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Synthesis of Sulfoxides in Water by New Magnetic Nanoparticles Supported Tungstic Acid (MNP-TA), as a Selective Oxidation Method of Sulfides

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Abstract

Different sulfides were oxidized to the corresponding sulfoxides, which is useful in drug industries and important in biological activities, with a novel magnetically separable catalyst consisting of tungstic acid supported on silica coated magnetic nanoparticles in water as a green solvent in a good to excellent yield without any over oxidation to sulfones in a simple, selective, and eco-friendly way. The catalyst can be separated from reaction condition using an external magnetic field and reused for several times as its first structure. Using some different microscopic and spectroscopic techniques such as transmission electron microscopy (TEM), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FT-IR), X-ray powder diffraction (XRD), and EDX spectroscopy.

Keywords: *Sulfoxide, tungstic acid, oxidation, Heterogeneous, catalyst, selective oxidation.*

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Introduction

Selective oxidation of sulfides tocorrespondingsulfoxidesis one of the most useful and basic synthetic method in industrial organic synthesis. Several important studies have currently been published on sulfides oxidation. Chemistry of sulfoxides is very important and marvelous because it has lots of biological and medical application and it is a significant type of organic reactions[1-3]. Importance of sulfoxide is not only limited to organic chemistry, but also it has therapeutic effects such as anti-bacterial, anti-ulcer and anti-atherosclerotic[4, 5]. Various methods have been reported in recent years as an efficient pathway to this issue, but most of them suffer from some disadvantages such as high temperature or high cost, long reaction time and formation of over-oxidation products. Also some disadvantages such as using toxic transition metal compounds in metal-catalyzed methods or remaining metals in products after the end of the reactioncould be exist[6-8].

Furthermore, green chemistry changes to one of the most important motifs these days. Thus, using environmentally benign reactions, reagents and solvents are particularly significant. In oxidation reactions using H_2O_2 as an oxidant has been seriously consider because of its advantages. But in this study water plays the oxidant rule which is cheaper, safer, readily available and environmentally benign as called “green oxidant”.An increase in the synthesis of sulfoxides derivatives has been observed in recent years[9-11]. By considering the ability of sulfoxide derivatives usages in different research areas, there is an eye catching future perspective for this kind of compounds specially in synthesizing of drugs[12, 13]. Known example of sulfinyl-based compounds with biological properties are the substituted benzyimidazoles by sulfides which are a noticeable anti-ulcer-agents [14].Here, we present the selective oxidation of sulfides to corresponding sulfoxide by using magnetic nanoparticles supported tungstic acid (MNP-TA) as catalyst in water. First 3-chloropropyl magnetic nanoparticle (3-CPMNP) was synthesized by the reaction of (3-chloropropyl)triethoxysilane with silica coated Fe_3O_4 as nanoparticle. Then tungstate salt was added to 3-COMNP consolidation of tungstic acid types on the surface of the magnetic nanoparticles (MNP-TA). By using this catalyst, intended sulfoxides obtained (Figure 1).

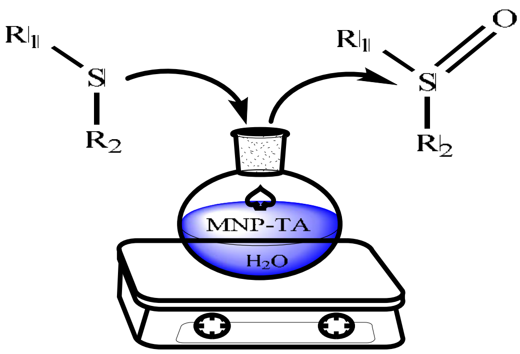


Figure 1.Graphical abstract of oxidation of sulfides to sulfoxides by MNP-TA catalyst in water.

Experimental

Chemicals without special descriptions were purchased from Merck and Aldrich chemical companies. ^{1}H and ^{13}C NMR were recorded on 500 MHz in $CDCl_3$ as the solvent and TMS as the internal standard. Infrared spectra (KBr pellets) were recorded on a Shimadzu FTIR-8300S spectrophotometer. Powder X-ray diffraction (XRD) data were obtained on an APD 2000 using Cu Kα radiation ($2\theta = 10^o$-120^o). The scanning electron micrograph (SEM) was obtained by SEM instrumentation (SEM, KYKY-EM3200, at 20-25 kV). Transmission electron microscopy (TEM) for characterization of the catalyst was done by Zeiss EM 900 at 80kV. Preoperative TLC using silicagel 60 $PF_{254+366}$ was used. An HPLC system (Agalent, Knawar, Shimadzu) was used to identify the product.

