



## Use of Magnesium Ferrite as Catalyst in Knoevenagel Condensation Reaction

Neha Godha<sup>1</sup>, Shubang Vyas<sup>1</sup>, Rakshit Ameta<sup>2</sup>  
and Suresh C. Ameta<sup>1\*</sup>

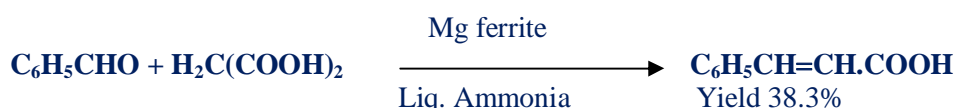
1. Department of Chemistry, PAHER University, Udaipur- 313003 (Raj), **INDIA**  
2. Department of chemistry, J.R.N. Rajasthan Vidhyapeeth (Deemed-to-be-University),  
Udaipur-313002 (Raj.) **INDIA**  
Email: [jainchiki8@gmail.com](mailto:jainchiki8@gmail.com)

Accepted on 28<sup>th</sup> August, 2022

### ABSTRACT

Magnesium ferrite was used to catalyse the Knoevenagel condensation of benzaldehyde and malonic acid in the presence of liquid ammonia. Magnesium ferrite was prepared by hydrothermal process. It was characterized by Field Emission Scanning Electron Microscopy (FESEM), X-Ray Diffraction Spectroscopy (XRD), and Energy Dispersive X-Ray Spectroscopy (EDX). The crystalline size of magnesium ferrite was found to have 82.47 nm and these are nano-flowers in shape. It was found that the yield of the product (cinnamic acid) in the presence of Mg ferrite was 38.3%, which is almost 2.4 times the yield obtained in the absence of catalyst.

### Graphical Abstract:



**Keywords:** Knoevenagel condensation, Magnesium ferrite, Catalyst, Synthesis, Hydrothermal method.

### INTRODUCTION

Khillare *et al.*, [1] used a green  $\text{Ni}_x\text{Mg}_{1-x}\text{Fe}_2\text{O}_4$  in Knoevenagel condensation for the synthesis of 5-arylidene malononitrile derivatives. They used different aromatic aldehydes and malononitrile in water in a stirring condition. It was reported that as-prepared catalyst offered some improvements in this reaction such as high yields and shorter reaction times. It was also revealed that as-prepared catalyst can be reused for three consecutive cycles without any significant loss of in its activity. Pippal and Singh [2] Used calcium ferrite nanoparticles as an efficient catalyst for carrying out Knoevenagel condensation of active methylene substrate with various carbonyl compounds in lesser reaction time. They obtained condensed products with excellent yields. It was revealed that this greener protocol is quite easy and prepared products do not require any further purification. It was found that the catalyst can easily be removed from the reaction mixture and reused at least for four times without any significant change in its activity.

Li *et al.*, [3] prepared NiFe<sub>2</sub>O<sub>4</sub> nanoparticle catalyst via hydrothermal method. The performance of this as-prepared catalyst was investigated for Knoevenagel condensation with different active methylene compounds and aldehydes under mild reaction conditions. It was reported that as-prepared catalyst exhibited higher catalytic activity with excellent yields, conversion (99.5%) and selectivity (99%). It was also reported this hybrid can be easily separated with the help of an external magnetic field and it could be recycled four times without any significant loss in its activity. Gao *et al.*, [4] synthesized super paramagnetic mesoporous Mg–Fe bimetal oxides as solid base catalysts with different Mg–Fe atomic ratios. It was reported that as-prepared catalyst M2F-400 with Mg/Fe atomic ratio = 2 exhibited very high activity for Knoevenagel reactions even at ambient conditions. It was also found that catalyst could be easily separated magnetically, then recycled, and reused again for at least five cycles.

Some multifunctional magnetic metal–organic framework nanomaterials were prepared by Yao *et al.*, [5] which consisted of different mass ratios of the metal–organic framework MIL-53(Fe) and magnetic SiO<sub>2</sub>@ NiFe<sub>2</sub>O<sub>4</sub> nanoparticles. They used these as heterogeneous catalysts for catalyzing Knoevenagel condensation. It was also reported that as-fabricated nanomaterials MIL-53(Fe)@ SiO<sub>2</sub>@ NiFe<sub>2</sub>O<sub>4</sub>(1.0) exhibited good catalytic activity even at room temperature. This was attributed to a synergistic interaction between active site of the magnetic SiO<sub>2</sub>@NiFe<sub>2</sub>O<sub>4</sub> nanoparticles and Lewis acid iron sites of MIL-53. This heterogeneous catalyst was easily recovered and could be reused for five times without any significant decrease in its catalytic activity, making it eco-friendly and economically viable.

