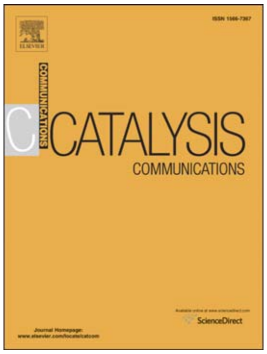


Microwave-assisted Fe_3O_4 nanoparticles catalyzed synthesis of chromeno[1,6]naphthyridines in aqueous media

Anshu Dandia, Vijay Parewa, Shyam L. Gupta, Amit Sharma, Kuldeep S. Rathore, Astha Jain

PII: S1566-7367(14)00517-2
DOI: doi: 10.1016/j.catcom.2014.12.015
Reference: CATCOM 4169

To appear in: *Catalysis Communications*

Received date: 14 November 2014
Revised date: 15 December 2014
Accepted date: 18 December 2014

Please cite this article as: Anshu Dandia, Vijay Parewa, Shyam L. Gupta, Amit Sharma, Kuldeep S. Rathore, Astha Jain, Microwave-assisted Fe_3O_4 nanoparticles catalyzed synthesis of chromeno[1,6]naphthyridines in aqueous media, *Catalysis Communications* (2014), doi: 10.1016/j.catcom.2014.12.015

Microwave-assisted Fe_3O_4 nanoparticles catalyzed synthesis of chromeno[1,6]naphthyridines in aqueous media

Anshu Dandia,*[a] Vijay Parewa,[a] Shyam L. Gupta,[a] Amit Sharma,[a] Kuldeep S. Rathore[b], Amit Sharma,[b] Astha Jain[b]
[a]Centre of Advanced Studies, Department of Chemistry,
University of Rajasthan, Jaipur, India.
[b]Semiconductor and Polymer Science Laboratory, Department of Physics, University of Rajasthan, Jaipur, India.
E-mail[a]: dranshudandia@yahoo.co.in E-mail[b]: kuldeep_ssr@yahoo.com

ABSTRACT

Fe_3O_4 nanocatalyst was prepared by co-precipitation method and characterized by XRD, FT-IR, TEM, VSM and BET analyses. The particles have an average size of 7 nm and possess highly open mesopores, moderate surface area, and uniform morphology with superparamagnetic behavior. Activity of catalyst was probed through the synthesis of chromeno[1,6]naphthyridines in water under microwave irradiation (MW) and it was about 7-fold higher as compared to conventional method. Nanocatalyst plays a dual role of catalyst as well as susceptor, and enhances the overall capacity to absorb MW. Fe_3O_4 NPs easily recovered by simple magnetic separation and recycled at least 5 times.

Keywords: Fe_3O_4 nanocatalyst, Microwave radiation, Water, Heterogeneous catalyst, Chromeno[1,6]naphthyridines.

1. Introduction

The applications of iron-based materials as catalysts in organic synthesis has attracted a lot of attention during the last decade [1]. Iron is most widely recommended due to its low cost, abundance, environmentally benign and non-toxic nature [2-3] for industrial scale synthesis of fine chemicals [4]. Iron oxides have been frequently used as catalysts and supports in bulk industrial processes, usually at high temperature and pressure [5]. However, Fe has a great deal to offer at the nanoscale, including potent magnetic and catalytic properties [6]. The strategy of magnetic separation of magnetic nanoparticles is typically more effective than filtration or centrifugation as it prevents loss of the catalyst. Furthermore, Fe_3O_4 nanoparticles have showed potential applications in many other fields [7-8].

Chromenes and 1,6-naphthyridines are associated with a wide spectrum of biological activities [9-11]. Consequently, integration of chromene moieties with naphthyridines in a single molecular-framework may increase their biological and fluorescence properties [12]. While a considerable number of naphthyridines fused with five-membered rings has been described in literature [13-14], corresponding derivatives condensed with six-membered heterocycles have been less investigated [15-16]. There are also few synthetic methods available in literature for the synthesis of chromeno[1,6]naphthyridines [17-20].

