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ARTICLE TYPE

Copper immobilized on ferromagnetic nanoparticles triazine dendrimer (FMNPs@TD-Cu(II))-catalyzed regioselective synthesis of 1,4-disubstituted 1,2,3-triazoles

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Copper immobilized on ferromagnetic nanoparticles triazine dendrimer (FMNPs@TD-Cu(II)) has been demonstrated for the first time as a recoverable and reusable heterogeneous nanocatalyst in the click synthesis of 1,4-disubstituted 1,2,3-triazoles by a one-pot three component reaction of halides, sodium azide and alkynes under mild conditions. The catalyst is very easy to handle and is environmentally safe and economical. FMNPs@TD-Cu(II) was characterized by transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray diffraction (XRD), FT-IR and EDX methods.

1 Introduction

During the last few decades, a central focus of modern synthetic organic chemistry is the design of new reactions and synthesis strategies that make easy the synthesis of biologically active compounds with potential application in the pharmaceutical or agrochemical industries.

Dendrimers are considered as the fourth generation of macromolecule building which have potential applications in biology, chemistry, and material science.[1] Generally, dendrimer synthesis is performed in solution phase. Incomplete and side reactions are two distinctive problems associated with dendrimer preparation and magnitude of these problems increases when dendrimer synthesis is carried out on solid phase. It requires great efforts to optimize reaction conditions to remove these problems and because of this, there are only few reports on solid phase dendrimer synthesis.[2]

By immobilizing homogeneous catalysts on insoluble supports, the benefits of both homogeneous as well as heterogeneous catalysts are obtained. These catalysts can be separated simply from the products by a simple filtration. In the past years, some dendrimers covalently-bonded to the inorganic or polymeric supports have been competently prepared.[3]

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However, the active sites in heterogeneous catalysts are not as accessible as in a homogeneous catalysts, and so the activity of the catalyst is usually decreased. Consequently, we need a catalyst system that not only demonstrates high activity and selectivity (such as a homogeneous system) but also possesses the ease of catalyst separation and recovery (such as a heterogeneous system). These objectives can be obtained by nanocatalysis. Nanocatalysts bridge the gap between homogeneous and heterogeneous systems, keeping the desirable attributes of both systems.[4]

Thus, nanocatalysts enjoy several advantages over conventional catalyst systems; however, separation and recovery of these tiny nanocatalysts from the reaction mixture is difficult. To overcome this problem, the use of magnetic nanoparticles has appeared as a viable solution; their insoluble and paramagnetic nature enables easy and effective separation of these catalysts from the reaction mixture with an external magnet.[4]

Ferromagnetic nanoparticles (FMNPs) have included an increasing attention in the fields of nanoscience and nanotechnology because of their incomparable and novel physicochemical properties that can be achieved in the light of their particle size and morphology. FMNPs improved with organic compounds have been widely employed for biomedical, biotechnological, and environmental applications, because their properties can be magnetically managed by applying an external magnetic field.[5] In general, it makes accessible high potential applications, like DNA extraction, cell separation, gene directing, drug delivery, magnetic resonance imaging and heavy metal ion removal.[6]

Triazoles are an important class of heterocyclic organic compounds and have a large spectrum of biological activities like antiallergenic,[7] anti-infective agents,[8] anti-HIV,[9] and anti-bacterial.[10] In addition, compounds belonging to this class are also useful as dyes, corrosion inhibitors, photographic materials, and photosensitizers.[11]

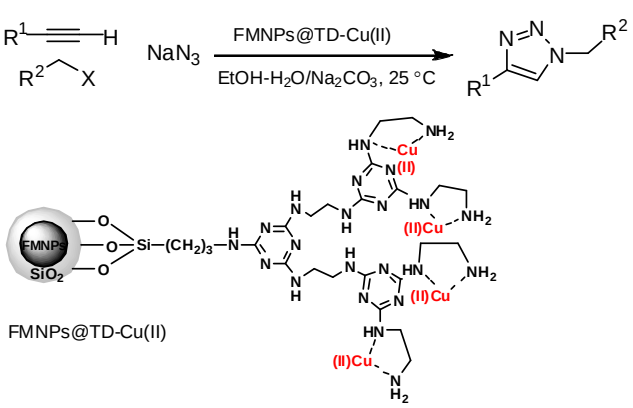
For the synthesis of 1,2,3-triazoles several synthetic methods using various catalysts[12-14] are accessible. Although, some of the reported methods are satisfactory, from the synthetic efficiency point of view, many of these methods suffer drawbacks such as

tedious work-up procedures, long reaction times, low yields, drastic reaction conditions, co-occurrence of several side reactions, or the use of organic solvents remain problematic. Another drawbacks of some of the existing methods is that the catalysts are destroyed during the work-up procedure and cannot be recovered and reused. Therefore, the introduction of efficient and green approaches using recoverable and reusable catalysts for the preparation of titled compounds is highly desirable.

Among the various procedures for the regioselective synthesis of triazoles, development of copper catalysed azide alkyne cycloaddition (CuAAC) proved to be an important milestone in the synthesis of 1,2,3-triazoles.[15-20]

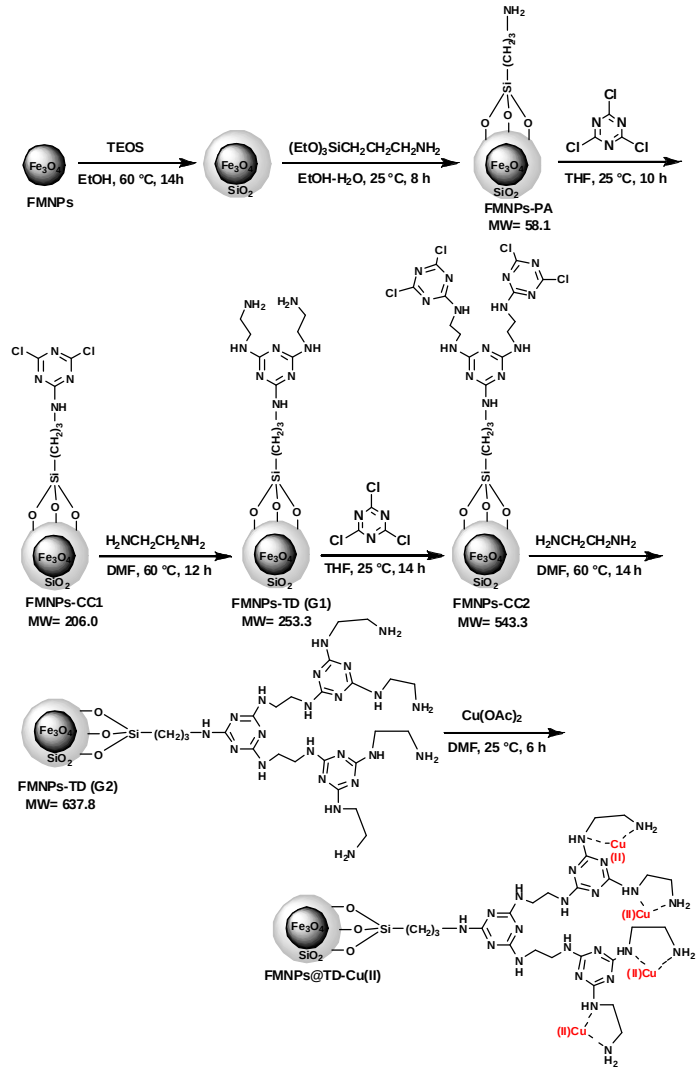
Nanocatalysis has become an active area of research, because these materials exhibit better catalytic activity due to the enhanced surface area towards organic transformations.[21] Copper-supported magnetic nanoparticles have been investigated for the preparation of 1,4-disubstituted 1,2,3-triazoles.[22]