Karimkhah *et al.*, [6] synthesized magnetic silica-supported Ag<sub>2</sub>CO<sub>3</sub> (MS/Ag<sub>2</sub>CO<sub>3</sub>) with core-shell structure. The MS/Ag<sub>2</sub>CO<sub>3</sub> nanocomposite was prepared through chemical modification of magnetic MS nanoparticles with AgNO<sub>3</sub> under alkaline conditions. It was reported that as-prepared MS/Ag<sub>2</sub>CO<sub>3</sub> nanocomposite can be used as an effective catalyst for Knoevenagel condensation at 60°C under solvent-free conditions in an ultrasonic bath. The MgFe<sub>2</sub>O<sub>4</sub> nanoparticles were synthesized by Eshtehardian *et al.*, [7] via a green approach. Then they used these nanoparticles to catalyze the synthesis of tetrahydrobenzo [b] pyran and 2-amino-7-hydroxy-4H-chromene derivatives by chemical reaction between resorcinol (ordimedone), malononitrile and different aldehydes using ethanol as solvent on ultrasound exposure. It was also indicated that as-synthesized MgFe<sub>2</sub>O<sub>4</sub> nanoparticles can be easily removed from reaction mixture using an external magnet and it can be reused for four times without any significant decrease in its catalytic activity.

Miao *et al.*, [8] synthesized a core-shell magnetic composite Fe<sub>3</sub>O<sub>4</sub>@P4VP@ZIF-8 (micro-spheres). They used polymerization on the surface of pre-made Fe<sub>3</sub>O<sub>4</sub> microspheres for the synthesis of Fe<sub>3</sub>O<sub>4</sub>@P4VP. Then zinc-derived zeolite imidazolate framework (ZIF) shell was introduced with it via a layer-by-layer strategy. Then as-obtained Fe<sub>3</sub>O<sub>4</sub>@P4VP@ZIF-8 core-shell structure was used as a catalyst for Knoevenagel condensation using a wide range of aldehydes. It was revealed that inner P4VP layer also served as a basic additive in such a process, when much less homogenous basic additive was employed. A very high catalytic reaction efficiency could be achieved, when the P4VP layer was utilized with a Lewis acidity bearing ZIF-8 layer. The as-prepared catalyst can be used for five cycles without any loss in its catalytic activity.

Solid base catalyst was prepared by Jain *et al.*, [9] via loading of CaO on thermally activated fly ash (FAC). It was reported that catalytic activity of FAC for Knoevenagel condensation under optimized condition was 87% using ethyl cyanoacetate and benzaldehyde to afford ethyl (E)- $\alpha$ -cyanocinnamate. It was also claimed that catalyst was completely recyclable upto three reaction cycles without any significant loss in its activity. Xue *et al.*, [10] developed an efficient method for grafting of ethylene diamine on graphine oxide (GO). Then they studied catalytic performance of as-prepared amine grafted GO samples in Knoevenagel condensation between benzaldehyde and malononitrile under mild conditions. It was reported that the grafting of amine on the surface of GO was through nucleophilic ring opening reaction between the amine and epoxide of GO.

Reddy *et al.*, [11] carried out Knoevenagel condensation with a wide range of aldehydes, aliphatic, aromatic and heterocyclic with malononitrile using sulfate-ion promoted zirconia (solid acid catalyst). It was reported that this catalyst promotes the reaction even at moderate temperature under solvent-free conditions affording excellent yield of products. It was also revealed that the incorporated sulphate-ions exert a significant influence on the surface as well as bulk properties of  $ZrO_2$ . This stabilizes tetragonal phase of metastable zirconia at ambient conditions increasing the total number and strength of acid sites. Viswanadham *et al.*, [12] synthesized Cu exchanged heteropolyacid catalysts via ion exchange method. It was suggested that acidity decreases on incorporation Cu ion in the heteropolyacid catalyst for the Knoevenagel condensation reaction. It was also revealed that Cu exhibited better performance as compared to phosphomolybdic acid catalyst.