A vigilant scrutiny described that most of the methodologies endure some setbacks owing to their limited utility i.e. usage of corrosive catalysts [17], multistep process [18], high temperature, long reaction time, non-compatible solvent [19], low yields and unavailable starting materials [20]. Although, some strategically sound modifications have been documented [21] for upliftment of reaction condition, but somewhere down the line it still lack the versatility. The employed catalytic systems are more often non-recoverable [21], thus plummeting the turn over frequency (TOF), which is significant from industrial point of view. As a result, the development of new synthetic methods for this purpose remains an attractive goal.

The use of nanomaterial as efficient catalysts in aqueous medium has attracted considerable interest [22-23]. The coupling of nanocatalyst with aqueous medium and MWs can offer an astonishing synergistic effect with superior potential than these components in solitude

[24]. In continuation of our efforts towards the development of newer nanocatalytic processes [25-27], herein, we wish to report the synthesis of magnetically recoverable Fe_3O_4 nanoparticles and their catalytic applications in the synthesis of chromeno[1,6]naphthyridines in water.

2. Experimental

General part including used instruments is provided in ESI.

2.1 Catalyst preparation

A mixture of ferric chloride (2.7 g) and ferrous chloride (0.99 g) in a fixed molar ratio of 2:1 (Fe^{+3}:Fe^{+2}) in 30 mL of ethylene glycol was introduced in a 50 mL heavy walled pear-shaped two necked flask with non-standard tapered outer joint. The flask was attached to a 12 mm tip diameter probe and the reaction mixture was sonicated at ambient temperature for the specified period at 50% power of the processor and in a 4 s pulse mode. After proper sonication of the mixture, sodium acetate was added and sonication was continued until a fine dispersion was seen. This assembly was then subjected to an oil bath where the temperature was increased to 190 °C. For uniform heating of the broth, oil was constantly stirred. After 6 hours of stirring, the temperature was lowered to room temperature and the nanoparticles were separated magnetically and washed repeatedly with isopropanol followed by centrifugation at 8000 rpm for 20 minutes. Drying in a vacuum oven at 60 °C for two hours gave a brown coloured fine powder.

2.2 Catalyst activity measurement

Aromatic aldehyde (1 mmol), malononitrile (2 mmol), 2-hydroxyacetophenone (1 mmol) and 5 mol% of Fe_3O_4 NPs in water (10 mL) was introduced in a 50 mL round-bottom flask. The flask was placed in the microwave cavity and subjected to irradiation for appropriate time at 70

°C using a power of 400W. On the completion of reaction, Fe_3O_4 NPs were separated by using external magnet and crude product was purified by crystallization from ethanol.

3. Results and discussion

3.1 Synthesis and characterization of catalyst

Fe_3O_4 NPs have been synthesized via co-precipitation method [28] with excellent catalytic properties and high stability. The morphology, behavior and structure of Fe_3O_4 nanoparticles were characterized by XRD, FT-IR, TEM, VSM and BET analyses. In FT-IR, the adsorption band of the Fe–O bonds in tetrahedral sites was observed at 606 cm^{-1}. In XRD patterns, characteristic peaks appeared at $2\theta = 30.15$, 35.48, 43.2, 56.83 and 62.64 correspond to the major planes (220), (311), (400), (511) and (440) respectively, confirmed the inverse spinel structure. TEM image showed that average diameter of Fe_3O_4 NPs is about 7 nm with a square shaped morphology. The excellent magnetically controllable behavior of Fe_3O_4 NPs was investigated by VSM. The hysteresis loops exhibit a superparamagnetic behavior with the saturation magnetization of about 67 emu/g (Fig 1).

(Fig. 1)

In the N_2 adsorption–desorption isotherm sample showed a typical type IV isotherm with ‘a’ type hysteresis loop. The isotherm accounts for the relatively ordered mesopores and the hysteresis loop. The BET surface area for the Fe_3O_4 NPs is 39 m^2g^{-1} with pore dimensions of 3.6 nm (Fig. 2).

(Fig. 2)

3.2 Assessment of catalytic activity

We began our study by evaluating the efficiency of MW (400 W) at 70 °C for 60 min. for the model reaction of 3-phenoxybenzaldehyde (1.0 mmol), malononitrile (2.0 mmol) and 2-hydroxyacetophenone (1.0 mmol) in aqueous medium without using any catalyst. Under these conditions the reaction did not proceed. In order to optimize the reaction conditions, different iron catalysts in water were examined (Table 1).

