEM images of MgFe₂O₄/Mg(OH)₂



FIGURE 4 FT-IR (KBr) spectra of (a) MgFe₂O₄, (b) Mg(OH)₂ and (c) MgFe₂O₄/Mg(OH)₂



FIGURE 5 EDS spectrum of MgFe₂O₄/Mg(OH)₂

(Fe– O and Mg– O) is confirmed by the absorption bands at around 400–600 $\rm cm^{-1}.^{[48]}$

3.2.5 | EDS analysis

The chemical composition of the $MgFe_2O_4/Mg(OH)_2$ nanocomposite was determined using EDS analysis. In the EDS spectrum, Fe, O and Mg signals are observed (Figure 5).

3.2.6 | TEM analysis

TEM images of the $MgFe_2O_4/Mg(OH)_2$ nanocomposite are shown in Figure 6. As can be seen from the images,



FIGURE 6 TEM images of MgFe₂O₄/Mg(OH)₂

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two sizes of particles are clearly distinguishable, with differences in their colour and morphology. The larger black spots with hexagonal shape were attributed to the $Mg(OH)_2$ particles.





3.3 | Conversion of Epoxides to β -Chloroacetates with NiCl₂·6H₂O Catalysed by MgFe₂O₄/Mg(OH)₂ Nanocomposite

In order to optimize the reaction conditions, we investigated the simultaneous one-pot chlorination and acetylation of styrene oxide with NiCl₂·6H₂O and Ac₂O under various reaction conditions (Scheme 3). Based on a literature survey, amount of catalyst, amount of reactants, temperature, solvents and reaction time were studied as experimental factors. Table 1 summarizes the results. The best result was obtained using styrene oxide (1 mmol), nickel chloride (2 mmol) and acetic anhydride

 $\label{eq:table_transform} \textbf{TABLE 1} \quad \text{Nano-MgFe}_2O_4/\text{Mg(OH)}_2\text{-} catalysed reaction of styrene oxide with NiCl}_2\cdot 6H_2O \text{ and } Ac_2O \text{ under various conditions}^a$

Entry	Ac ₂ O (mmol)	MgFe ₂ O ₄ / Mg(OH) ₂ (g)	NiCl₂·6H₂O (mmol)	Conditions	Time (min)	Conversion (%) ^b	Yield (%) ^c
1	5	_	2	EtOH/r.t.	60	0	0
2	3	0.01	2	EtOH/65 °C	10	100	75
3	3	0.01	2	EtOH/r.t.	70	100	75
4	3	0.005	2	EtOH/r.t.	80	100	70
5	3	0.02	2	EtOH/r.t.	40	100	79
6	3	0.02	1	EtOH/r.t.	60	100	73
7	3	0.02	3	EtOH/r.t.	35	100	79
8	1	0.02	2	EtOH/r.t.	66	100	75
9	2	0.02	2	EtOH/r.t.	50	100	77
10	4	0.02	2	EtOH/r.t.	35	100	82
11	5	0.02	2	EtOH/r.t.	30	100	87
12	10	0.02	2	EtOH/r.t.	15	100	88
13	5	0.02	1	EtOH/r.t.	40	100	81
14	5	0.02	2	Solvent-free/r.t./grinding	30	80	69
15	5	0.02	2	Solvent-free/r.t.	240	70	60
16	5	0.02	2	Solvent-free/oil bath (70 °C)	360	90	77
17	5	0.02	2	Solvent-free/oil bath (90 °C)	120	100	73
18	5	0.02	2	CH ₃ CN/r.t.	120	100	78
19	5	0.02	2	CHCl ₃ /r.t.	60	70	60
20	5	0.02	2	<i>n</i> -Hexane/r.t.	120	40	Trace
21	5	0.02	2	EtOAc/r.t.	120	60	51
22	5	0.02	2	H ₂ O/r.t.	40	80	65
23 ^d	5	0.02	2	EtOH/r.t.	60	50	20
24 ^e	5	0.02	2	EtOH/r.t.	60	80	50

^aAll reactions were carried out with 1 mmol of styrene oxide.

^bConversion of less than 100% was determined on the basis of the recovered epoxide.

^cIsolated yields.

^dCatalysed by MgFe₂O₄.

eCatalysed by Mg(OH)2.

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TABLE 2 Conversion of epoxides to β -chloroacetates with NiCl₂·6H₂O and Ac₂O catalysed by nano-MgFe₂O₄/Mg(OH)₂^a

Entry	Epoxide (a)	β-Chloroacetate (b)	Time (min)	Yield (%) ^b	Ref.
1		OAc	30	87	[36]
2			75	83	[43]
3			40	85	[36]
4		OAc CI	22	98	[36]
5		OAc Cl	27	91	[36]
6	CI	Cl Cl OAc	80	82	[36]
7			60	97	[41]
8		OAc	29	89	[36]
9		Cl	24	80	[43]
10	0	OAc '''Cl	60	80	[36]
11	0	OAc	60	85	[36]
12	0		40	92	[36]

^aAll reactions were carried out with 1 mmol of epoxide in the presence of NiCl₂·6H₂O (1 mmol), Ac₂O (5 mmol) and nano-MgFe₂O₄/Mg(OH)₂ (0.02 g, 0.077 mmol, 7.7 mol%) in ethanol at room temperature.