Preparation of Fe_3O_4 nanoparticles

Co-precipitation method was used to synthesize magnetic nanoparticles for this work. 2 g $FeCl_2.4H_2O$ and 502 g $FeCl_3.6H_2O$ and 0.85 mL HCl were dissolved in 25 mL deionized water under nitrogen gas. Then the resulting solution was added to a 250 mL solution of NaOH (0.1 M) dropwise under potent stirring at 80 °C for 30 min. after washing magnetite sediment with deionized water, it was stored in deionized water at a concentration of 10 g L^{-1}.

Preparation of Fe_3O_4@SiO_2 nanoparticles

Fe_3O_4@SiO_2 nanoparticles were prepared based on the stober method in the paper[15]: to a mixture of 125 mL heptanes, 2 g of Fe_3O_4, 20 mL of PEG-300, 25 mL of i-PrOH and 20 mL of water were added. After stirring the mixture under nitrogen gas for 30 minutes, 20 mL of tetraethyl orthosillicate (TEOS) was added and again stirred for 12 h at 30 . Then 10 mL of ammonia was added and stirred for 12 h. After washing the blend with ethanol (3 in10 mL) and collecting by an external magnetic field, the product was dried under vacuum overnight.

Preparation of 3-CPMNP

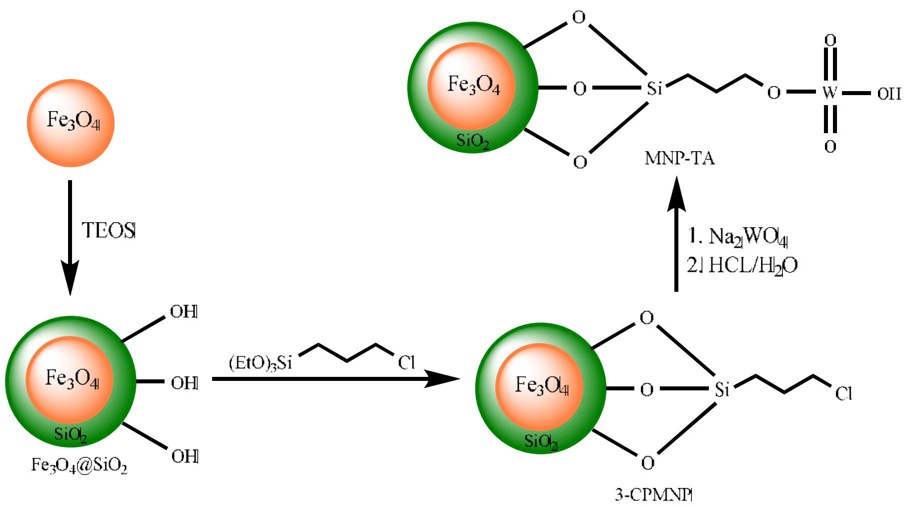
5.0 g Fe_3O_4@SiO_2 nanoparticles were added to a mixture a 250 mL water/ethanol (1 : 1) and sonicated for 30 minutes. Then 0.96 g (4 mmol, 0.96 mL) (3-chloropropyl)triethoxysilane was added and again sonicated for 5 h. after that, the solution was washed with EtOH (3 in 5 mL) and 5.35 g dark solid as 3-CPMNP was obtained.

Preparation of MNP-TA catalyst

5.0 g 3-CPMNP and 1.47 g (5 mmol) sodium tungstate were mixed and 10 mL n-Hexane was added to them. Then the solution was stirred for 4 h under reflux condition. When the reaction completed, it was filtered, washed with distilled water, and dried. After that, it was stirred in 40 mL HCL (0.1 N) for 1 h and again the mixture was filtered, washed with distilled water, and dried. 5.5 g MNP-TA was obtained.

General procedure for the synthesis of sulfoxides using MNP-TA catalyst

1 mmol of each sulfide derivatives and 0.1 g MNP-TA 5 mol% was added to a mixture of 2 mL acetonitrile and 2 mL water under reflux conditions with vigorous stirring. After completion of the reaction that was monitored by TLC, an external magnet was used to separate the catalyst. To take the desired product, the precipitated solid was filtered, washed with water and ethanol, and then purified by recrystallization from ethanol. To apply the catalyst for further reactions, the magnetically separated nanoparticles were washed with EtOAC and MeOH and dried at 60 °C for 8 h.