(Table 1)

When $FeCl_2.4H_2O$ was used as a catalyst the product were obtained in low yields. When $FeCl_3.6H_2O$ was used, the yield was still lower, whereas with $Fe(NO_3)_3.9H_2O$ the yield of **4h** is 36% with no reusability of catalyst (Table 1). However, reaction occurred smoothly in the presence of Fe_3O_4 NPs affording product in 88 % yield. Fe_3O_4 NPs exhibit higher TOF value than corresponding bulk iron oxide. These results proved the superiority of this method in terms of yield and reaction time. The presence of Fe^{2+}/Fe^{3+}species in reaction mixture alone cannot drive the reaction adequately to produce **4h;** it should be in a definite structure, shape and size (Fe_3O_4 NPs). As indicated from Table 1, 5 mol % of catalyst loading was adequate to catalyze the reaction, excessive amount of catalyst did not increase the yield remarkably. Furthermore, water was proved as a superior solvent as compared to commonly employed organic solvents (See ESI).

The model reaction was also investigated under different nonconventional and conventional conditions (See ESI). Under MW, the catalytic activity of Fe_3O_4 NPs was found to be 7-fold higher than conventional method. To interpret the enhanced catalytic activity under MW, two hypotheses were proposed. First one assumes the existence of thermal effect only, i.e. a different temperature regime and second theory assumes that non-thermal effects can also exist.

But, the theory behind non-thermal effect is controversial [29]. If non-thermal effects are ruled out, then the enhanced catalytic activity must be due to a different temperature regime.

Since, it is well known that for a given temperature for both heating techniques (conventional and microwave), nanocatalyst can be heated up more selectively by MW [30-33]. The selective heating may be created by the difference in dielectric properties of materials, by the uneven distribution of electromagnetic field strength, or by the volumetric dielectric heating under MW [34]. It suggested that temperature of nanoparticles was much higher than the average temperature measured. Thus, nanocatalysts can act as a susceptor [24, 26, 35] and serve as an internal heating source for the reaction by transferring heat to the reactants and prevent their own deactivation.

To study the scope and limitations of this protocol, we have employed a wide range of aromatic aldehydes **(**Table 2**)**. Catalytic efficiency was not significantly affected by the substituents on the aromatic ring. Both electron-rich and electron-deficient substituents were highly effective, although slightly lower yields were obtained when ortho substituted aromatic substrates were employed. Further, at the expense of time up to 40 min, heterocyclic aldehydes also afforded good yields.

(Table 2)

A plausible mechanistic insight of the reaction involves consequent aldol, Knoevenagel condensation and intra molecular ring closure followed by aromatization leading to the formation of chromeno[1,6]naphthyridines catalyzed by Fe_3O_4 NPs (See ESI).

Recyclability

When reaction was completed, Fe_3O_4 NPs were collected on the side wall of the reaction vessel with the aid of an external magnet and water was removed from the mixture to leave a residue (including the product and catalyst). Then, the residue was dissolved in ethanol and catalyst was easily separated from the product by attaching an external magnet onto the reaction vessel, followed by decantation of product solution. Remaining catalyst was washed with ethanol to remove the residual product, dried under vacuum and reused for five subsequent reaction cycles without any significant loss in catalytic activity (Fig. 3).

(Fig. 3)

The characteristics obtained from TEM of fresh and used catalysts are almost similar, which suggest the retention of structure and morphology of Fe_3O_4 NPs after repeated use as catalyst. According to ICP-AES results, there was no nanocatalyst present in the final product and water.

4. Conclusions

The present work illustrates the advantages of microwave-assisted nano-catalysis in aqueous medium. Fe_3O_4 NPs have been synthesized, characterized and probed as a catalyst for the synthesis of chromeno[1,6]naphthyridines in water. Under MW, catalytic activity of Fe_3O_4 NPs was about 7-fold higher as compared to the conventional method. MW energy can be focused on the surface of the nanocatalyst and rapidly transferred to the reactants, the residence time of nano-catalyst at this high temperature is minimum. In this way, thermal decomposition and deactivation of the catalyst can be avoided by shorter reaction time and it can acts as susceptor. Formation of water as the only by-product is additional advantages of present methodology.