Jadhav *et al.*, [13] prepared some pyrazole derivatives via Knoevenagel condensation in acidic medium. They used three methods: Conventional, grinding and microwave assisted reaction. It was reported that most of the as-prepared compounds exhibited less to moderate antibacterial as well as antifungal activity. Prakash *et al.*, [14] carried out one pot condensation reaction of naphthafuran-2-carbaldehyde, ethyl acetoacetate and thiourea or urea. The derivatives obtained were characterized by spectroscopic techniques. It was found that synthesized compounds exhibited moderate to good antimicrobial as well as anti-inflammatory activities as compared to standard drugs.

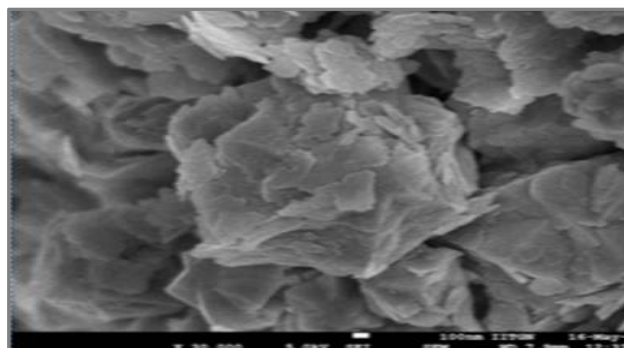
## MATERIALS AND METHODS

**Materials:** Magnesium nitrate hexa hydrates (SRL) was utilized with a purity of 99% and NaOH (98%) for the production of nanoparticles. Benzaldehyde, malonic acid and liquid ammonia were procured from Rankem, and Fischer scientific respectively.

**Synthesis of Magnesium ferrite nanoparticles:** A hydrothermal approach similar to that employed by Naidu and Madhuri [15] was utilized to synthesize magnesium ferrite using a Teflon-coated autoclave. Magnesium nitrate hexahydrate and ferric nitrate nanohydrate were utilized as magnesium and iron precursors, respectively. Magnesium and iron nitrates were dissolved in distilled water in a nitrate: water ratio 1:3. The resulting solution was stirred, and then NaOH was added drop by drop in 1:4 ratios until the pH reached 11. After rapid stirring for 2 h, the liquid was moved to a Teflon-coated stainless steel autoclave and sealed. The autoclave was then heated to 150°C for about 48 h. The autoclave was allowed to cool at ambient temperature after heating is over.

## RESULTS AND DISCUSSION

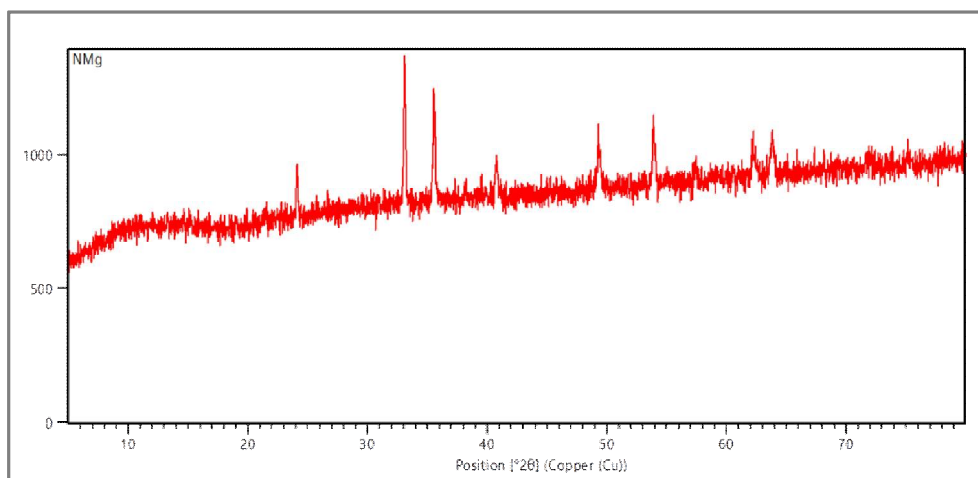
**Field Emission Scanning Electron Microscopy (FESEM):** The JSM-6100 (JEOL) with a digital image processor was used to record FESEM to know the morphology of as-prepared magnesium ferrite particles. The FESEM images are shown in figure 1.