In order to further improve the practicality of the CuAAC reaction and as a part of our ongoing research on the development of useful synthetic protocols,[23] herein, we describe a convenient and efficient one-pot method for the synthesis of 1,4-disubstituted 1,2,3-triazoles compounds using FMNPs@TD-Cu(II) as a recoverable and reusable nanocatalyst under mild conditions (Scheme 1).



Scheme 1 FMNPs@TD-Cu(II) catalyzed one-pot synthesis of 1,4-disubstituted 1,2,3-triazoles.

corresponding Cu(II) supported on magnetic nanoparticles (FMNPs@TD-Cu(II)). The characterization of the catalyst was carried out by FT-IR, TGA, XRD, EDX, SEM, and TEM.



Scheme 2 Synthetic route of FMNPs@TD-Cu(II) catalyst.

2 Results and discussion

2.1 Catalyst characterization

The FMNPs@TD-Cu(II) was prepared by the route outlined in Scheme 2. Naked magnetic Fe_3O_4 nanoparticles were synthesized through chemical precipitation procedure, and subsequently were coated with 3-aminopropyltriethoxysilane (APTS). The reaction of cyanuric chloride (CC) with FMNPs-PA was performed at 25 °C to substitute one chlorine atom of cyanuric chloride to produce FMNPs-CC1 which upon treatment with ethylenediamine gave FMNPs-TD (G1). The same procedure was applied to increase the dendrimer generation, FMNPs–CC2 and FMNPs-TD (G2). In the end, the reaction of G2 group with $Cu(OAc)_2$ was led to the

The FT-IR spectrum for the FMNPs–PA (Fig. 1a) shows a stretching vibration at ~3464 cm^{-1} which includes the contributions from both symmetrical and asymmetrical modes of the O-H bonds attached to the surface iron atoms. The presence of an adsorbed water layer is confirmed by a stretch for the vibrational mode of water found at 1653 cm^{-1}. The band formation between FMNPs and 3-aminopropyltriethoxysilane group is confirmed by Fe–O–Si absorption band that appears at ~985 cm^{-1}.[24] Also, the characteristic bands for C-H aliphatic bond appear at ~1460 and ~2921 cm.$^{-1}$ Moreover, the bands at ~1642 $cm^{-1}$of the C=N is a good reason for the presence of triazine moiety on the Fe_3O_4 MNPs.

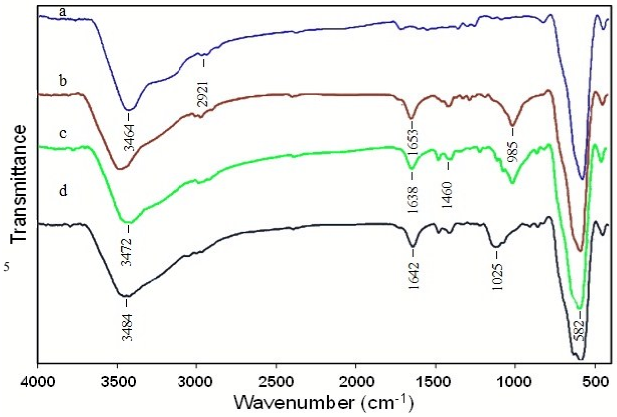


Fig. 1 FT-IR spectrum of a: FMNPs-PA; b: G1; c: FMNPs-CC2; d: G2.

The amount of organic moieties attached to FMNPs was measured by using TGA and elemental analysis. The TGA plots of FMNPs-PA, FMNPs-CC1, G1, FMNPs-CC2 and G2 show that thermal decomposition occurred in two steps (Fig. 2). Weight loss first occurred in the temperature range of 150 to 250 °C; and next above 250 °C. The first step weight loss corresponds to elimination of physically adsorbed water. The second-step weight loss is due to removal of organic moieties on the surface. The TGA results are summarized in Table 1. The observed total weight loss for FMNPs-PA, FMNPs-CC1, G1, FMNPs-CC2, and G2 are 7%, 10.4%, 11.2%, 13.1% and 15.3%, respectively. The weight loss of G1 and G2 appears about 11.2% and 15.3% at 250-550 °C is contributed to the thermal decomposition of 3-aminopropyltrimethoxysilane, triazine, and diamines groups and shows an irreversible process (Fig. 2c,e). On the basis of these values, the theoretical conversion at each stage is 41% (FMNPs-PA→ FMNPs-CC1), 88% (FMNPs-CC1→G1), 54% (G1 → FMNPs-CC2) and 95% (FMNPs-CC2 → G2).

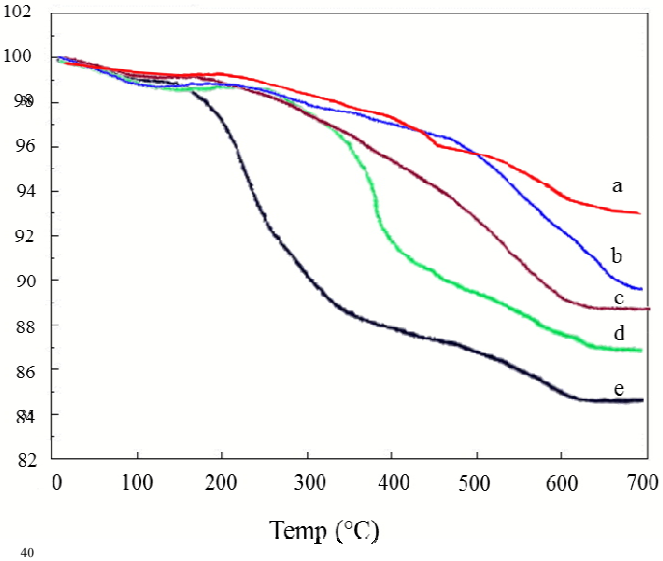


Fig. 2 TGA curve of: (a) MNPs-PA, (b) MNPs-CC1, (c) G1, (d) MNPs-CC2, (e) G2.

Table 1 Thermogravimetric analysis (TGA) results

Entry	Sample	Organic (wt%)	Organic (mmol/g MNPs)	Yield (%)
1	FMNPs-PA	7.02	1.20	-
2	FMNPs-CC1	10.43	0.50	41
3	G1	11.21	0.44	88
4	FMNPs-CC2	13.10	0.24	54
5	G2	15.32	0.23	95

A summary of the elemental analysisand TGA data is presented in Table 2, indicating a good agreement between the two methods.