Acknowledgments

Financial assistance from CSIR [02(0143)/13/EMR-II] and UGC, New Delhi is gratefully acknowledged. We are also thankful to Central Drug Research Institute (CDRI), Lucknow and IIT Delhi for the spectral analyses.

References

[1] A. Correa, O.G. Mancheno, C. Bolm, Chem. Soc. Rev. 37 (2008) 1108-1117.

[2] F.A. Cotton, G. Wilkinson, Inorganic Chemistry, fourth ed., Verlag Chemie: Weinheim, 1982.

[3] N.U. Kumar, B.S. Reddy, V.P. Reddy, R. Bandichhor, Tetrahedron. Lett. 53 (2012) 4354-4356.

[4] C. Bolm, J. Legros, J. Le Paih, L. Zani, Chem. Rev. 104 (2004) 6217-6254.

[5] B. Moens, H. DeWinne, S. Corthals, H. Poelman, R. De Gryse, V. Meynen, P. Cool, B.F. Sels, P.A. Jacobs, J. Catal. 247 (2007) 86-100.

[6] D. Huber, Small 1 (2005) 482-501.

[7] S. Zhu, A.C. Marschilok, E.S. Takeuchi, K.J. Takeuchi, Electochem. Solid State Lett. 12 (2009) A91-A94.

[8] L. Wang, K.G. Neoh, E.T. Kang, B. Shuter, S.C. Wang, Biomaterials 31 (2010) 3502-3511.

[9] M.A. Bhat, N. Siddiqui, S.A. Khan, Acta. Pol. Pharm. 65 (2008) 235-39.

[10] J.J. Bowling, H.K. Pennaka, K. Ivey, S. Wahyuono, M. Kelly, R.F. Schinazi, F.A. Valeriote, D.E. Graves, M.T. Hamann, Chem. Biol. Drug Des. 71 (2008) 205-215.

[11] W. Gul, N.L. Hammond, M. Yousaf, J.J. Bowling, R.F. Schinazi, S.S. Wirtz, G.A. Andrews, C. Cuevas, M.T. Hamann, Bioorg. Med. Chem. 14 (2006) 8495-8505.

[12] H. Wang, J. Shi, C. Wang, X. Zhang, L. Zhao, Y. Wan, H. Wu, Spectrochimica Acta Part A 103 (2013) 62-67.

[13] M.J. Winn, Heterocycl. Chem. 12 (1975) 523-524.

[14] M.J. Wanner, G.J. Koomen, U.K. Pandit, Tetrahedron 38 (1982) 2741-2748.

[15] H.C. Van der Plas, M. Wozniak, H.J.W. Van der Haak, Adv. Heterocycl. Chem. 33 (1983) 95-146.

[16] W.W. Paudler, R.M. Sheets, Adv. Heterocycl. Chem. 33 (1983) 147-184.

[17] J.A. VanAllan, C.C. Petropoulos, G.A. Reynolds, D.P. Maier, J. Heterocycl. Chem. 7 (1970) 1363-1368.

[18] M.S. Schiedel, C.A. Briehn, P. Bauerle, Angew. Chem., Int. Ed. 40 (2001) 4677-4680.

[19] J. Světlík, F. Tureček, V. Hanuš, J. Chem. Soc., Perkin Trans 1. (1988) 2053-2058.

[20] S. Chandrasekhar, K. Vijeender, C. Sridhar, Tetrahedron Lett. 48 (2007) 4935-4937.

[21] H. Wu, W. Lin, Y. Wan, H-Q. Xin, D-Q. Shi, Y-H. Shi, R. Yuan, R-C. Bo, W. Yin, J. Comb. Chem. 12 (2010) 31-34.

[22] V. Polshettiwar, B. Baruwati, R.S. Varma, Chem. Commun. (2009) 1837-1839.