**Figure 1.** FESEM Image of magnesium ferrite.

It was observed that these magnesium ferrite particles are having a nanoflower like structure.

**X-Ray Diffraction (XRD):** A X'Pert Pro XRD equipped with an X'Cebrator solid state detector was used to record X-ray diffraction pattern. The XRD of magnesium ferrite revealed the crystalline character of this sample. The result tare reported in figure 2.



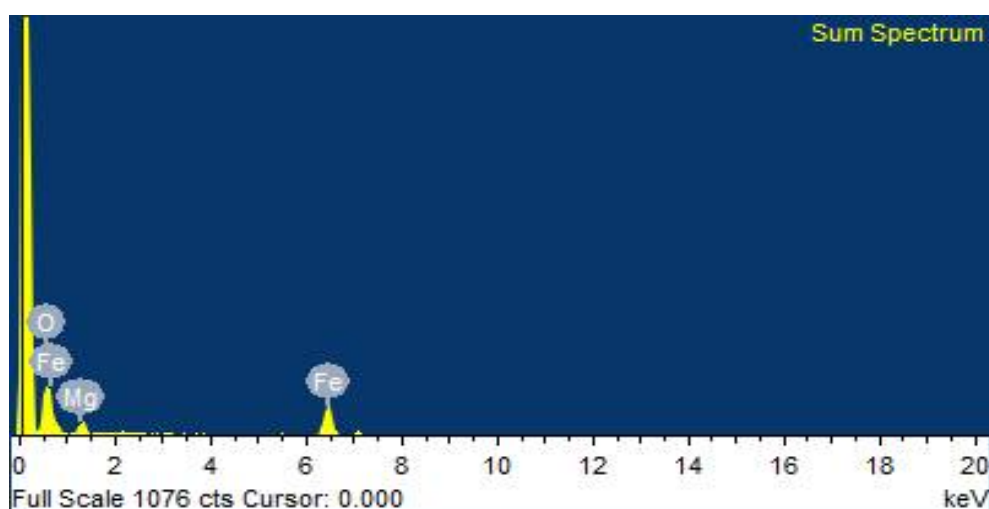
**Figure 2.** XRD pattern of magnesium ferrite.

The Debye-Scherrer equation was used to compute the average particle size of particles, which was found to be in the nano-range (82.47 nm).

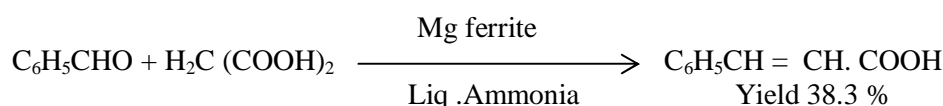
**X-Ray Photoelectron Spectroscopy (XPS):** A Thermo K-alpha+X-ray spectrometer was used for X-ray photoelectron spectral analysis. A KRUSS drop shape analyzer was used to measure the contact angle. XPS of magnesium ferrite indicated that Mg, Fe, and O are present in 1s, 2p, and 1s states, respectively in this sample.

**Energy-Dispersive X-Ray Spectroscopy (EDX):** Energy-dispersive X-ray spectrum was recorded with JSM 7600 F (Jeol). The results are reported in figure 3.

The EDX of magnesium ferrite revealed peaks for Mg, Fe and O only, which indicated that the sample of magnesium ferrite is pure and free of any impurity.



**Figure 3.** EDX spectrum of magnesium ferrite.

**Knoevenagel Condensation catalyzed by magnesium ferrite-**

Malonic acid (15 g) was dissolved with benzaldehyde (14.3 mL) and 60 mL of 8% alcoholic ammonia solution in a flask and 0.08 g of magnesium ferrite was added to it. The flask was heated on a water bath to produce a clear solution. Then, reaction mixture was transferred to a beaker, where it was heated to about 150°C until no more carbon dioxide was evolved. The residue was dissolved in water and then dilute hydrochloric acid was added to the solution to make it acidic. The products was filtered and recrystallized in hot water. The product of Knoevenagel condensation was characterized on the basis of FT-IR and NMR spectra.