Scheme 1.Synthetic route for the preparation of MNP-TA catalyst.

Representative spectral data

1-chloro-4-((phenylsulfinyl)methyl)benzene: ^{1}H NMR (500 MHz; $CDCl_3$, δ, ppm): 7.70-7.71 (d, *J*= 7 Hz, 2H), 7.63-7-66 (M, 3H), 7.59-7-60 (d, *J*= 7.5 Hz, 2H), 7-53-7.54 (d, *J*= 7.5 Hz, 2H), 5.3 (S, 2H). ^{13}C NMR (250 MHz; $CDCl_3$, δ, ppm): 132.07, 130.90, 128.72, 123.02, 122.38, 118.40, 62.40.

(benzylsulfinyl)benzene: ^{1}H NMR (500 MHz; $CDCl_3$, δ, ppm): 7.70-7.71(d, *J*= 7 Hz, 2H), 7.63-7.66(M, 3H), 7.59-7.60 (d, *J*=7.5 Hz, 2H), 7.51-7.54 (t, M, 3H), 5.32 (s, 2H). ^{13}C NMR (250 MHz; $CDCl_3$, δ, ppm): 141.59, 134.78, 131.99, 130.85, 128.72, 125.97, 123.06, 122.54, 62.39.

1-fluoro-4-(((4-methoxyphenyl) sulfinyl)methyl)benzene: ^{1}H NMR (500 MHz; $CDCl_3$, δ, ppm): 7.58-7.61(dd, ^{3}J=8.5Hz, ^{4}J=5Hz, 2H), 7.33-7-34 (dd, ^{3}J=3.5 Hz, ^{4}J=2 Hz, 2H), 7.12-7.16 (t, ^{3}J=8 Hz, ^{4}J=7.5 Hz, 2H), 6.91-6.93(d, *J*=4 Hz, 2H), 6.63 (s, 2H), 3.7(s, 3H).^{13}C NMR (250 MHz; $CDCl_3$, δ, ppm):159.98, 158.06, 157.60, 139.17, 136.13, 128.74, 126.64, 126.58, 114.61, 114.43, 114.24, 62.22, 55.29.

1-chloro-4-(methylsulfinyl)benzene: ^{1}H NMR (500 MHz; $CDCl_3$, δ, ppm): 7.29-7.31(d, *J*= 8.5, 2H), 7.21-7.23 (d, *J*=8, 2H), 4.56 (s, 3H). ^{13}C NMR (250 MHz; $CDCl_3$, δ, ppm): 122.91, 117.71, 116.97, 114.4, 56.34.

1-(benzylsulfinyl)-4-methoxybenzene:^{1}H NMR (500 MHz; D_2O, δ, ppm): 8.02-8.03(d, *J*=7, 2H), 7.50-7.54 (d, *J*= 17.5, 2H), 7.22-7.43 (M, 3H), 7.08-7.10 (d, J= 7.5, 2H), 4.86 (s, 2H), 2.5 (s, 3H). ^{13}C NMR (250 MHz; D_2O, δ, ppm): 122.91, 117.7, 116.97, 114.44, 56.34.

1,2,3-trimethoxy-5-(((4-methoxyphenyl)sulfinyl)methyl)benzene: ^{1}H NMR (500 MHz; D_2O, δ, ppm): 7.72-7.74 (d, *J*=8.5, 2H), 7.0-7.02 (d, *J*=8.5, 2H), 6.42 (s, 2H), 4.73 (s, 2H), 3.82 (s, 3H), 3.03 (M, 6H), 2.5 (s, 3H).^{13}C NMR (250 MHz; D_2O, δ, ppm): 185.32, 157.30, 145.12, 131.86, 128.91, 126.70, 123.92, 115.08, 114.18, 62.73, 55.52, 54.81.