[23] A. Dandia, V. Parewa, A.K. Jain, K.S. Rathore, Green Chem. 13 (2011) 2135-2145.

[24] V. Polshettiwar, R.S. Varma, Green Chem. 12 (2010) 743-754.

[25] A. Dandia, V. Parewa, K.S. Rathore, Catal. Commun. 28 (2012) 90-94.

[26] A. Dandia, V. Parewa, S. Maheshwari, K.S. Rathore, J. Mol. Catal. A: Chem. 394 (2014) 244-252.

[27] A. Dandia, V. Parewa, S.L. Gupta, K.S. Rathore, J. Mol. Catal. A: Chem. 373 (2013) 61-71.

[28] Y. Sahoo, H. Pizem, T. Fried, D. Golodnitsky, L. Burstein, C. N. Sukenik and G. Markovich, Langmuir, 17 (2001), 7907-7911.

[29] N. Kuhnert, Angew. Chem. Int. Ed. 41(2002) 1863-1865.

[30] F. Chemat, D. Esveld, M. Poux, J. Di-Martino, J. Microwave Power EE 33 **(**1998) 88-94.

[31] G. Roussy, S. Hilairea, J.M. Thiébauta, G. Maireb, F. Garinb, S. Ringler, Appl. Catal. A 156 (1997) 167-180.

[32] T. Razzaq, J.M. Kremsner, C.O. Kappe, J. Org. Chem. 73 (2008) 6321-6329.

[33] N. Li, C. Hu, M. Cao, Phys. Chem. Chem. Phys. 15 (2013) 7685-7689.

[34] X. Zhang, D. O. Hayward, D. M. P. Mingos, Catal. Lett., 88 (2003) 33-38.

[35] A. Hoz, A. Ortiz, A. Moreno, Chem. Soc. Rev. 34 (2005) 164-178.