Table 2 Elemental analysis results

Entry	Sample		C	H	N	Total
1	FMNP-PA	TGA(Wt%)	4.35	0.97	1.69	7.02
		EA(wt%)	4.68	1.04	1.69	7.54
2	FMNPs-CC1	TGA(Wt%)	3.64	0.35	2.83	10.43
		EA(wt%)	3.66	0.36	2.84	10.48
3	G1	TGA(Wt%)	5.31	0.94	4.95	11.21
		EA(wt%)	5.52	0.97	5.15	11.66
4	FMNPs-CC2	TGA(Wt%)	6.37	0.60	2.70	13.10
		EA(wt%)	6.46	0.61	2.74	13.29
5	G2	TGA(Wt%)	8.65	1.28	5.38	15.32
		EA(wt%)	8.83	1.31	5.49	15.64

The XRD patterns of magnetite and FMNPs@TD-Cu(II) are depicted in Figure 3. The magnetite XRD peaks clearly seen in XRD profile such as 220, 311, 400, 422, 511 and 440 (JCPDS file, no. 901-3024).

The crystallite size of the catalysts was determined by Debye−Scherrer equation was found to be 23.5 nm, which is an agreement with the result obtained from the TEM which shows a size distribution between 20 and 35 nm (Fig.5b).

The copper content of FMNPs@TD-Cu(II), measured by ICP analysis, was obtained to be 0.41 mmol per gram of FMNPs@TD-Cu(II) catalyst. The EDX results in Fig. 4 shows that Cu exists in the nanoparticles.

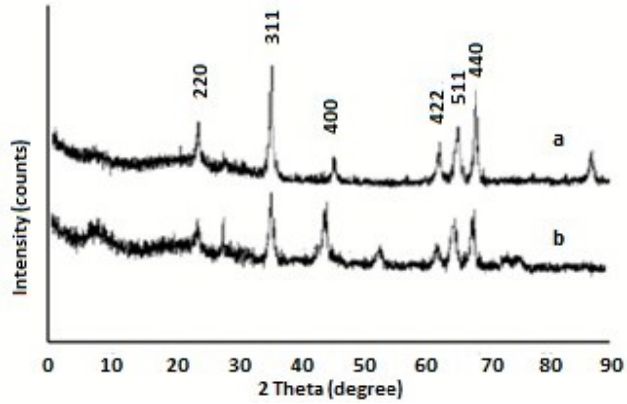


Fig. 3 The XRD pattern of (a) FMNPs and (b) FMNPs@TD-Cu(II).

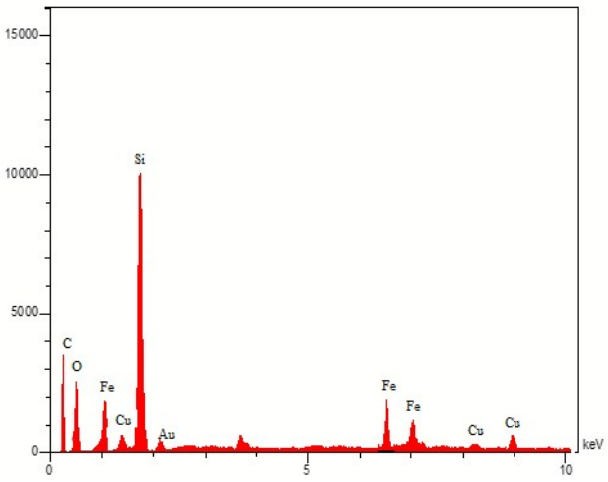


Fig. 4 EDX pattern of FMNPs@TD-Cu(II).

The FMNPs (Fig. 5a) and FMNPs@TD-Cu(II) (Figure 5b) was also characterized by TEM. The dark colored regions or black spots in the photograph correspond to the Fe_3O_4 species while the colorless parts being that of silica.

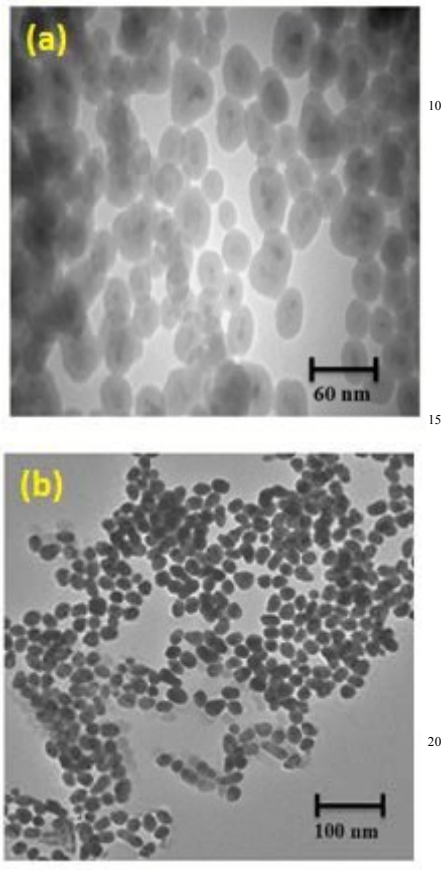


Fig. 5 TEM images of a:FMNPs-SiO_2; b: FMNPs@TD-Cu(II).

SEM image is shown in Figure 6. The SEM image shows that FMNPs (Figure 6a) and FMNPs@TD-Cu(II) (Figure 6b) have a mean diameter of about 35 nm and a nearly spherical shape, which is consistent with XRD, SEM and TEM image shows the nanoparticles are well dispersed and uniform in shape and size.

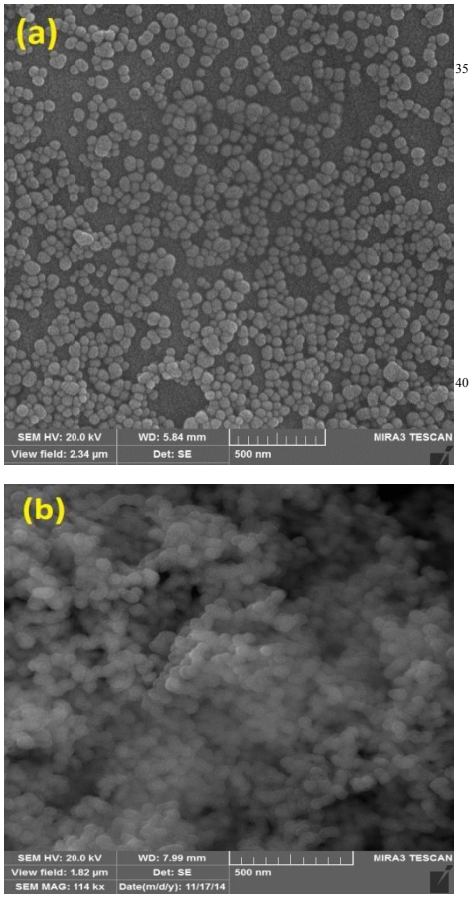


Fig. 6 SEM images of a: FMNPs-SiO_2; b: FMNPs@TD-Cu(II).