(benzhydrylsulfinyl)methanol: ^{1}H NMR (500 MHz; D_2O, δ, ppm): 10.34(s,1H), 7.43-7.45 (d, *J*=7.5, 2H), 7.30-7.33 (t, *J*=7.25, 2H),7.22-7.25 (t, *J*=7 , 2H), 5.11 (s, 1H), 3.49 (s, 2H).^{13}C NMR (250 MHz; D_2O, δ, ppm): 170.63, 136.02, 128.67, 128.45, 128.91, 127.57, 69.30, 61.13.

benzhydrylsulfinyl)methanamine: ^{1}H NMR (500 MHz; D_2O, δ, ppm): 7.39-7.41 (d, *J*=7, 4H), 7.30-7.33 (t, *J*=7.25, 4H), 7.22-7.25 (t, *J*=7.25 ,2H), 5.99-6.50 (Broad ,2H), 5.18 (s, 1H), 3.70 (s, 2H).^{13}C NMR (250 MHz; D_2O, δ, ppm): 171.37, 135.10, 128.72, 128.24, 127.60, 69.01, 61.00.

Results and discussion

Synthesis of MNP-TA is shown in scheme 1. MNs were prepared by the procedure that reported in the literature[15]with a Co-illuviation method. Then, to obtain core shell MNPs (Fe_3O_4@SiO_2), by using a sol-gel process, synthesized MNs were coated by silica. After that, 3-chloropropyl magnetic nanoparticles (3-CPMNP) substrate was obtained by reacting Fe_3O_4@$SiO_2$with (3-chloropropyl)triethoxysilane. Finally, the MNP-TA catalyst was formed by treating 3-CPMNP with sodium tungstate (Na_2WO_4), followed acidification of the obtained material. The synthesized catalyst was characterized by Elemental analysis XRD, TEM, SEM, FT-IR, and EDX.Presence of the expected elements of Si, Fe, O, C and W in the scaffold of the MNP-TA demonstrated in the EDX spectrum of the catalyst (Figure 2).

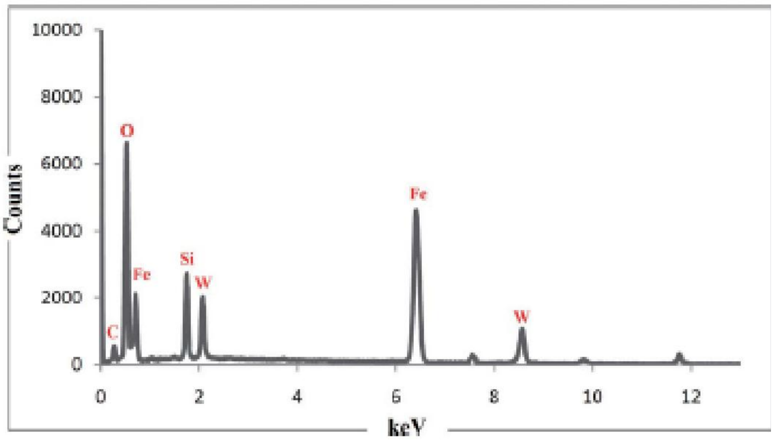


Figure 2. EDX analysis of the MNP-TA catalyst.

The morphologies of MNP-TA catalyst were examined by transmission electron microscope (TEM) and scanning electron microscopy (SEM). Figure 3 shows a representativeTEM pictures of catalyst and illustrate that near spherical morphology of nanoparticles of MNP-TA are assembled with relatively good monodispersity.

Having near spherical morphologywith relatively good monodispersity of the MNP-TA catalyst was shown in SEM images of the catalyst (Figure 4). Almost 45 nm is the estimated average diameter of the catalyst in this study.

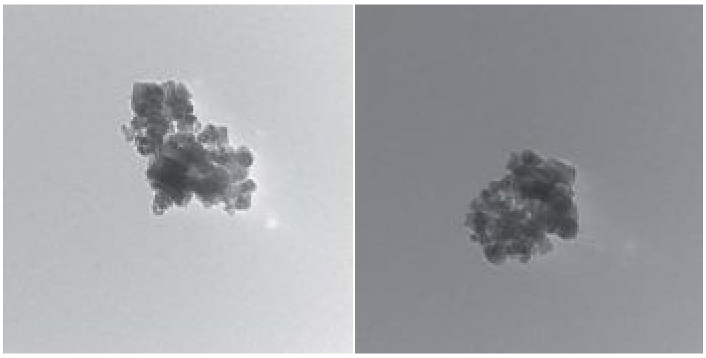


Figure 3. TEM images of two different positions of the MNPTA catalyst.