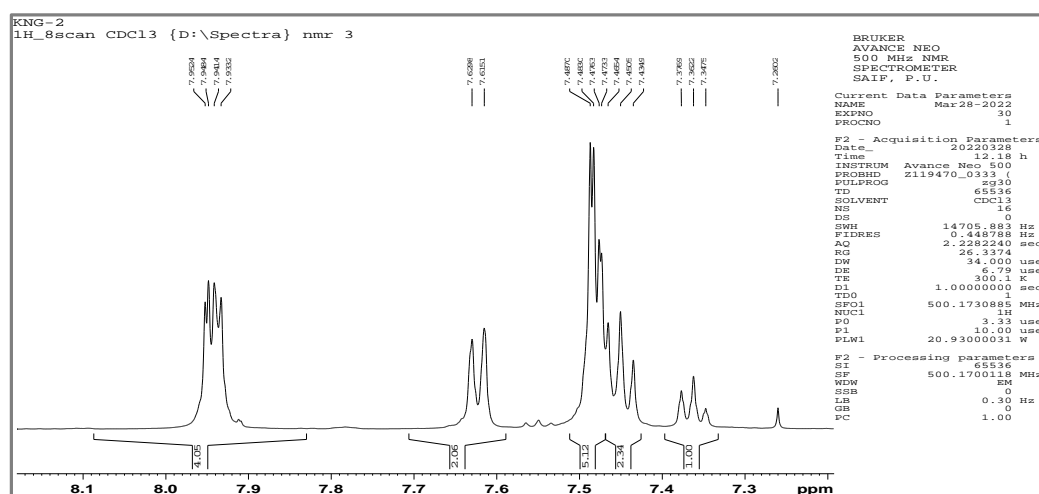
**Fourier transform infrared (FTIR) spectrum:** The FTIR Spectrometer RX-I was used to record IR spectrum of the product. The spectrum is given in table 1.

**Table 1.** FTIR data of product

Frequency (cm <sup>-1</sup> )	Assignment
3550 – 3310	-OH stretching vibration
3060 - 3010	C-H stretching vibrations (Aromatic)
1670 and 1500	C = C stretching vibration
1450 and 1268	C – C stretching vibration
1312	< - O stretching vibration
1185	O – H in-plane bending vibration
1162 - 1028	C- H in-plane bending vibration (Aromatic)
988	C = O in-plane bending vibration
847	C - O in-plane bending vibration
720	O-H out-of-plane vibration

These bands are quite close to the results reported earlier [16].

**Nuclear magnetic resonance spectrum (NMR):** FT-NMR spectrometer model Advance-II (Bruker) (400 MHz) was used to record NMR spectrum of the product. The spectrum is given in figure 5.



**Figure 5.** NMR spectrum of product.

NMR spectrum gives signals at 6.06 δ, which is quite close to 5.96 δ as reported by Hanai *et al.*, [17]. Signals at 7.26 δ may be due to olefinic proton. There are some multiplets between 7.34- 7.63δ due to a presence of aromatic protons. There is a very weak signal at 10.05 δ, which can be attributed

the presence of carboxylic proton. There are also some signals due to the presence of trans- form of cinnamic acid. The product was found to be cinnamic acid based on FT-IR and NMR data. It was observed that cis- form of cinnamic acid was the major product while its trans- form was a minor product.

**Effect of Various Parameters:** Many factors were varied to achieve optimum conditions such as amount of benzaldehyde catalyst, malonic acid and liquid ammonia. The effect of benzaldehyde was observed in the range of 10- 18 mL. The pH was maintained at 10-10.5 and the results are shown in table 2.

**Table 2.** Effect of benzaldehyde

Benzaldehyde (mL)	Yield (%)
10.0	5.2
11.8	15.1
14.3	38.3
16.6	20.1
18.0	4.6

Malonic acid = 15 g, Liquid ammonia = 60.0 mL,  
Magnesium ferrite = 0.08 g

It was observed that on increasing the quantity of benzaldehyde keeping all other parameters constant, the yield increases up to 38.3% for 14.3 mL of benzaldehyde, but it was reduced drastically on increasing the amount of benzaldehyde.

Effect of amount of malonic acid was observed by varying its amount from between 10-20 g and results are reported in table 3.