Figure 7 shows the magnetization curves of Fe_3O_4 and FMNPs@TD-Cu(II). As can be observed from the figure, the saturation magnetization was decreased. The lower saturation magnetization of the FMNPs@TD-Cu(II) relative to that of bare Fe_3O_4 nanoparticles, can be attributed to the formation of a silica shell around the Fe_3O_4 core.

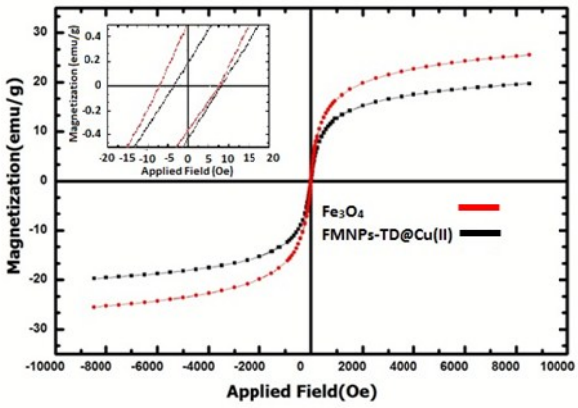
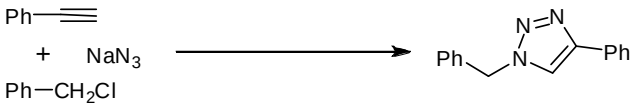


Fig. 7 Magnetization curves of Fe_3O_4 and FMNPs@TD-Cu(II).

2.2 Catalytic studies

Initially, for screening experiments, three-component reaction between phenylacetylene (1 mmol), benzyl choloride (1 mmol), and sodium azide (1.1 mmol) was selected as a model reaction (Table 3). The model reaction was first carried out in the absence of FMNPs@TD-Cu(II). Stirring was continued in H_2O-EtOH (1:1) as solvent at 25 °C. Timely analysis of the reaction mixture (TLC) did not indicate any appreciable progress of the reaction. (Table 3, entry 1). In the presence of FMNPs@TD-Cu(II) (8 mg), the corresponding product was obtained in 99% yield (Table 3, entry 2). Then, the same reaction was carried out in the presence of FMNPs@TD-Cu(II) (8 mg) in different single and mixed solvents at room temperature (Table 3, entries 3−8). As shown, the maximum yields were obtained in both H_2O-EtOH (1:1) and H_2O-MeOH (1:1) mixed solvent systems (Table 3, entries 2 and 8). However, H_2O-EtOH (Table 3, entry 12) was preferred because of safety problems. Next, we examined the catalyst loading (5-10 mg), and 8 mg was found to be the optimum catalyst loading for completion of this reaction. However, upon decreasing the loading of catalyst to 5 mg and 6 mg reduced the yields to 55 and 68 respectively (Table 3, entries 9 and 10). When a catalyst loading of 10 mg was used, the yield of the product was 98%, but the reaction rate increased, so that the reaction was complete within 10 min (Table 3, entry 11).

Table 3 Optimization of the reaction conditions[a]

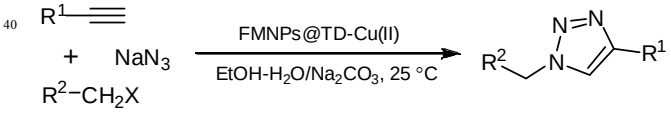


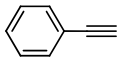
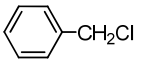
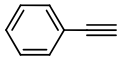
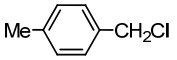
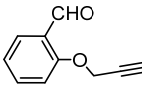
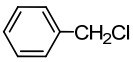
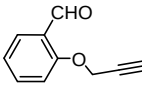
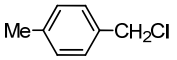
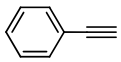
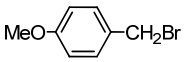
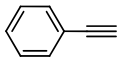
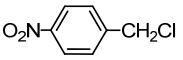
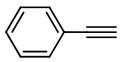
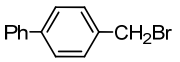
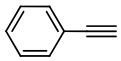
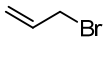
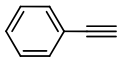
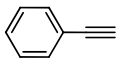
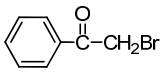
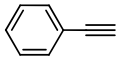
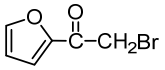
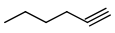
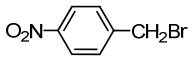
Entry	FMNPs-TD@Cu(II) (mg)	Solvent	Time (min)	Yield[b] (%)
1	-	H_2O/EtOH (1:1)	15	-
2	8	H_2O/EtOH (1:1)	15	99
3	8	EtOH	15	80
4	8	CH_3CN	15	50
5	8	DMF	15	68
6	8	EtOAc	15	37
7	8	H_2O	15	73
8	8	H_2O/MeOH (1:1)	15	95
9	5	H_2O/EtOH (1:1)	15	55
10	6	H_2O/EtOH (1:1)	15	68
11	10	H_2O/EtOH (1:1)	10	98

[a]Reaction conditions: Phenylacetylene (1 mmol), benzyl choloride (1 mmol), sodium azide (1.1 mmol), sodium carbonate (1 mmol) FMNPs@TD-Cu(II), 25 °C.
[b]Isolated yields.

Under the optimized reaction conditions, the scope of the methodology was investigated for the synthesis of various 1,4-disubstituted 1,2,3-triazoles and the results are described in Table 4. Various benzylic, allylic and aliphatic halides afforded excellent yields of the products under these reaction conditions (Table 4). Aliphatic halides are usually known to be less reactive than aromatic ones, but with this catalytic system, the reaction of phenylacetylene with hexyl bromide (Table 4, entry 9) proceeded efficiently to provide the desired 1,4-disubstituted 1,2,3-triazole in 93% yields. In addition, α-bromoacetophenone reacted

Table 4 FMNPs@TD-Cu(II) Catalyzed click synthesis of 1,4-disubstituted 1,2,3-triazoles[a]



Entry	R^1	R^2-CH_2X	Yield %[b]/t (min)	Ref.
1			99 (15)	25
2			99 (22)	25
3			95 (20)	-
4			98 (16)	-
5			95 (25)	12b
6			95 (40)	26
7			97 (35)	-
8			94 (40)	27
9		$C_6H_{13}Br$	93 (30)	28
10			95 (27)	28
11			90 (37)	2b
12			98 (20)	2b

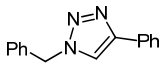
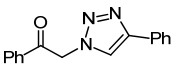
[a]The purified products were characterized by mp, ^1H and ^{13}C NMR spectroscopy.
[b] Yields refer to pure isolated products.

smoothly with phenylacetylene to produce the corresponding β-keto-1,2,3-triazole in 95% yield within 27 min (Table 4, entry 10). 2-Bromo-1-(furan-2-yl)ethanone, as a heteroaromatic substrate, also worked well in this reaction under similar reaction conditions to afford the desired product in 90% yield after 37 min (Table 4, entry 11). Aryl acetylenes such as phenylacetylene and 2-(prop-2-ynyloxy)benzaldehyde as well as alkyl acetylenes such as 1-hexyne reacted rapidly and smoothly to produce the

corresponding 1,4-disubstituted 1,2,3-triazoles in excellent yields (Table 4). Interestingly, the presence of aldehyde group did not interfere with this reaction, and desired products were obtained in excellent yields (Table 4, entries 3 and 4). It is noteworthy that the reactions were completed within 15-40 minutes at 25 °C, and the products were produced in excellent yields with high purity and excellent regioselectivity, in which only 1,4-regioisomeric products were formed.