^bYields refer to isolated pure products.

(5 mmol) in the presence of nano-MgFe₂O₄/Mg(OH)₂ (0.02 g, 0.077 mmol, 7.7 mol%) as catalyst in ethanol solvent at room temperature (Table 1, entry 11). The presence of a catalytic amount of the nanoparticles was essential to accomplish the reaction. It is worth noting that in the absence of catalyst, the reaction did not proceed even after 60 min (entry 1). The quantity of catalyst was optimized using various amounts of MgFe₂O₄/Mg(OH)₂ (0.005, 0.01 and 0.02 g), and the best result was obtained with 0.02 g of catalyst. An increase in the amount of catalyst from 0.01 to 0.02 g not only accelerated the rate of reaction but also increased the product yield. This showed that the catalyst concentration plays a consequential role in the optimization of the product yield (entries 3–5).

The effect of temperature on the reaction was studied by comparing the obtained results from performing the reaction at room temperature and 65 °C. The results



FIGURE 7 Recycling of nano-MgFe $_2O_4/Mg(OH)_2$ in the conversion of styrene oxide to 2-chloro-2-phenylethylacetate

showed that the higher temperature led to a decrease in the reaction time but did not increase the product yield (entries 2 and 3).



FIGURE 8 (a) Magnetization curve, (b) XRD pattern and (c) FT-IR (KBr) spectrum of recovered $MgFe_2O_4/Mg(OH)_2$

Various amounts of nickel chloride (1, 2 and 3 mmol) were also examined in the conversion of styrene oxide to 2-chloro-2-phenylethylacetate, and the quantity of 2 mmol was chosen as the optimum option (entries 5–7).

In this reaction, acetic anhydride was used as an acetylating agent. Increasing the amount of acetic anhydride from 1 to 5 mmol reduced the reaction time and enhanced the product yield (entries 8–11). The desired reaction was also accomplished using 1 mmol of Ac_2O , but at a longer reaction time and with a lower product yield (entry 8). The molecules of ethanol solvent are competing with the resulting chlorohydrin from the ring opening of epoxide for reaction with acetic anhydride to produce the corresponding ester and subsequently reducing the amount of acyl groups in the reaction mixture. So, in order to increase the product yield and reduce the reaction time, we had to use an additional amount of acetic anhydride (5 mmol). Greater amounts of Ac_2O did not improve the yield of product (entry 12).

In order to highlight the effect of solvent on the procedure efficiency, the model reaction was also investigated under solvent-free conditions. In the absence of solvent, the reaction was not complete even under grinding in the mortar (entries 14 and 15).

Furthermore, the reaction was carried out under oil bath conditions (70 and 90 °C). The obtained results were not satisfactory under solvent-free conditions at various high temperatures (entries 16 and 17).

The effect of solvent was investigated by performing the reaction in various solvents such as water, *n*-hexane, acetonitrile, chloroform and ethanol (entries 18-22). selected as the best solvent for Ethanol was β-chloroacetylation of epoxides under optimized conditions. The results showed that in comparison with ethanol, the reaction times were longer and the yields of product were considerably lower in all other solvents. Ethanol as a polar and protic organic solvent is more effective and facilitates the ring opening of epoxides by nucleophilic reagents. The non-polar solvents such as *n*-hexane were not able to facilitate the reaction. The chloroacetylation of styrene oxide was executable in acetonitrile as a polar solvent but the reaction time was long (120 min). Ethyl acetate and chloroform were not identified as appropriate solvents due to low product yields.

We also investigated the β -chloroacetylation of styrene oxide using bare MgFe₂O₄ and Mg(OH)₂ nanoparticles (entries 23 and 24). The yields of these reactions were far less than those of reactions using the MgFe₂O₄/Mg(OH)₂ composite catalyst. These results indicate that the interactions between the Mg(OH)₂ and MgFe₂O₄ nanoparticles may increase the catalytic activity of MgFe₂O₄/Mg(OH)₂.

To establish the generality and diversity of the presented method in the preparation of β -chloroacetates



SCHEME 4 Proposed mechanism for conversion of epoxides to β -chloroacetates with NiCl₂·6H₂O and Ac₂O catalysed by nano-MgFe₂O₄/Mg(OH)₂

from epoxides, the conversion of various epoxides bearing aryl, alkyl and allyl substituted groups was further studied under optimized conditions. Table 2 presents the results relating to the capability of this synthetic method. Regioselective ring opening and chloroacetylation of various epoxides containing electron-releasing or electron-withdrawing groups were carried out efficiently in ethanol at room temperature, and the corresponding β -chloroacetates were produced in high to excellent yields.