**Table 3.** Effect of malonic acid

Malonic acid (g)	Yield (%)
10.0	12.5
12.5	20.8
15.0	38.3
17.5	18.2
20.0	9.6

Benzaldehyde = 14.3 mL, Liq. ammonia = 60.0 mL,  
Magnesium ferrite = 0.08 g

It was found that when the amount of malonic acid was increased, the yield of product increases up to 15 g of malonic acid and then it declined on further increasing its amount.

The effect of liquid ammonia was observed by keeping it in the range of 50-70 mL and the result are reported in table 4

**Table 4.** Effect of liquid ammonia

Liq. Ammonia (mL)	Yield (%)
50.6	7.2
55.6	17.1
60.0	38.3
65.0	24.4
70.0	19.6

Malonic acid = 15 g, Benzaldehyde = 14.3 mL,  
Magnesium ferrite = 0.08 g

It was observed that an increase in the amount of liquid ammonia enhanced the yield up to 60 mL of liquid ammonia but exhibited a decreasing behaviour above 60 mL. It may be due to increase or decrease in pH above and below 10–10.5 (the desired pH for the reaction).

The effect of magnesium ferrite (catalyst) was observed in the range of 0.05–0.15 g and the results are reported in [table 5](#).

**Table 5.** Effect of magnesium ferrite

Magnesium ferrite (g)	Yield (%)
0.05	35.4
0.06	36.0
0.07	37.1
0.08	38.3
0.10	33.2
0.12	31.5
0.15	29.5

Benzaldehyde = 14.3 mL, Malonic acid = 15 g,  
Liq ammonia = 60.0 mL

It was found that increase in the quantity of magnesium ferrite promoted the synthesis of cinnamic acid up to 0.08 g, because more active sites were available, but the yield of the product started decreasing above 0.08 g. It might be attributed to the fact that all active sites are occupied, resulting in a fall in yield.

The highest yield of cinnamic acid (product) could be obtained under the following optimum conditions: Benzaldehyde = 14.3 mL, Malonic acid = 15 g, Liq. Ammonia = 60 mL, Magnesium ferrite = 0.08g.

The catalyst was washed and dried after the reaction is over. It was used again five times for this condensation without any significant decrease in its activity. Thus, catalyst is recyclable. The results are reported in [table 6](#).

**Table 6.** Reusability of magnesium ferrite

Used	Yield (%)
First	100.0
Second	98.4
Third	97.2
Fourth	96.3
Fifth	95.2

## APPLICATION

The magnesium ferrite has been successfully used as nanocatalyst in driving Knoevenagel condensation. It can be applied as catalyst to other organic reactions of synthetic importance.

## CONCLUSION

The MgFe<sub>2</sub>O<sub>4</sub> nanoparticles with an average size of 82.47 nm were prepared via a hydrothermal procedure using Teflon lined autoclave. These nanoparticles were utilized as a catalyst in the presence of liq. Ammonia for the Knoevenagel condensation of malonic acid and benzaldehyde at 150°C. This approach has several significant advantages such as good yield in lesser time. This technique is simple, and the catalyst may be reused more than five times without any major lose in its catalytic activity. Thus, magnesium ferrite can be used as benign catalysts for Knoevenagel reactions.

## ACKNOWLEDGEMENT

I am grateful to the Indian Institute of Technology, Gandhinagar for FESEM and EDX, as well as the National Chemical Laboratory, Pune for XPS. I would also like to thank SAIF at Panjab University for recording XRD, FTIR, and NMR spectrum data and Department of Chemistry, PAHER University, Udaipur, Rajasthan, India for providing necessary laboratory facilities.