A comparison of the efficiency of this method with selected previously methods[29-31] is collected in Table 5. As can be seen, the present protocol is indeed superior to several of the other protocols.

Table 5 Comparison of click synthesis of 1,4-disubstituted 1,2,3-triazoles by the FMNPs@TD-Cu(II) catalytic system with some of those reported in the literature

Product	Conditions[Ref.]	Yield%[b]/Time
	this work	99 (15 min)
	C/Cu NPs/H_2O/70 °C[29]	98 (6 h)
	5 mol%/Cu/H_2O/55 °C[30]	94 (25 h)
	this work	97 (30 min)
	C/Cu NPs/H_2O/70 °C[29]	80 (7 h)
	0.5 mol% Cu NPs/C/H_2O-EtOH/70 °C[31]	82 (7 h)

The reusability of the catalyst for the cycloaddition reaction of phenyl acetylene, sodium azide and benzyl chloride, was subsequently investigated. When the reaction was completed, the mixture was separated catalyst by an external magnet then diluted with water and EtOAc. The catalyst was separated by simple filtration, dried, and used for subsequent runs. Thus, after recovery the catalyst was subjected to a second reaction from which it gave the desired product in 97% yield; the average chemical yield for six consecutive runs was 96%, which clearly demonstrates the practical recyclability of this catalyst (Fig. 8). The slight decrease of catalytic activity should be due to the normal loss of the catalyst during the work-up stage.

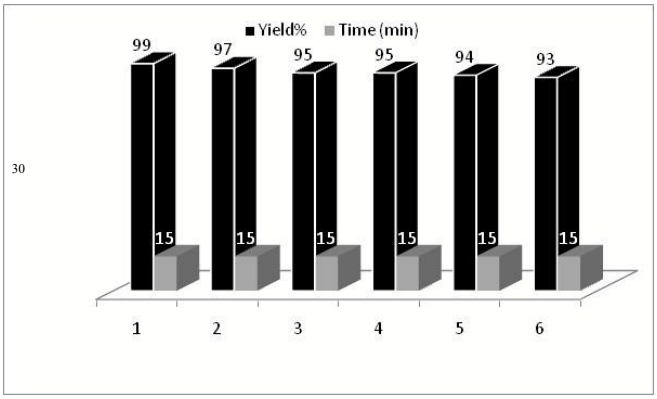


Fig. 8 Recyclability of FMNPs@TD-Cu(II) for the preparation of 1-benzyl-4-phenyl-1H-1,2,3-triazole.

To test for leaching we filtered the catalyst after 8 min and the reaction continued uninterrupted in the absence of catalyst. We found that the reaction was not completed, even at long reaction times. These observations showed FMNPs@TD-Cu(II) is stable under the reactions, and can be recycled multiple times.

3 Conclusions

In conclusion, the synthesis and characterization of a new stable and heterogeneous catalyst, Cu(II) containing Fe_3O_4 triazine dendrimer (FMNPs@TD-Cu(II)), is reported. FMNPs@TD-Cu(II) catalyzes three-component reaction for the construction of 1,4-disubstituted1,2,3-triazole from phenylacetylenes, sodium azide and aromatic, heteroaromatic, allylic and aliphatic halides. The reaction has good substrate scope and furnishes the products in excellent yields and regioselectivity. Furthermore, the catalyst is stable under the reaction conditions and can be recycled and reused several times without a significant loss in activity. Importantly, recovery of the catalyst can be accomplished easily using a simple external magnet. Therefore, this synthetic methodology can be considered as a useful practical achievement in the preparation of these important heterocyclic compounds. Further studies are on going in our laboratory to understand other applications of the catalyst in various organic reactions.

4 Experimental

4.1 Material and physical measurements

The materials were purchased from Merck and Fluka and were used without any additional purification. All reactions were monitored by thin layer chromatography (TLC). Melting points were determined using a Stuart Scientific SMP2 apparatus. FT-IR spectra were determined on a Perkin-Elmer 683 instrument. ^1H and ^{13}C NMR spectra were recorded on a Bruker (200, 500 MHz) spectrometer in $CDCl_3$ as solvent. X-ray powder diffraction patterns were obtained on SE1FERT-3003TT. Thermogravimetric analysis (TGA) was carried out on a PL-STA-1640 form heating rate of the range of 30-600 °C. Scanning electron microscopy measurements were performed on a VEGA TESCAN microscope (FE-SEM). Transmission electron microscopy (TEM) measurements were carried out on a Zeiss-EM10C Germany operating at 80 Kv and formvar carbon coated grid Cu Mesh 300.

4.2 Preparation and modification of large-scale the ferromagnetic nanoparticles (FMNPs)

FMNPs modified with citrate groups were prepared according to reported literature procedure.[32] Iron (III) chloride hexahydrate (5.40 g, 20 mmol) and iron (II) chloride tetrahydrate (2 g, 10 mmol) were dissolved in deionized H_2O (120 mL) under N_2 atmosphere. Then, 10 mL of ammonium hydroxide 25% was quickly added into the solution under rapid mechanical stirring (500 rpm), and the mixture was heated up to 60 °C, while stirred vigorously by a mechanical stirrer for 1 hour under N_2 atmosphere. After cooling to room temperature, the resultant nanoparticles were gathered using a external magnet and the collected magnetic solid were dispersed in a 200 mL of trisodium citrate solution (0.3 M) and heated at 80 °C for 1 hour. Finally, the precipitates were collected using an external magnet and washed with acetone to eliminate remainder trisodium citrate.

4.3 Preparation of silica-coated FMNPs

The surface modified FMNPs (1 g) were redispersed in deionized H_2O (50 mL) by the ultrasonic treatment for 25 min. Subsequently, the resulting dispersion was centrifuged for 30 min and adjusted to 2.0 wt %. Then, 2 mL of the ferro fluid was first diluted with H_2O (40 mL), the resultant suspension and $NH_3.H_2O$ (5 mL) were poured into ethanol (140 mL) with stirring at 40 °C. A solution of TEOS (1 mL) in EtOH (10 mL) was added to the dispersion in a dropwise manner under continuous mechanical stirring. Then, the resultant dispersion was stirred mechanically for 14 hours at 25 °C. Finally, the silica-coated ferromagnetic nanoparticles were composed by magnetic separation and washed with EtOH and deionized H_2O.