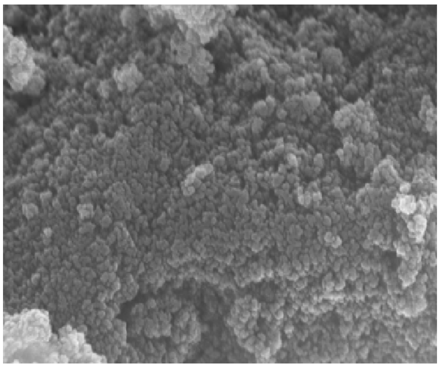


Figure 4. SEM image of the MNP-TA catalyst.

Figure 5 shows a comparison of the FT-IR spectra of Fe_3O_4, Na_2WO_4, and MNP-TA catalyst. Presence of WO_4 moieties in the structure of the MNP-TA can be confirmed by the absorption band which was seen in this comparison. Peaks in the range of 624 cm^{-1} and peak at 833 cm^{-1} related to the bending vibration of the Si-O-Si bonds and stretching vibration of W=O, respectively. A strong absorption band at about 586 cm^{-1} has corresponded to Fe-O/Fe-O binding of magnetic. Presence of the WO_4 group was indicated by the absorptions at 1691 and 1465 cm^{-1}. A broad band about 1118 cm^{-1} has attributed to asymmetric stretching of the Si-O-Si bond in $Fe_3O_4@SiO_2$.

The XRD pattern of the catalyst shows in Fig. 6 indicated the presence of MNPs in the structure of MNP-TA. The peaks in 2θ = 220°, 311°, 400°, 422°, 511°, and 440°corresponded to Fe_3O_4 nanoparticles. The peak in 2θ = 35.8° is due to Fe_3O_4 and the peak in 2θ = 18.5° attributed to SiO_2 and the peaks.

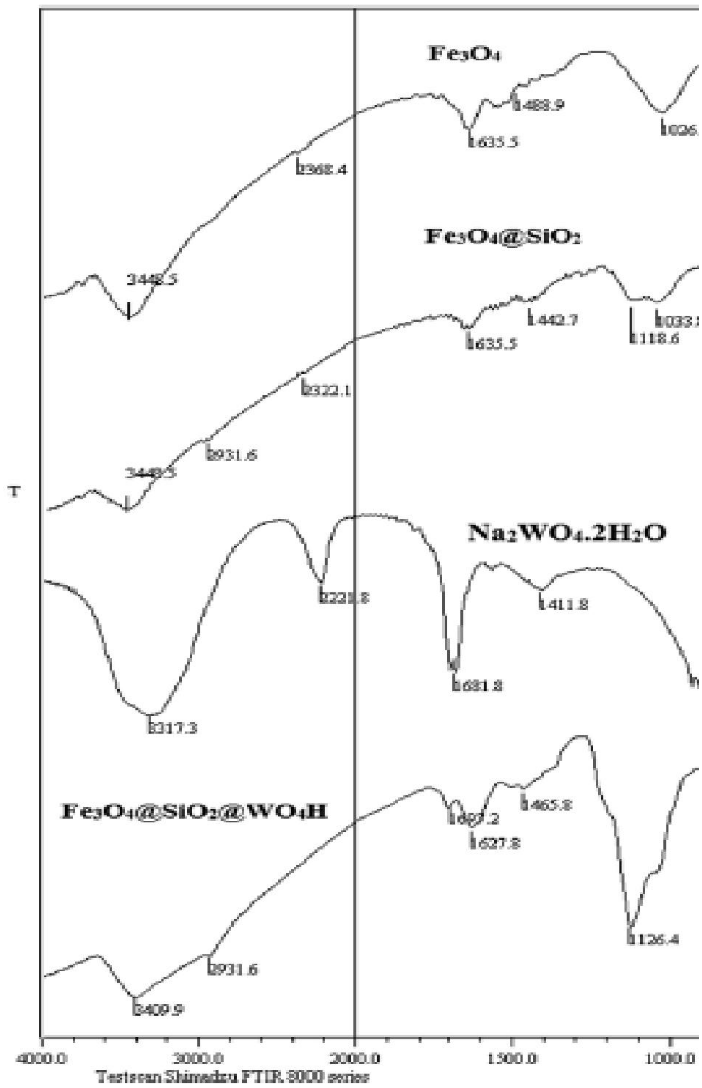


Figure 5. FT-IR spectra of $Fe_3O_4@SiO_2$, $Na_2WO_4.2H_2O$ and MNP-TA catalyst.