**Disclaimer:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## REFERENCES

- [1]. S. L. Khillare, A. O. Dhokte, M. K. Lande, B. R. Arbad, Synthesis and characterization of magnetically separable  $\text{Ni}_x\text{Mg}_{1-x}\text{Fe}_2\text{O}_4$  (Ni–Mg ferrite) catalyst for Knoevenagel reaction in water, *Int. J. Chem.*, **2014**, 5, 96-101.
- [2]. P. Pippal, P. P. Singh, Calcium ferrite, an efficient catalyst for Knoevenagel condensation A green approach, *Orient. J. Chem.*, **2017**, 33(4), 1736-1743.
- [3]. Q. Li, X. Wang, Y. Yu, Y. Chen, L. Dai, Tailoring a magnetically separable  $\text{NiFe}_2\text{O}_4$  nanoparticle catalyst for Knoevenagel condensation, *Tetrahedron*, **2016**, 72(50), 8358-8363.
- [4]. Z. Gao, J. Zhou, F. Cui, Y. Zhu, Z. Hua, J. Shi, Super paramagnetic mesoporous Mg–Fe bi-metal oxides as efficient magnetic solid-base catalysts for Knoevenagel condensations, *Dalton Trans.*, **2010**, 39(46), 11132-11135.
- [5]. N. Yao, J. Tan, Y. Liu, Y. L. Hu, An efficient and reusable multifunctional composite magnetic nanocatalyst for Knoevenagel condensation, *Synlett*, **2019**, 30(06), 699-702.
- [6]. F. Karimkhah, D. Elhamifar, M. Shaker,  $\text{Ag}_2\text{CO}_3$  containing magnetic nanocomposite as a powerful and recoverable catalyst for Knoevenagel condensation, *Sci. Rep.*, **2021**, 11(1), doi.10.1038/s41598-021-98287-z
- [7]. B. Eshtehardian, M. Rouhani, Z. Mirjafary, Green protocol for synthesis of  $\text{MgFe}_2\text{O}_4$  nanoparticles and study of their activity as an efficient catalyst for the synthesis of chromene and pyran derivatives under ultrasound irradiation, *J. Iran. Chem. Soc.*, **2020**, 17(2), 469-481.
- [8]. Z. Miao, F. Yang, Y. Luan, X. Shu, D. Ramella, Synthesis of  $\text{Fe}_3\text{O}_4@ \text{P4VP}@ \text{ZIF-8}$  core-shell microspheres and their application in a Knoevenagel condensation reaction, *J. Solid State Chem.*, **2017**, 256, 27-32.
- [9]. D. Jain, C. Khatri, A. Rani, Fly ash supported calcium oxide as recyclable solid base catalyst for Knoevenagel condensation reaction, *Fuel Proc. Technol.*, **2010**, 91(9), 1015-1021.
- [10]. B. Xue, J. Zhu, N. Liu, Y. Li, Facile functionalization of graphene oxide with ethylenediamine as a solid base catalyst for Knoevenagel condensation reaction, *Catal. Commun.*, **2015**, 64, 105-109.
- [11]. B. M. Reddy, M. K. Patil, K. N. Rao, G. K. Reddy, An easy-to-use heterogeneous promoted zirconia catalyst for Knoevenagel condensation in liquid phase under solvent-free conditions, *J. Mol. Catal.*, **2006**, 258(1-2), 302-307.
- [12]. B. Viswanadham, J. Pedada, H. B. Friedrich, S. Singh, The role of copper exchanged phosphomolybdic acid catalyst for Knoevenagel condensation, *Catal. Lett.*, **2016**, 146(8), 1470-1477.
- [13]. A. D. Jadhav, P. U. Barhate, A. N. Durrani, Synthesis of some pyrazole derivatives via Knoevenagel condensation proven effective as antibacterial and antifungal activity, *J. Applicable Chem.*, **2020**, 9(3), 459-465.
- [14]. M. S. Prakash, P. A. Suchetan, G. Krishnaswamy, Synthesis, characterization and biological evaluation of dihydropyrimidinone and dihydropyrimidinethionones derivatives of naphthofuran via one pot reaction, *J. Applicable Chem.*, **2018**, 7(5), 1158-1165.
- [15]. K. C. Babu Naidu, W. Madhuri, Hydrothermal synthesis of  $\text{NiFe}_2\text{O}_4$  nano-particles: Structural, morphological, optical, electrical and magnetic properties, *Bull. Mater. Sci.*, **2017**, 40, 417-425.



- [16]. K. S. Vinod, S. Periandy, M. Govindarajan, Spectroscopic analysis of cinnamic acid using quantum chemical calculations, *Spectrochim. Acta Part A: Mole. and Biomole. Spectro.*, **2015**, 136, 808-817.
- [17]. K. Hanai, A. Kuwae, T. Takai, H. Senda, K. K. Kunimoto, A comparative vibrational and NMR study of cis-cinnamic acid polymorphs and trans-cinnamic acid, *Spectrochim. Acta Part A: Mol. Biomol. Spectro*, **2001**, 57(3), 513-519.