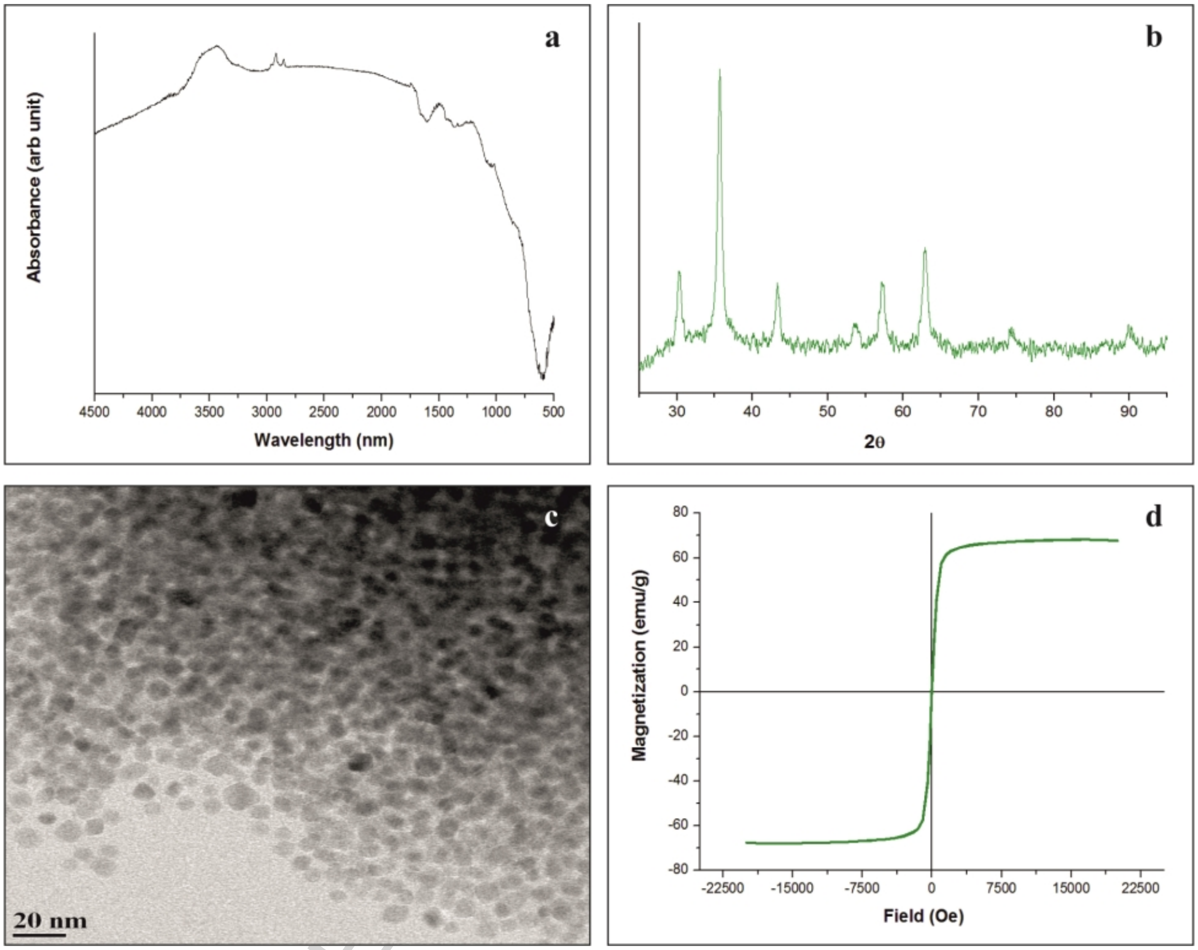
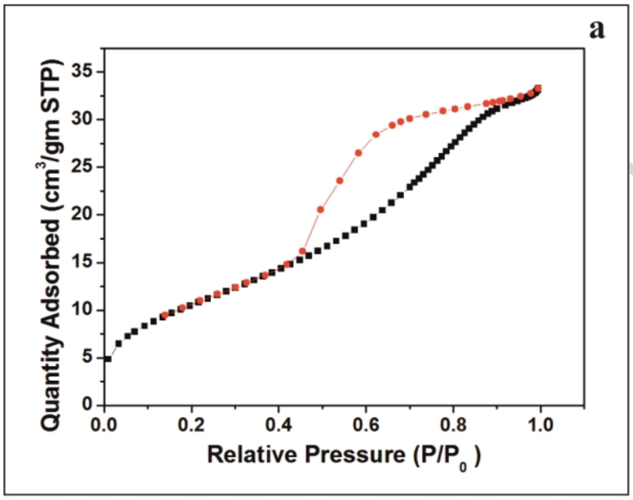


Fig. 1 (a) FT-IR spectra **(b)** XRD pattern **(c)** TEM image and **(d)** Magnetic hysteresis loops of Fe_3O_4 NPs



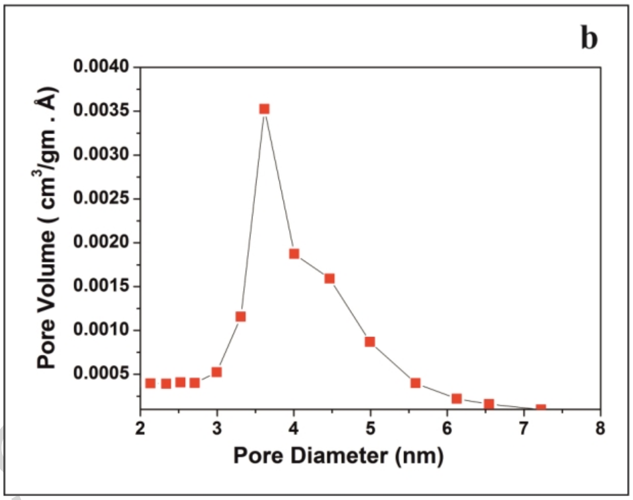


Fig. 2 (a) N_2 adsorption–desorption isotherm and **(b)** Pore dimensions of Fe_3O_4 NPs