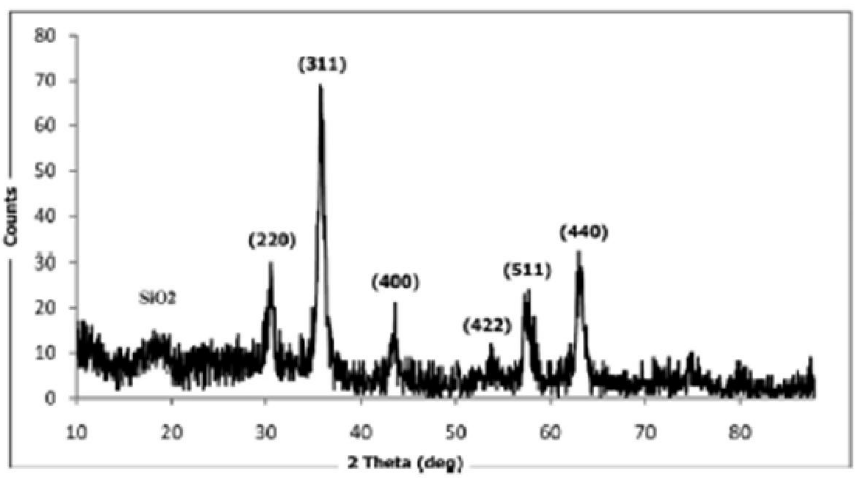


Figure 6. XRD pattern of the MNP-TA catalyst.

In this new protocol oxidation of sulfides, a variety of sulfoxides were synthesized, then generality and applicability of the MNP-TP catalyst were investigated, as shown in table 1, all sulfoxides without any over oxidation to sulfones were produced selectively in good-to-excellent yields.
This is the general pathway for oxidation of sulfides to sulfoxides by the using MNP-TA as catalyst, in the presence of CH_3CN and water as the oxidant, in reflux condition.

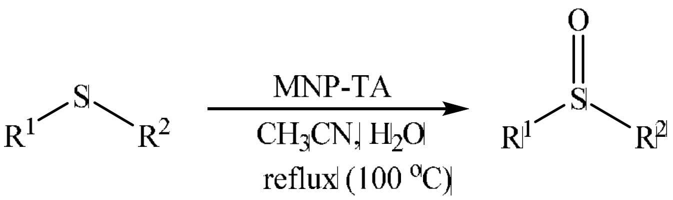
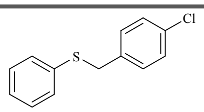
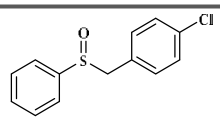
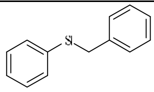
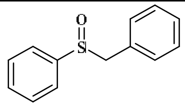
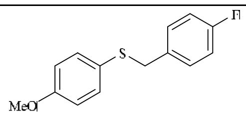
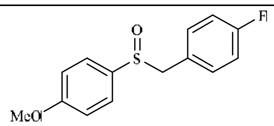
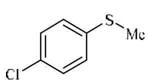
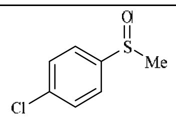
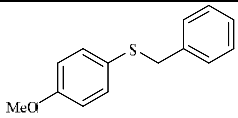
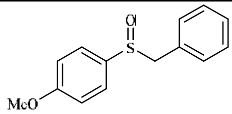
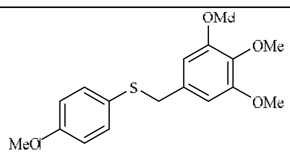
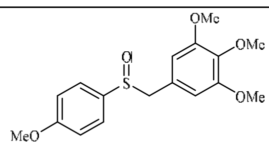
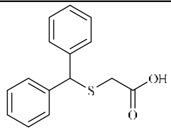
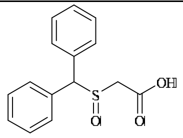
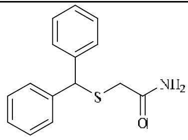
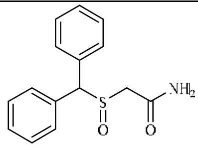


Table 1. Oxidation of sulfides to sulfoxides in the presence of MNP-TA.