4.4 Preparation of FMNPs coated by 3-aminopropyltriethoxysilane (FMNPs-PA)

The obtained silica-coated FMNPs powder (1.5 g) was dispersed in 250 mL H_2O-EtOH (1:1) solution by sonication for 30 min, and then APTS (2.5 mL) was added to the mixture. The reaction resulting mixture was mechanically stirred under N_2 atmosphere for 8 h at room temperature. The suspension was centrifuged to separate the precipitated material, which was then re-dispersed in ethanol by sonication. The final product was separated by an external magnet and washed five times with ethanol and stored in a fridge for future use.

4.5 Preparation of triazine-based dendrimer supported on FMNPs-PA (G2 or FMNPs-TD)

A mixture of FMNPs-PA (2 g), cyanuric chloride (1.85 g, 10 mmol) and triethylamine (1.4 mL, 10 mmol) in THF (10 mL) was shaken for 10 hours at 25 °C. The solid material (MNPs-CC1) was separated by an external magnet and washed five times with hot THF and then dried in a vacuum oven at 50 °C. Then, to a slurry of FMNPs-CC1 (1 g) in DMF (12 mL), ethylenediamine (0.53 mL, 8 mmol) and triethylamine (1.1 mL, 8 mmol) were added. The resulting mixture was mechanically stirred at 60 °C for 12 hours. The resulting first generation (FMNPs-TD or G1) was separated by an external magnet, washed five times with hot ethanol and dried in a vacuum oven at 50 °C. The second generation FMNPs-TD (G2) was prepared according to the above procedure for the preparation of G1. A mixture of G1 (1 g), cyanuric chloride (CC) (1.66 g, 9 mmol) and triethylamine (1.2 mL, 9 mmol) in THF (20 mL) was shaken for 14 hours at 25 °C. The final sample was separated by an external magnet (FMNPs-CC2) washed with hot THF in five times and dried in a vacuum oven at 50 °C. Then, to a slurryof FMNPs-CC2 (1 g) in DMF (20 mL) were added ethylenediamine (0.63 mL, 9.5 mmol) and triethylamine (1.3 mL, 9.5 mmol). The resulting mixture was stirred at 60 °C for 14 hours and then separated by an external magnet. The resulting second generation of ferromagnetic nanoparticles supported dendrimer (G2 or FMNPs-TD) was washed with hot ethanol five times and dried in a vacuum oven at 50 °C.

4.6 Preparation of Cu(II) containing ferromagnetic nanoparticles triazinedendrimer (FMNPs@TD-Cu(II))

To a mixture of ferromagnetic nanoparticles supported dendrimer (G2) (0.5 g) in DMF (10 mL) was added $Cu(OAc)_2$ (0.09 g, 0.5 mmol). The mixture was stirred for 6 hours at 25 °C. The resulting mixture was separated by an external magnet, the solid material was washed sequentially with 25 mL of acetone and then dried in a vacuum oven at 40°C. Finally, FMNPs@TD-Cu(II) catalyst was obtained as a dark green solid.

4.7 General procedure for synthesis of 1,2,3-triazoles in the presence of FMNPs@TD-Cu(II) nanocatalyst

A mixture of sodium carbonate (0.1 g, 1mmol) and FMNPs@TD-Cu(II) (0.008 g, containing 0.41 mmol Cu(II))/g in 3 mL of H_2O-EtOH (1:1) in a round bottom flask (25 mL) was stirred for 1 min. NaN_3 (0.04 g, 0.6 mmol) was added and vigorously stirred for few seconds. Then a halide derivative (0.5 mmol) and a acetylene derivative (0.5 mmol) were added to the reaction medium, and the mixture was stirred at 25 °C for the indicated reaction time (Table 4). The reaction progress was monitored by TLC (eluent: *n*-hexane/EtOAc, 5:1). After completion of the reaction, the mixture was diluted with water and ethyl acetate and the catalyst was recovered using an external magnet. The organic layer was separated, and the aqueous layer was extracted with ethyl acetate (3 × 5 mL). The organic phases were combined, dried with magnesium sulfate, filtered, and concentrated under reduced pressure to afford the pure triazole in most cases. The recovered catalyst was reused for further runs without removing the catalyst from the flask. Spectral and analytical data for new compounds follow.

4.7.1 2-((1-Benzyl-1*H*-1,2,3-triazol-4-yl)methoxy)benzaldehyde (Table 4, entry 4)

Light yellow solid; M.p.: 115 °C: ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.31 (s, 2H), 5.55 (s, 2H),7.05-7.58 (m, 9H), 7.82 (s, 1H), 10.41 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 53.85, 62.09, 112.51, 120.82, 122.27, 124.54, 127.61, 128.18, 128.43, 128.71, 133.78, 135.50, 143.31, 159.92, 189.07; Anal. Calcd for $C_{17}H_{15}N_3O_2$: C, 69.61; H, 5.15; N, 14.33. Found: C, 69.47; H, 5.34; N, 14.40.

4.7.2 2-((1-(4-Methylbenzyl)-1*H*-1,2,3-triazol-4-yl)methoxy)benzaldehyde (Table 4, entry 5)

Light yellow solid; M.p.: 119 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 2.32 (s, 3H), 5.39 (s, 2H), 5.77 (s, 2H), 7.06-7.27 (m, 6H), 7.56-7.81 (m, 2H), 7.83-8.09 (m, 1H), 10.42 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 22.89, 53.08, 62.07, 112.48, 115.66, 115.83, 120.87, 121.01, 122.11, 128.27, 129.48, 129.54, 135.51, 143.42, 159.87, 167.39, 189.07; Anal. Calcd for $C_{18}H_{17}N_3O_2$:C, 70.34; H, 5.58; N, 13.67. Found: C, 70.18; H, 5.51; N, 13.55.

4.7.3 1-([1,1'-Biphenyl]-4-ylmethyl)-4-phenyl-1*H*-1,2,3-triazole (Table 4, entry 8)

White solid; M.p.:185 °C; ^{1}H NMR (200 MHz, $CDCl_3$): δ 5.11 (s, 2H), 7.25-7.63 (m, 12H), 7.55-7.63 (m, 1H), 7.71 (s, 1H), 7.79-7.83(m, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 52.54, 122.02, 122.32, 128.20, 128.28, 128.49, 128.62, 129.51, 129.58, 129.69,

130.02, 131.94, 134.72, 136.58, 137.07; Anal. Calcd for $C_{21}H_{17}N_3$: C, 80.00; H, 5.50; N, 13.49. Found: C, 80.21; H, 5.43; N, 13.61.