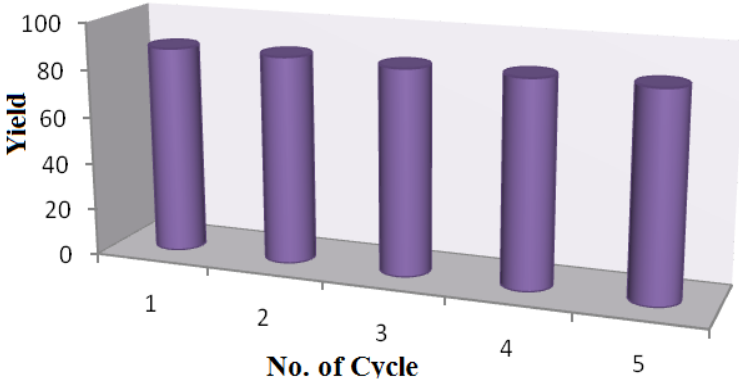
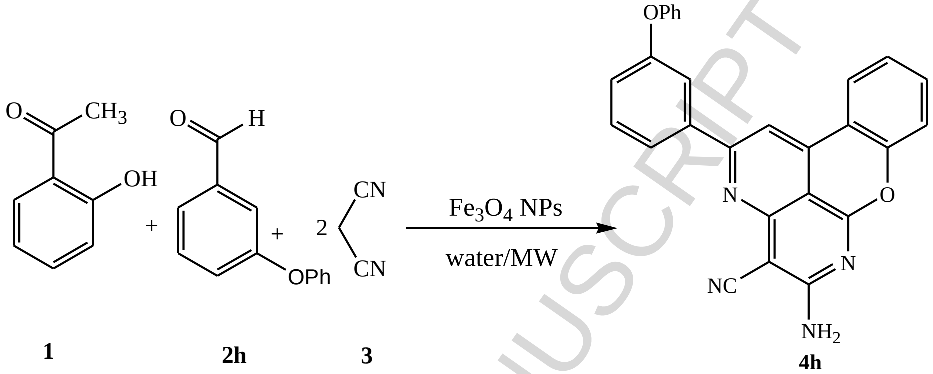


Fig. 3 Recyclability of Fe_3O_4 NPs

Table 1 Comparison of catalytic activity of Fe_3O_4 NPs with other iron catalysts for the synthesis of chromeno[1,6]naphthyridine derivatives (4h)[a]

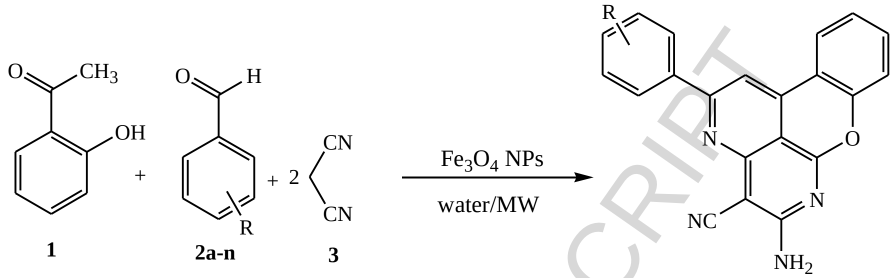


Entry	Condition	Time	Yield (%)*	TOF(h^{-1})
1.	$FeCl_2.4H_2O$ (10 mol %)	45 min	17	51
2.	$FeCl_3.6H_2O$ (10 mol %)	38 min	28	99
3.	$Fe(NO_3)_3.9H_2O$ (10 mol %)	34 min	36	143
4.	Bulk Iron oxide (10 mol %)	30 min	62	279
5.	Fe_3O_4 NPs (10 mol %)	25 min	88	475
6.	Fe_3O_4 NPs (5 mol %)	25 min	88	1003

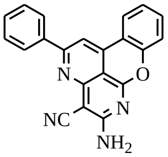
* Isolated yield

[a]Reactions performed on a 1:2:1 ratio of 3-phenoxybenzaldehyde, malononitrile and 2- hydroxyacetophenone in aqueous medium under microwave irradiation.