Entry	*Sulfide*	*Product*	*Time (h)*	*Yield (%)*	*m.p.(□)*
1			*8*	92	49-50
2			8	90	45-56
3			8	91	50-51
4			8	93	44-45
5			*8*	92	49-50
6			*8*	92	51-52

7			*8*	93	149-150[16]
8			*8*	94	161-162[16]

Catalyst activity

Time and amount of the present catalyst for best yield of the reaction has been optimized. As shown in table 2, 8 h and 5% mol was the best mode. The results of investigation of the recyclability of the MNP-TA catalyst expressed that it can be recovered by simple external magnetic attraction without any significant loss in its catalytic activity after five cycle of reusability (table 3).

Table 2.Optimization of the MNP-TA catalyst.

Entry	*Catalyst (mol %)*	*Time (h)*	*Solvent*	*Yield (%)*
1	0	24	H_2O	0
2	1	24	H_2O	Trace
3	2	24	H_2O	15
4	3	24	H_2O	70
5	4	24	H_2O	72
6	5	24	-	50
7	5	8	EtOH	47
8	5	8	H_2O	94
9	5	12	H_2O	92
10	6	8	H_2O	93
11	7	8	H_2O	93
12	8	12	H_2O	86
13	10	12	H_2O	80

Table 3.Reusability of the MNP-TA catalyst in the reaction of oxidation of sulfides in the presence of CH_3CN and H_2O.

Run	Yield of product (%)	Recovery of catalyst (%)
1	94	99
2	92	97.5
3	91	96
4	90	95.5
5	89	94.5

Conclusion

In conclusion, we have successfully synthesized magnetic nanoparticles-supported tungstic acid (MNP-TA) using the reaction of sodium tungstate with the pre-prepared 3-chloropropyl magnetic nanoparticles. By using this heterogeneous catalyst, oxidation of various sulfides to sulfoxides,as an important compound in pharmacy and biological activity, took place in a simple, efficient, selective, and eco-friendly procedure in water as a green solvent. The products were obtained in excellent yield and short reaction time and the catalyst can be recovered bysimple external magnet, washed with water and ethanol, then purified by recrystallization from ethanol and reuse for five times without any difference in its structure.

Acknowledgments

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References

[1] S. Aoyagi, M. Makabe, K. Shimada, Y. Takikawa, C. Kabuto, *TetrahedronLett*., 48 (26), 4639(2007).

[2] F. Yu, R. Huang, H. Ni, J. Fan, S. Yan, J. Lin, *Green Chem*., 15 (2), 453(2013).

[3] T. P. Gao, J. B. Lin, X. Q. Hu, P. F. Xu, *Chem. Commun*., 50 (64), 8934 (2014).

[4] L.Villalobos, T. Ren, *Inorg. Chem. Commun*., 28, 52(2013).

[5] S. Okabe, K. Shimosako, K. Amagase, *J Physiol Pharmacol*., 52, 639(2001).

[6] P. Gogoi, M. Kalita, T. Bhattacharjee, P. Barman, *Tetrahedron Lett*., 55 (5), 1028(2014).

[7] M. Ciclosi, C. Dinoi, *Organometallics*, 27 (10), 2281(2008).

[8] V. Hulea, A. L. Maciuca, F. Fajula, E. Dumitriu, *Appl. Catal., A: General,* 313 (2), 200(2006).

[9] P. Anastas, N. Eghbali, *Chem. Soc. Rev*., 39 (1), 301(2010).

[10] C. Capello, U. Fischer, K. Hungerbühler, *Green Chem*., 9 (9), 927(2007).

[11] S. L. Tang, R.L. Smith, M. Poliakoff, *Green Chem*., 7(11), 761(2005).

[12] H. Weissbach, L. Resnick, N. Brot, *Biochimica et Biophysica Acta*,1703 (2), 203(2005).

[13] C. Friend, W. Scher, J. G. Holland, *Proc. Natl. Acad. Sci*., 68 (2), 378(1971).

[14] J. Legros, J.R. Dehli, C. Bolm, *Adv. Synth. Catal.*, 347 (1), 19(2005).

[15] Y. Kang, L. Zhou, X. Li, J. Yuan,*J. Mater. Chem*., 21 (11), 3704(2011).

[16] Y. Chi, Q. Yuan, Y. Li, J. Tu, L. Zhao, N. Li, X. Li, *J Colloid Interface Sci*., 383 (1), 96(2012).