3.4 | Recycling of Nano-MgFe₂O₄/Mg(OH)₂

The recycling of the green nanocatalyst was investigated under the optimized reaction conditions (Table 2, entry 1). The nanoparticles were easily accumulated by applying an external magnetic field, washed with distilled water and, after drying, reused seven times without any significant loss of activity (Figure 7). The structure of the recovered catalyst was confirmed using XRD, FT-IR and VSM analyses after three runs (Figure 8).

3.5 | Proposed Mechanism for Conversion of Epoxides to β -Chloroacetates with NiCl₂·6H₂O and Ac₂O Catalysed by MgFe₂O₄/Mg(OH)₂ Nanocomposite

Although the exact mechanism of this reaction is not still clear, a possible mechanism is presented in Scheme 4. The coating of $MgFe_2O_4$ using $Mg(OH)_2$ was carried out in order to reduce the self-aggregation tendency of $MgFe_2O_4$ nanoparticles and also to increase the amount

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of hydroxyl functional groups on the surface of the nanocatalyst. The hydroxyl groups are capable of activating the epoxide ring through formation of hydrogen bonds with oxygen and facilitating the ring opening of oxirane. On the other hand, the coordination of oxygen in epoxide with magnesium also catalyses the opening of oxirane ring especially in a protic solvent medium. The regioselective cleavage of epoxides bearing alkyl and allyl groups by chloride ion proceeded from less hindered carbon of the epoxide ring via $S_N 2$ type of mechanism (\beta-cleavage); however, aryl-substituted epoxides prefer to be opened from the more hindered position via $S_N 1$ type of mechanism (α -cleavage). In the case of aryl-substituted epoxides, the positive charge on the aryl-substituted position is stabilized by mesomeric effects of aryl ring, while in the transformation of alkylated epoxides to the corresponding β -chloroacetates, the steric factor plays the key role. In this reaction, nickel chloride is just used as the source of chloride nucleophile for the chlorination of ring-opened epoxide and does not have any catalytic effect because it is not able to promote the reaction in the absence of the nanocatalyst (Table 1, entry 1).

3.6 | Comparison of Catalytic Activities of MgFe₂O₄/Mg(OH)₂ and Other Catalysts

The advantages of the presented synthetic method were manifested by comparison of β -chloroacylation of styrene oxide with methods reported in the literature (Table 3). From viewpoints of perfect regioselectivity, short reaction times, mild and eco-friendly conditions, recoverability,

TABLE 3 Comparison of catalytic activity of $MgFe_2O_4/Mg(OH)_2$ with that of various other catalysts reported for β -chloroacylation of styrene oxide^a

		$Ph \qquad \qquad$	$\xrightarrow{\text{oroacylation}} Ph \underbrace{\frown}_{Cl} O_2 CR$	+ Ph $\overbrace{O_2CF}$	°CI R		
Entry	Catalyst system	Acylation reagent	(I) Conditions	(II) Product	Time (h)	Yield (%)	Ref.
1	MgFe ₂ O ₄ /Mg(OH) ₂	Ac ₂ O	EtOH/r.t.	Ι	0.5	87	This work
2	TiCl ₄ /imidazole	EtOAc	r.t.	I + II	3.5	95 (4:96)	[36]
3	Co (II)Cl ₂	PhCOCl	CH ₃ CN/r.t.	I + II	1	80 (96:4)	[40]
4	ⁿ Bu ₂ SnCl ₂ /Ph ₃ P	PhCOCl	Benzene/60 °C	Ι	24	63	[41]
5	PBGSiCl	MeCOCl	Solvent-free/50 °C	II	3	80	[42]
6	PBGSiCl	PhCOCl	Solvent-free/100 °C	II	5	70	[42]
7	Zn	MeCOCl	Petroleum ether/N ₂ /28 °C	Ι	2	84	[44]
8	LiClO ₄	MeCOCl	EtOAc/r.t.	Ι	3	68	[43]
9	(<i>n</i> -Hexyl) ₄ NCl	Ac ₂ O	Solvent-free/reflux	I + II	8	79 (19:81)	[52]

^aAll reactions were carried out with 1 mmol of styrene oxide.

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and easy preparation and separation of magnetic nanocatalyst, our procedure is preferable.

4 | CONCLUSIONS

The preparation of eco-friendly $MgFe_2O_4/Mg(OH)_2$ nanocomposite has been developed as a novel and efficient heterogeneous magnetic catalyst in the one-pot conversion of structurally diverse epoxides to β -chloroacetates with nickel chloride and acetic anhydride in ethanol at room temperature. The mentioned protocol offers several benefits such as reusability and easy separation of the catalyst from the reaction medium, perfect regioselectivity, low temperature, short reaction times, high product yields and simple work-up procedure.

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