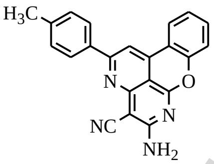
Table 2 Synthesis of chromeno[1,6]naphthyridines



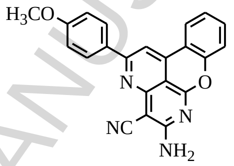
4a-n



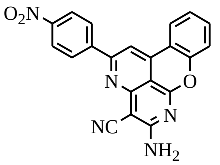
4a
82%



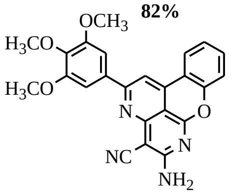
4b
85%



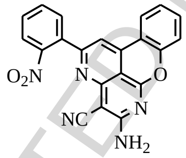
4c
88%



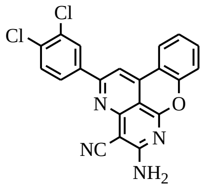
4d
83%



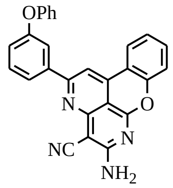
4e
80%



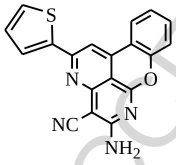
4f
81%



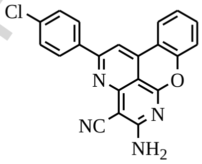
4g
80%



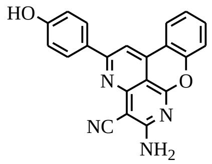
4h
88%



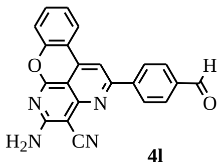
4i
82%



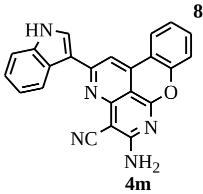
4j
84%



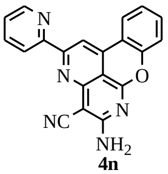
4k
81%



4l
83%



4m
80%

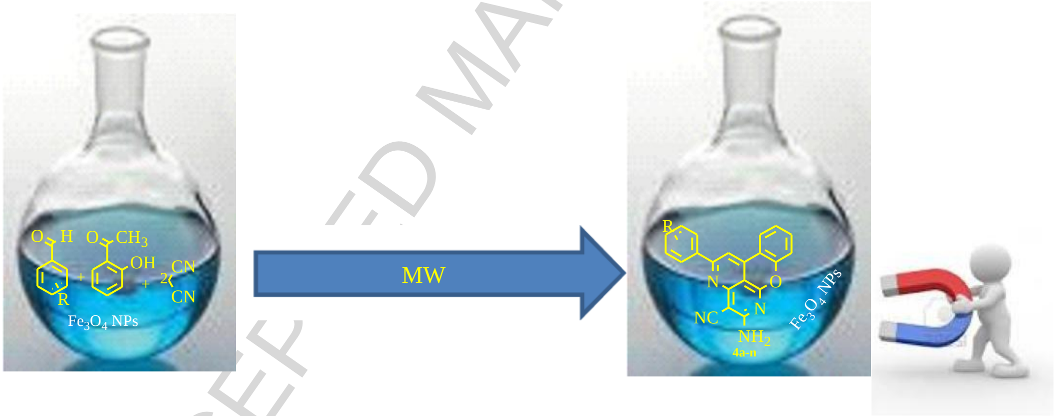


4n
82%

Microwave-assisted Fe_3O_4 nanoparticles catalyzed synthesis of chromeno[1,6]naphthyridines in aqueous media

Anshu Dandia,*[a] Vijay Parewa,[a] Shyam L. Gupta,[a] Amit Sharma,[a] Kuldeep S. Rathore[b] Amit Sharma,[b] Astha Jain[b]
[a]Centre of Advanced Studies, Department of Chemistry,
University of Rajasthan, Jaipur, India.
[b]Semiconductor and Polymer Science Laboratory, Department of Physics, University of Rajasthan, Jaipur, India.
E-mail[a]: dranshudandia@yahoo.co.in E-mail[b]: kuldeep_ssr@yahoo.com

Graphical Abstract



Highlights

- Fe_3O_4 NPs was prepared by co-precipitation method.

- Fe_3O_4 NPs catalyzed efficient synthesis of chromeno[1,6]naphthyridines.

- Reaction takes place *via* MW-assisted nano-catalysis in aqueous medium.

- The catalyst can be simply recovered by magnetic separation.
- High TOF value, recycling and economic viability of the catalyst.