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Notes and references

1 (*a*) R. K. Gopalakrishna Panicker and S. Krishnapillai, *Tetrahedron Lett.,* 2014, **55**, 2352-2354; (*b*) S. T. Lo, A. Kumar, J. T. Hsieh and X. Sun, *Molecular pharm.,* 2013, **10**, 793-812; (*c*) A. M. Caminade, A. Ouali, M. Keller and J. P. Majoral, *Chem. Soc. Rev.,* 2012, **41**, 4113-4125; (*d*) M. A. Mintzer and M. W. Grinstaff, *Chem. Soc. Rev.,* 2011, **40**, 173-190; (*e*) Y. Cheng, L. Zhao, Y. Li and T. Xu, *Chem. Soc. Rev.,* 2011, **40**, 2673-2703; (*f*) F. Vögtle, G. Richardt and N. Werner, *Front Matter*. Wiley Online Library: 2009.

2 (*a*) A. Y. T. Huang, C. H. Tsai, H. Y. Chen, H. T. Chen, C. Y. Lu, Y. T. Lin and C. L. Kao, *Chem. Commun.,* 2013, **49**, 5784-5786; (*b*) M. Nasr-Esfahani, I. Mohammadpoor-Baltork, A. R. Khosropour, M. Moghadam, V. Mirkhani, S. Tangestaninejad and H. Amiri Rudbari, *J. Org. Chem.,* 2014, **79**, 1437−1443; (*c*) M. Nasr-Esfahani, I. Mohammadpoor-Baltork, A. R. Khosropour, M. Moghadam, V. Mirkhani and S. Tangestaninejad, *J. Mol.r Catal. A: Chem.,* 2013, **379**, 243–254; (*d*) G. R. Krishnan and K. Sreekumar, *Eur. J. Org. Chem.*, 2008, **28**, 4763-4768; (*e*) T. Kehat, K. Goren and M. Portnoy, *New J. Chem.,* 2007, **31**, 1218-1242; (*f*) A. Dahan and M. Portnoy, *J. Poly. Sci. Part A,* 2005, **43**, 235-262; (*g*) P. Wu, A. K. Feldman, A. K. Nugent, C. J. Hawker, A. Scheel, B. Voit, J. Pyun, J. M. Frechet, K. B. Sharpless and V. V. Fokin, *Angew. Chem.,* 2004, **43**, 3928-3932; (*h*) G. Sanclimens, L. Crespo, E. Giralt, M. Royo and F. Albericio, *Peptide Sci*., 2004,**76**, 283-297; (*i*) S. Lebreton, S. Monaghan and M. Bradley, *Aldrich. Acta.,* 2001, **34**, 75-83; (*j*) A. Basso, B. Evans, N. Pegg and M. Bradley, *Chem. Commun.,* 2001, **8**, 697-698.

3 (*a*) T. Selvam, A. Machoke and W. Schwieger, *Applied Catalysis A General,* 2012, **445**, 92-101; (*b*) A.V. Biradar, A. A. Biradar and T. Asefa, *Langmuir*,2011,**27**, 14408-14418; (*c*) S. J. Dilly, S. J. Carlisle, A. J. Clark, A. R. Shepherd, S. C. Smith, P. C. Taylor and A. Marsh, *J. Poly. Sci. Part A,* 2006, **44**, 2248-2259; (*d*) J. P. Reynhardt,Y. Yang, A. Sayari and H. Alper, *Advanced Mat.,*2005, **15**, 1641-1646; (*e*) J. P. Reynhardt,Y. Yang, A. Sayari and H. Alper, *Chem. mat.,* 2004, **16**, 4095-4102.

4 V. Polshettiwar, R. Luque, A. Fihri, H. Zhu, M. Bouhrara and J. M. Basset, *Chem. Rev.,* 2011, **111**, 3036–3075.

5 (*a*) A. S. Albuquerque, M. V. Tolentino, J. D.Ardisson, F. C. Moura, R. Mendonça and W. A. Macedo, *Ceramics International,* 2012, **38**, 2225-2231; (*b*) M. Florea, M. Alifanti, V. Parvulescu, D. Mihaila-Tarabasanu, L. Diamandescu, M. Feder, C. Negrila and L. Frunza, *Catalysis Today,* 2009, **141**, 361-366; (*c*) A.H. Latham and M. E. Williams, *Accounts Chem. Research,* 2008, **41**, 411-420; (*d*) P. D. Stevens, G. Li, J. Fan, M. Yen and Y. Gao, *Chem. Commun.*, 2005, **35**, 4435-4437; (*e*) T. Hyeon, *Chem. Commun.*, 2003, **8**, 927-934; (*f*) D. Chiba, M. Yamanouchi, F. Matsukura and H. Ohno, *Science*, 2003, **301**, 943-945.

6 (*a*) Y. Weng, J. Zhao, S. Y. Yu and S. Y. Song, *Cryst. Eng. Commun.*, 2014, **16**, 6257-6262; (*b*) J. Feng, W. Q. Fan, S. Y. Song, Y. N. Yu, R. P. Deng and H. J. Zhang, *Dalton Trans.,* 2010, **39**, 5166-5171; (*c*) L. Zhang, S. Qiao, Y. G. Jin, Z. G. Chen, H. Gu and G. Q. Lu, *Adv. Mater.,* 2008, **20**, 805-809; (*d*) Y. S. Lin, S.H. Wu, Y. Hung, Y. H. Chou, C. Chang, M. L. Lin, C. P. Tsai and C. C. Y. Mou, *Chem. Mater.,* 2006, **18**, 5170-5172; (*e*) Y. M. Huh, Y. W. Jun, H. T. Song, S. Kim, J. S. Choi, J. H. Lee, S. Yoon, K. S. Kim, J. S. Shin and J. S. Suh, *J. Am. Chem. Soc.,* 2005, **127**, 12387-12391.

7 D. R. Buckle, D. J. Outred, C. J. Rockell, H. Smith and B. A. Spicer, *J. Med. Chem.,* 1983, **26**, 251-254.

8 M. Damodiran, D. Muralidharan and P. T. Perumal, *Bioorg. Med. Chem. Lett*., 2009, **19**, 3611-3614.

9 R. Alvarez, S. Velazquez, A. San-Felix, S. Aquaro, E. D. Clercq, C. F. Perno, A. Karlsson, J. Balzarini and M. J. Camarasa, *J. Med. Chem.,* 1994, **37**, 4185-4194.

10 M. J. Genin, D. A. Allwine, D. J. Anderson, M. R. Barbachyn, D. E. Emmert, S. A.Garmon, D. R. Graber, K. C. Grega, J. B. Hester and D. K. Hutchinson, *J. Med. Chem.,* 2000, **43**, 953-970.

11 (*a*) H. Dehne, *Methoden der OrganischenChemie*, 1994, **8**, 305-405; (*b*) W. Q. Fan and A. R. Katritzky, *Compr. Heterocycl. Chem.,* 1996, **4**, 1-126.

12 (*a*) S. R. Kale, S. S. Kahandal, M. B. Gawande and R. V. Jayaram, *RSC Adv.,* 2013, **3**, 8184-8192; (*b*) P. V. Chavan, K. S. Pandit, U. V. Desai, M. A. Kulkarni and P. P. Wadgaonkar, *RSC Adv.,* 2014, **4**, 42137-42146; (*c*) A. Kamal and P. Swapna, *RSC Adv.,* 2013, **3**, 7419-7426; (*d*) X. Xiong and L. Cai, *Catal. Sci. Technol.,* 2013, **3**, 1301-1307; (*e*) W. Li, X. Zhou, Y. Luan and J. Wang, *RSC Adv*., 2015, **5**, 88816-88820; (*f*) A. Ali, A. G. Correa, D. Alves, J. Zukerman-Schpector, B. Westermann, M. A. B. Ferreira and M. W. Paixao, *Chem. Commun*., 2014, **50**, 11926-11929.

13 (*a*) B. J. Borah, D. Dutta, P. P. Saikia, N. C. Barua and D. K. Dutta, *Green Chem.,* 2011, **13**, 3453-3460; *(b*) J. Kim, J. Park and K. Park, *Chem. Commun.*, 2010, **46**, 439-441; *(c*) Z. Shi, B. Li, X. Wan, J. Cheng, Z. Fang, B. Cao, C. Qin and Y. Wang, *Angew. Chem. Int. Ed.,* 2007, **46**, 5554-5558; (*d*) M. Tajbakhsh, M. Farhang, S. M. Baghbanian, R. Hosseinzadeh and M. Tajbakhsh, *New J. Chem*., 2015, **39**, 1827-1839; (*e*) H.-W. Bai, Z.-J. Cai, S.-Y. Wang. and S.-J. Ji, *Org. Lett*., 2015, **17**, 2898-2901.

14 (*a*) S. Aerry, A. Kumar, A. Saxena, A. De and S. Mozumdar, *Green Chem. Lett. Rev.,* 2013, **6**, 183-188; (*b*) A. Kumar, S. Aerry, A. Saxena and S. Mozumdar, *Green Chem.,* 2012, **14**, 1298-1301; (*c*) S. L. Jain, B. S. Rana, B. Singh, A. K. Sinha, A. Bhaumik, M. Nandi and B. Sain, *Green Chem.,* 2010, **12**, 374-377; (*d*) Z.-J. Cai, X.-M. Lu, Y. Zi, C. Yang, L.-J. Shen, J. Li, S.-Y. Wang and S.-J. Ji, *Org. Lett*., 2014, **16**, 5108–5111.

15 (*a*) H. C. Kolb, M. G. Finn and K. B. Sharpless, *Angew. Chem.,* 2001, **40**, 2004-2021; (*b*) A. N. Prasad, B. M. Reddy, E.-Y. Jeong and S.-E. Park, *RSC Adv*., 2014, **4**, 29772-29781.

16 (*a*) A. Krasinski, Z. Radic, R. Manetsch, J. Raushel, P. Taylor, K. B. Sharpless and H. C. Kolb, *J. Am. Chem. Soc.,* 2005, **127**, 6686-6692; (*b*) M. Vashist, K. Kushwaha, R. Kaushik and S. C. Jain, *RSC Adv*., 2014, **4**, 23679-23684.

17 (*a*) L. V. Lee, M. L. Mitchell, S. Huang, V. V. Fokin and K. B. Sharpless, C. Wong, *J. Am. Chem. Soc.,* 2003, **125**, 9588-9589; (*b*) Sasikala, S. K. Rani, D. Easwaramoorthy and K. Karthikeyan, *RSC Adv*., 2015, **5**, 56507-56517.

18 J. E. Hein, J. C. Tripp, L. B. Krasnova, K. B. Sharpless and V. V. Fokin, *Angew. Chem. Int. Ed.,* 2009, **48**, 8018-8021.

19 P. Appukkuttan, V. P. Mehta and E. V. Eycken, *Chem. Soc. Rev.,* 2010, **39**, 1467-1477.

20 C. O. Kappe and E. V.Eycken, *Chem. Soc. Rev.,* 2010, **39**, 1280-1290.

21 (*a*) J. Virkutyte and R. S. Varma, *Chem. Science,* 2011,**2**, 837-846; (*b*) L. De Rogatis, M. Cargnello, V. Gombac, B. Lorenzut, T. Montini and P. Fornasiero, *Chem. Sus. Chem.,* 2010, **3**, 24-42.

22 R. Hudson, C. J. Li and A. Moores, *Green Chem.,* 2012, **14**, 622-624.

23 (*a*) K. Bahrami, M. M. Khodaei and F. Naali, *J. Org. Chem.,* 2008, **73**, 6835-6837; (*b*) K. Bahrami, M. M. Khodaei and M. Sheikh Arabi, *J. Org. Chem.,* 2010, **75**, 6208-6213; (*c*) K. Bahrami, M. M. Khodaei and M. Soheilizad, *J. Org.Chem.,* 2009, **74**, 9287-9291; (*d*) K. Bahrami, M. M. Khodaei and P. Fattahpour, *Catal. Sci. Technol.,* 2011, **1**, 389-393; (*e*) K.

Bahrami, M. M. Khodaei, H. Targhan and M. SheikhArabi, *Tetrahedron Lett.*, 2013, **54**, 5064-5068; (*f*) K. Bahrami, M. M. Khodaei and M. Roostaei, *New J. Chem.*, 2014, **38**, 5515-5520; (*g*) K. Bahrami, M. M. Khodaei and A. Nejati, *Green Chem.*, 2010, **12**, 1237-1241; (*h*) K. Bahrami, M. M. Khodaei, P. Fattahpour and M. Sheikh Arabi, *J. Porous Mater.;* 2015, **22**, 211-218.

24 S. Luo, X. Zheng, H. Xu, X. Mi, L. Zhang and J. P. Cheng, *Adv. Synth. Catal.*, 2007, **349**, 2431-2434.

25 J. González, V. M. Pérez, D. O. Jiménez, G. Lopez Valdez, D. Corona, E. Cuevas Yañez, *Tetrahedron Lett.*, 2011, **52**, 3514-3517.

26 F. Friscourt and G.-J. Boons, *Org. Lett.*, 2010, **12**, 4936-4939.

27 S. Kamijo, T. Jin, Z. Huo and Y. Yamamoto, *J. Org. Chem.*, 2004, **69**, 2386-2393.

28 C. Shao, X. Wang, J. Xu, J. Zhao, Q. Zhang and Y. Hu, *J. Org. Chem.*, 2010, **75**, 7002-7005.

29 M. Nasrollahzadeh, B. Jaleh, P. Fakhri, A. Zahraei and E. Ghadery, *RSC Adv.*, 2015, **5**, 2785-2793.

30 C. Zhang, B. Huang, Y. Chen and D.-M. Cui, *New J. Chem.*, 2013, **37**, 2606-2609.

31 F. Alonso, Y. Moglie, G. Radivoy and M. Yus, *Org. Biomol. Chem.*, 2011, **9**, 6385-6395.

32 D. Yang and J. Hu, S. Fu, *J. Phy. Chem. C,* 2009, **113**, 7646-7651.

Graphical Abstract

The synthesis, characterisation and catalytic activity of FMNPs@TD-Cu(II) for the synthesis of 1,4-disubstituted 1,2,3-triazoles is reported.